



# Proceedings

for

## Managing Water in the 21st Century

American Water Resources Association Montana Section 2023 Conference

October 10 - October 12, 2023  
Holiday Inn Downtown, Missoula, MT

### **Contents**

Thanks to Planners and Sponsors  
Full Meeting Agenda  
About the Keynote Speakers

*\*Link to oral and poster presentation abstracts on [MT AWRA website](#)*

## THANKS TO ALL WHO MAKE THIS EVENT POSSIBLE!

- **The AWRA Officers**

Tom Michalek, President -- RESPEC, Butte, MT

Lou Volpe, Vice President -- Montana Dept of Environmental Quality, Helena, MT

Sara Edinberg, Treasurer -- Montana Bureau of Mines and Geology, Butte, MT

Ron Breitmeyer, Secretary -- Carroll College, Helena, MT

Nancy Hystad, Executive Secretary -- Montana State University, Bozeman, MT

- **Montana Water Center**

Stephanie Ewing, Director, and Whitney Lonsdale, Assistant Director

And especially the conference presenters, field trip leaders, moderators, student judges, and volunteers.



Tom Michalek



Lou Volpe



Sara Edinberg



Ron Breitmeyer



Nancy Hystad

The Montana Section of the American Water Resources Association would like to thank our sponsors



## REGISTRATION

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8:00 am – 6:00 pm Registration available at the Holiday Inn. Preconference registration is preferable and is available through the [MT AWRA website](#).

## MORNING WORKSHOP

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9:30 am – 11:30am **Water Data Management in the 21st Century** (*please register; coffee provided*) - Join us for a conversation about the quality, accessibility, and usability of water data in Montana.

## LUNCH, FIELD TRIP, HYDROPHILE RUN, and HAPPY HOUR

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12:00 pm Sack **LUNCH** provided to all field trip attendees

12:00 pm – 5:00 pm **FIELD TRIP** - Depart Holiday Inn promptly at 12 PM noon. Individuals must have registered to participate. Please bring or wear footwear appropriate for muddy conditions and stream crossings.

- Rattlesnake Creek Dam removal project with Trout Unlimited
- Miller Creek restoration projects with the Clark Fork Coalition
- Brennan's wave in Downtown Missoula

6:00 pm **HYDROPHILE 5K WALK/RUN** - departs and finishes at the Holiday Inn; route map [here](#)

6:00 - 9:00 pm **HAPPY HOUR** at Cranky Sam Public House, 233 W. Main in downtown Missoula

**REGISTRATION**

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7:30 am REGISTRATION, COFFEE, AND CONVERSATION

**OPENING DAY PLENARY SESSION**

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8:00 am WELCOME WITH INTRODUCTIONS, LOGISTICS, AND ANNOUNCEMENTS  
Tom Michalek - *AWRA Montana Section President*

8:10 A MESSAGE FROM THE MONTANA WATER CENTER  
Stephanie Ewing - *Montana Water Center, Director*

8:25 LEGISLATIVE UPDATE  
Jason Mohr - *Research Analyst, Montana Legislative Environmental Policy Office*

8:45 PLENARY SESSION 1: Current and Planned Research in Montana's Geosciences  
John Metesh, *State Geologist and Director of Montana Bureau of Mines and Geology*

9:15 PLENARY SESSION 2: People and Pipes: The convergence of peak demand and age  
Chris Dorrington, *Director, Montana Department of Environmental Quality*

9:45 PLENARY SESSION 3: Basin-Scale Irrigation Rehabilitation, Betterment and Modernization on the Flathead Indian Irrigation Project: An Integral Component of the Confederated Salish and Kootenai Tribes Water Rights Settlement  
Seth Makepeace, *Hydrologist and Compact Project Officer, Natural Resources Department, Confederated Salish & Kootenai Tribes.*

10:15 BREAK

10:30 PLENARY SESSION 4: Facing future water challenges  
Nate Ward, *Water Rights Bureau Chief, Montana Department of Natural Resources and Conservation.*

11:00 DISCUSSION

TECHNICAL SESSIONS: ORAL PRESENTATIONS (Blue text indicates student presenters)

SESSION 1 (Concurrent)  
HYDROLOGY

Moderator: Payton Gardner, University of Montana

- 1:00 pm **Jenna Dohman**, Montana Bureau of Mines and Geology, Hydrogeologic Influences on Water Supply in the Big Hole River Near Glen, MT
- 1:25 **Ann Hanson**, Montana Bureau of Mines and Geology, Detecting and Monitoring Cold- and Warm-Water Inputs to the Lower Big Hole River Near Glen, MT
- 1:50 **Ron Breitmeyer**, Carroll College, Lysimetry Study of Deep Percolation Beneath Irrigated Fields
- 2:15 **Roy Sando**, US Geological Survey, WY-MT Water Science Center, Development of a Surface-Water Index of Permanence
- 2:40 **Nancy Barth**, US Geological Survey, WY-MT Water Science Center, Evaluating Changes in the Seasonality of Peak Streamflow Caused by Hydroclimatic Variability in Montana Using Circular Statistics
- 3:00 **BREAK** with light refreshments

SESSION 2 (Concurrent)  
WATER QUALITY

Moderator: Rachel Malison, Flathead Lake Biological Station, University of Montana

- 1:00 pm **Joe Griffin**, Montana Technological University, 40 Years of Water Quality and Biological Monitoring at the Confluence Clark Fork Superfund Complex - The Case for Weight of Evidence Analysis
- 1:25 **Madison Foster**, US Geological Survey, WY-MT Water Science Center, Tracking trends in selenium concentrations through the Upper Columbia River Basin
- 1:50 **Kylie Bodle**, Montana State University, Aerobic granular sludge: assessing a novel approach to pharmaceutical removal from wastewater.
- 2:15 **Amos Taiswa**, Montana Technological University, Membrane Technology as a Promising Solution for Water Security and Challenges
- 2:40 **Seth Siefken**, US Geological Survey, WY-MT Water Science Center, USGS Water Temperature Data in Montana – Collection, Access, and Application
- 3:00 **BREAK** with light refreshments

**SESSION 3 (Concurrent)**  
**HYDROLOGY**

- Moderator: Theodore Barnhart, US Geological Survey
- 3:25 pm **Daniel Armstrong**, US Geological Survey, WY-MT Water Science Center, USGS StreamStats Application: Development and updates for Wyoming and Montana
- 3:50 **Kayla Jamerson**, University of Montana, Montana Climate Office, Evaluating the relative influence of soil water potential, soil moisture, and vapor pressure deficit of semi-arid vegetation dynamics
- 4:15 **Lila Rickenbaugh**, Montana State University, Leveraging stable water isotopes and synthetic aperture radar to assess the complex hydrology of snow-fed agricultural lands in Southwestern Montana
- 4:40 **Fin Malone**, University of Montana, Montana Climate Office, Landscape Influences on Microclimate and Forest Growth Cessation in a Semi-arid Montane Forest

5:30 **BREAK & POSTER SET UP**

**SESSION 4 (Concurrent)**  
**WATER QUALITY & HYDROLOGY**

- Moderator: Seth Seifken, US Geological Survey
- 3:25 **Skye Keeshin**, Montana State University, Water Quality, Mixing, and Groundwater Age in an Urbanizing Agricultural Intermountain Basin, Gallatin Valley, Montana
- 3:50 **Hannah Riedl**, Montana Department of Environmental Quality, Monitoring restored wetland water quality and quantity
- 4:15 **Jared Glass**, Montana Flathead Lake Biological Station, Monitoring Montana Waters, Year Three of Monitoring Montana Waters (MMW): A Flathead Lake Biological Station program supporting watershed monitoring
- 4:40 **Craig Kendall**, USDA Forest Service, Comparison of stream morphological metrics in reference and managed catchments across Western Montana and Northern Idaho
- 5:05 **Rachel Malison**, Flathead Lake Biological Station, University of Montana, Title TBD.

5:30 **BREAK & POSTER SET UP**

5:30 - 6:15 pm **STUDENT-WATER WORKFORCE SOCIAL** - A focused chance for students to learn about career opportunities and connect with agency and private sector water professionals.

6:15 - 9:00 pm **POSTER SESSION & EVENING SOCIAL:** Heavy appetizers, drinks, and photo contest

7:00 pm **HENDERSON AWARD PRESENTATION & TREASURER NOMINATIONS**

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## **AWRA 2023 POSTER PRESENTATIONS**

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### **AQUATIC BIOLOGY**

**Dylan White**, *University of Montana*, Examining the influence of nutrients and colloidal metals on metal accumulation in the base of a river food web

### **CLIMATE**

**Abaye Abebe**, *Montana State University*, Simulating the influence of climate change on patterns in recharge of mountain aquifers in snow-dominated headwaters

**Kevin Hyde**, *Montana Climate Office*, The Montana Mesonet: Status and Development

**Kyle Bocinsky**, *Montana Climate Office*, MCO Climate Extension: Tribal Engagement

**Zachary Hoylman**, *Montana Climate Office*, Drought Monitoring in Montana: Science, Application and Partnerships

### **COLLABORATION & COMMUNICATION**

**Drew Shafer**, *Gallatin Local Water Quality District*, "Who'd you get?!": Creating and Disseminating Benthic Macroinvertebrate Trading Cards as an Education and Outreach Project

### **ECOLOGY**

**Matthew Nichols**, *University of Montana*, Understanding Groundwater-Surface Water Interactions in Western Montana

**Jadyn Bellander**, *Montana State University*, Towards Understanding in the Upper Clark Fork River: Assessing Spatial and Temporal Changes in Macroinvertebrate Diets and Role in Energy Flow Food Webs

**Lillian Strong**, *Montana State University*, Potential effects of water temperature on patterns of aquatic insect emergence in Gallatin Valley streams

### **GEOMORPHOLOGY**

**Zack Deluca**, *University of Montana*, Dimensionless impulse framework for investigating hydrogeomorphic response to flooding in northern Yellowstone National Park

## **AWRA 2023 POSTER PRESENTATIONS (continued)**

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### **GROUNDWATER**

**Megan Heath**, Montana Bureau of Mines and Geology, Data Map for Wells and Springs Visited during the Park-Sweet Grass Characterization Study, Ground Water Characterization Program: Montana Bureau of Mines and Geology

**Wyatt Kray**, Montana State University, Effects of residue management on snow retention and subsequent belowground water storage in a small plot study near Bozeman, MT

**Camela Carstarphen**, Montana Bureau of Mines and Geology, The Aquifers of the Lower Clark Fork: Lincoln and Sanders Counties Aquifer Characterization, Northwest Montana

**Carl Krause**, Montana State University, Low Level Pesticide Attenuation in Agricultural Riparian Reaches of the Judith River Watershed

### **HYDROLOGY**

**Aaron Heldmyer**, US Geological Survey, WY-MT Water Science Center, Using machine learning to uncover spatial patterns of streamflow drought mechanisms in the Contiguous U.S.

### **MODELING**

**Angela Lucero**, NewFields. Analyzing Creek Realignment Effects on Stormwater Management in the Grant Creek-Mullan Road Area.

**Sarah Washko**, Cramer Fish Sciences, Prioritizing Restoration through the Lens of Floodplain Connectivity: A Case Study in Coupling 2D Hydraulic Models and Relative Elevation Models

### **WATER QUALITY**

**Meghan Robinson**, Montana State University, Data Driven Irrigation Scheduling for Water and Nitrogen Use Efficiency

**Angelique Frier**, Lewis and Clark Water Quality Protection District, Water Quality in Unionville, MT

**Adam Sigler**, Montana State University, Cumulative Human Health Risk from 19 Contaminants in Montana Groundwater

**Jack Poole**, Montana State University, Subsurface Characteristics of Prairie Riparian Corridors Dictate Water Quality Patterns

**Vicki Watson**, University of Montana, Long term trends in nutrients and attached algae levels in the Clark Fork River

**Shannon Hamp**, Montana State University, Progress Toward a Low-Cost Multispectral Imager for River Algae Monitoring

**Riley Logan**, Montana State University, UAV-Based Hyperspectral Imaging for Identifying and Monitoring Riverine Algal Blooms in Western Montana

**Christy Meredith**, Montana Department of Environmental Quality, Patterns of nutrient limitation along the Gallatin River near Big Sky during August 2023: Results from nutrient diffusing substrate experiments

**Caitlin Cliff**, Aaniiih Nakoda College, Lodge Pole Groundwater Quality Assessment, Fort Belknap Reservation

**Nick Banish**, Gallatin Local Water Quality District, Nutrient and Hydrologic Mass Balance of Ben Hart Creek, Belgrade, MT

## THURSDAY, OCTOBER 12, 2023

7:30 am GATHER FOR COFFEE AND CONVERSATION WITH COLLEAGUES

### TECHNICAL SESSIONS: ORAL PRESENTATIONS

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#### SESSION 5 (Concurrent)

##### ECOLOGY

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Moderator: Lila Rickenbaugh, Montana State University

8:00 am **William Hamilton**, US Geological Survey, WY-MT Water Science Center, Mapping Optimal Restoration Sites for Persistence of Greenback and Colorado River Cutthroat Trout

8:25 **Michelle Fillion**, University of Montana, Beaver dam analogs influence macroinvertebrate communities and fluxes between aquatic and terrestrial ecosystems in headwater streams of western Montana

9:15 **Nate Heili**, Montana State University, Patterns of aquatic insect emergence from irrigation canals in the lower Gallatin watershed, Montana

9:40 **Ben Coleman**, University of Montana, Examining the roles of beavers and time in driving recovery following stream channel restoration.

10:00 **BREAK** with light refreshments

#### SESSION 6 (Concurrent)

##### COLLABORATION & MANAGEMENT

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Moderator: Kathy Chase, US Geological Survey

8:00 am **Sale Rhodes**, Montana State University, Conceptualizations of Ecological Drought in Montana, and Implications for Management

8:25 **Megan Moore**, US Geological Survey, WY-MT Water Science Center, Partner Engagement Across Eco-Hydrologic Projects in the American West: A Case Study in the Tongue River Basin of Montana and Wyoming

8:50 **Melissa Schaar**, US Geological Survey, WY-MT Water Science Center, Collaborative Science Opportunities in the Mining-Affected Transboundary Kootenai River Watershed, United States and Canada

9:15 **Nicole Stine**, US Geological Survey, WY-MT Water Science Center, Vermilion River Restoration Effectiveness Monitoring: Year One and More to Come

9:40 **Robert Sain**, Kroenke Ranches, Ecosystem Restoration of Elbow Coulee, design, construction, and monitoring

10:00 **BREAK** with light refreshments

SESSION 7 (Concurrent)

GROUNDWATER & GEOCHEMISTRY

Moderator: Hannah Riedl, MT Department of Environmental Quality

10:25 **Caitlin Mayernik**, *Montana State University*, Pathways of nitrate processing across agricultural riparian corridors characterized through geochemical analyses of water from shallow aquifers and streams.

10:50 **David Baude**, *University of Montana*, Discerning bedrock recharge spatial variability as a function of topography and lithology of mountainous watersheds in Montana.

11:15 **Andrew Bobst**, *Montana Bureau of Mines and Geology*, Investigating Hydrologic Connections Between Aquifers and Surface Waters in the East Flathead Valley

11:40 **Payton Gardner**, *University of Montana* Comparative Observations of Mountain Aquifer System Dynamics in western Montana and Colorado

12:05 **Evan Norman**, *Montana Department of Natural Resources and Conservation, Water Sciences Bureau*, Assessing Hydrological Connectivity of the Upper Teton Alluvial Aquifer, Choteau, MT

SESSION 8 (Concurrent)

MODELING & CLIMATE

Moderator: Amos Taiswa, Montana Tech

10:25 **Brett Heitshusen** *Montana Department of Agriculture, Sustainable Agriculture Section*, A GIS Method for Agricultural Chemical Groundwater Monitoring Well Site Selection

10:50 **Katherine Chase** *USGS WY-MT Water Science Center*, Developing CE-QUAL-W2 Models of Kootcanusa Reservoir and the Kootenai River, Montana and Idaho

11:15 **Brett Oliver**, *University of Montana*, Coupling Groundwater Simulations with Geodetic Forward Models to Parameterize the Bedrock in a Snow-dominated Mountain Watershed

11:40 **Theodore Barnhart**, *US Geological Survey, WY-MT Water Science Center*, High-Resolution Snow Modeling for the Crown of the Continent

12:05 **Todd Blythe**, *Montana Department of Natural Resources and Conservation, Water Sciences Bureau*, Everything is better in 2D: use of a 2-dimensional hydraulic model for indirect discharge estimation and other applications in stream gaging.

SESSION 7 (Concurrent)

GROUNDWATER & GEOCHEMISTRY

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Moderator: Hannah Riedl, MT Department of Environmental Quality

12:25 **Meryl Storb**, US Geological Survey, WY-MT Water Science Center, Groundwater quality on the Fort Peck Reservation: A three-decade evaluation of nitrogen extent, magnitude and sources related to land use.

12:50 pm **Nick Banish**, Gallatin Local Water Quality District, Results of 5 years of Monitoring the Big Sky Meadow Village Aquifer

1:15 pm **CLOSING PLENARY: New Officer, Student Awards, Next Year's Location**

SESSION 8 (Concurrent)

MODELING & CLIMATE

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Moderator: Amos Taiswa, Montana Tech

12:25 **Theodore Barnhart**, US Geological Survey, WY-MT Water Science Center, Future Streamflow Estimates Suggest a Shift in Streamflow Magnitude and Timing by the End of the Century - Preliminary Results from the Tongue River 2100 Project

12:50 **Kelsey Jencso**, Montana Climate Office, Enhancing the Upper Missouri River Basin's Drought Early Warning System

## KEYNOTE SPEAKER 1

### **Current and Planned Research in Montana's Geosciences.**

John Metesh, *State Geologist and Director of Montana Bureau of Mines and Geology*

John Metesh will provide a summary of Bureau activities in geosciences throughout Montana including water, geology, hazards, and minerals

John Metesh is presently the Director and State Geologist of the Montana Bureau of Mines (MBMG). He was previously a Research Hydrogeologist and Assistant Director/Research Division Chief for the MBMG. He received an M.S. in geological engineering from Montana College of Mineral Science and Technology and a Ph.D. in geology from The University of Montana. His 32-year association with the MBMG and the Montana University System has provided opportunities to explore groundwater-surface water management under a wide variety of hydrogeologic settings. He has published 50+ reports, articles, and abstracts related to hydrogeology and geochemistry as well as many unpublished reports relied upon for critical decisions related to legislation, natural resource damages, mine permitting/reclamation, and water rights. Metesh is a Registered Professional Geologist (Wisconsin) and is presently President of Association of American State Geologists (2023-24).

## KEYNOTE SPEAKER 2

### **People and Pipes: The convergence of peak demand and age**

Chris Dorrington, *Director,*

*Montana Department of Environmental Quality*

Chris Dorrington will share perspective on the new and real demands on our water infrastructure and our people, as both age and experience real stresses. He will speak about the opportunity for more inclusive planning and thought, capturing generational funding and looking ahead to what sound planning can bring to our communities.

Chris Dorrington now serves as the Director of the Montana Department of Environmental Quality (DEQ). With an agency mission to champion a healthy environment for a thriving Montana, Chris has set his agency mission to improve the efficiencies and protections of the industrial permitting and energy policy programs in Montana. In July 2022 Governor Gianforte appointed Dorrington as the Chair of the Housing Task Force, with an objective of quickly researching and then proposing improvements that both the Montana Legislature, Executive branch and locals could implement to address Montana's housing crisis. Prior to his current role as Director, Dorrington led the Air, Energy, and Mining Division at DEQ for four and a half years. Before joining state government over 17 years ago, Chris worked for six years in private industry. Chris earned his bachelor's of science in mechanical engineering from Gonzaga University, and a master's degree in public policy from George Mason University.

## KEYNOTE SPEAKER 3

### **Basin-Scale Irrigation Rehabilitation, Betterment and Modernization on the Flathead Indian Irrigation Project: An Integral Component of the Confederated Salish and Kootenai Tribes Water Rights Settlement.**

Seth Makepeace, *Hydrologist and Compact Project Officer, Natural Resources Department, Confederated Salish & Kootenai Tribes.*

Seth Makepeace has been a hydrologist for a number of years, working on surface water, groundwater, water supply, water quality, and water rights topics. He earned a BS from the University of Washington and an MS from the University of Montana.

The Confederated Salish and Kootenai Tribes (CSKT) water rights settlement was enacted by Congress in December, 2021 as the Montana Water Rights Protection Act. The Act enables: a water rights compact which, among other elements, defines the Tribes' aboriginal and reserved water rights and water management protocols to meet environmental instream flows and irrigation water uses on the Flathead Indian Irrigation Project (FIIP); a water rights administrative ordinance that authorizes the Tribes and State of Montana to jointly administer existing and prospective water rights; and authorization and appropriation of the financial component of the settlement including rehabilitation, betterment and modernization of the FIIP, as well as restoration and remediation of land and water resources affected by construction and operation of the FIIP. Here, we focus on the strategic approach to rehabilitate and modernize the irrigation project to support water supply management intended to meet historic on farm water use while inserting senior priority date environmental instream flows.

## KEYNOTE SPEAKER 4

### **Facing Future Water Challenges**

Nate Ward, *Water Rights Bureau Chief, Montana Department of Natural Resources and Conservation.*

Nate Ward will cover the Comprehensive Water Review, which has included an overhaul of how DNRC collaborates with stakeholders on important water policy issues, and implementation of HB 114 and the associated significant changes to the water right permit and change process. He will also highlight the newly updated Water Rights Query System.

Nate is the Water Rights Bureau Chief for the Montana Department of Natural Resources and Conservation. The Water Rights Bureau provides technical assistance to the Water Court for all pre-July 1, 1973, statements of claim, and also manages all new water right permitting (July 1, 1973, and newer). Nate has 10 years of water rights experience with DNRC and has worked in regional offices both east and west of the divide. Nate holds a B.S. in Biology from Lake Superior State University in Sault Ste. Marie, Michigan.

## SPECIAL SPEAKERS

### MONTANA WATER CENTER UPDATE

*Stephanie Ewing*, Director, Montana Water Center

*Stephanie Ewing is the Director of the Montana Water Center, and a professor in the Department of Land Resources and Environmental Sciences at Montana State University. She directs the Soil Biogeochemistry Laboratory and Environmental Analytical Laboratory, and is broadly interested in soil-groundwater-surface water connections with an emphasis on water quality related to land use. As Montana Water Center Director, she is interested in championing collaborative approaches to water related research across the Montana University System and Montana's diverse network of water resource professionals.*

### LEGISLATIVE UPDATE

*Jason Mohr*, Research Analyst, Legislative Environmental Policy Office

*Jason Mohr is a research analyst for the nonpartisan Montana Legislative Environmental Policy Office (LEPO). He also serves as staff for the Water Policy Interim Committee. Mr. Mohr has worked for the Montana Legislature for more than 10 years. He has previously worked as a newspaper reporter and editor in Minnesota and Montana, and has degrees in chemistry and journalism.*

**Daniel W Armstrong**

US Geological Survey

**USGS StreamStats Application: Development and updates for Wyoming and Montana**

The U.S. Geological Survey (USGS), in cooperation with the Wyoming Water Development Office, is developing low-flow, basic, flow-duration and peak-flow statistics for streams in and around Wyoming. The streamflow statistics were developed for the use with the StreamStats application, which is a web-based geographic information system application developed by the USGS for assessing water conditions and land-use alternatives. The presentation will provide an overview of the steps used to develop StreamStats for Wyoming, how the data can be accessed, appropriate uses for the streamflow statistics, and a new method for assessing levels of streamflow alteration due to dams and diversions. The presentation will also include updates to the Montana StreamStats application including the continued work to update peak-flow frequencies at streamgages in Montana using Bulletin 17C methods.

**Nick Banish<sup>1</sup>, Meggie Olsen<sup>2</sup>, Drew Schafer<sup>1</sup>**

<sup>1</sup>Gallatin Local Water Quality District, <sup>2</sup>Gallatin Local Water Quality District, now Montana Tech

**Results of 5 years of Monitoring the Big Sky Meadow Village Aquifer**

As part of the Big Sky Area Sustainable Watershed Stewardship Plan, the GLWQD has been routinely monitoring groundwater chemistry in the Big Sky Meadow Village Aquifer (MVA) since 2018. This study presents the first long-term (5 year) assessment of aquifer conditions in the Big Sky area and provides detail into seasonal and annual changes in groundwater quality, while characterizing the abundance and spatial distribution of dissolved forms of plant-available nutrients nitrate, orthophosphate, and the wastewater indicator chloride. The MVA is an alluvial, unconfined, aquifer composed of modern alluvium and quaternary glacial outwash characterized by high transmissivity and strong connectivity to stream ecosystems. Using submersible pumps and bailers, groundwater was sampled from nine wells of varying depths to characterize aquifer chemical and nutrient conditions on a semi-routine basis resulting in 161 paired observations of N and Cl and 65 observations of SRP. Concentrations of nitrate ranged from 0.03 to 9.80 mg/L (mean = 2.93 mg/L) with most values below 0.6 mg/L. Chloride concentrations ranged from 2 to 181 mg/L (mean = 36.54 ± 0.51 mg/L), with 65% of samples above 20 mg/L. Paired observations of nitrate and chloride suggest a moderately strong, statistically significant correlation ( $r = 0.83$ ;  $p < 0.05$ ). SRP values were commonly below detection or low (mean = 0.0086 mg/L). Spatial patterns highlight elevated nitrate and chloride at three sites where wintertime roadways are treated with salt, domestic sewage discharge occurs, and wastewater irrigation is used. Temporal patterns reveal seasonal and intra-annual variation of N and Cl that appear to be strongly linked to snowmelt-dominated hydrograph. Results of this work suggest that groundwater in the MVA is moderately affected by elevated levels of nitrate and chloride in some areas. This study has implications for pollution mitigation and implementing management practices that aim to reduce nutrient loads to the W. Gallatin.

## **High-Resolution Snow Modeling for the Crown of the Continent**

**Theodore B Barnhart<sup>1</sup>, Erich Peitzsch<sup>2</sup>, Zachary Miller<sup>2</sup>, Sheree Watson<sup>2</sup>**

<sup>1</sup>U.S. Geological Survey Wyoming-Montana Water Science Center, <sup>2</sup>U.S. Geological Survey Northern Rocky Mountain Science Center

The Crown of the Continent centers on Glacier National Park, MT and drains to three major river basins. A 40-year simulated snow climatology dataset was recently completed by the U.S. Geological Survey to aid Glacier National Park, the Confederated Salish and Kootenai Tribes, the Blackfeet Nation, and the Montana Department of Natural Resources and Conservation in contextualizing the water resources of the region. The snow simulation was conducted using SnowModel at a spatial resolution of 90 m for a domain encompassing the Upper Flathead River, Glacier National Park, and the Blackfeet Indian Reservation. Data from a new U.S. Geological Survey meteorology reanalysis dataset generated using the Weather Research and Forecasting numerical weather prediction model at a spatial resolution of 4 km was used to drive SnowModel from September 1, 1980 through August 31, 2020. The resulting dataset contains outputs such as simulated snow water equivalent (SWE) surfaces and other variables such as solid and liquid precipitation, air temperature, snow depth, and snow sublimation. When compared to the 26 Snotel stations in the simulation domain, accuracy is spatially variable with RMSE scores ranging from 4 cm to 59 cm. A smaller simulation domain focused on Glacier National Park with a spatial resolution of 30 m had similar accuracy, with an RMSE range of 15 cm to 44 cm. These high-resolution snow simulations will aid water and resource managers in contextualizing drought and flood years as well as understanding potential trends in precipitation, snowfall fraction, and variables relevant to water resources. These datasets also serve as a foundation for locating new snow measurement stations around the Crown of the Continent and for future climate snow studies.

## **Future Streamflow Estimates Suggest a Shift in Streamflow Magnitude and Timing by the End of the Century - Preliminary Results from the Tongue River 2100 Project**

**Theodore B Barnhart<sup>1</sup>, Shanara Span-Gion<sup>2</sup>, Jason Whiteman<sup>3</sup>, Todd Blythe<sup>4</sup>, Nicholas Taylor<sup>1</sup>, Megan Moore<sup>5</sup>, Jay Alder<sup>6</sup>**

<sup>1</sup>U.S. Geological Survey Wyoming-Montana Water Science Center, <sup>2</sup>University of Idaho, <sup>3</sup>Northern Cheyenne Tribe Natural Resources Department, <sup>4</sup>Montana Department of Natural Resources and Conservation, <sup>5</sup>U.S. Geological Survey North-Central Climate Adaptation Science Center, <sup>6</sup>U.S. Geological Survey Geology, Minerals, Energy, and Geophysics Science Center

The Tongue River 2100 project seeks to understand how streamflow in the Tongue River watershed might change by the end of the century. The Tongue River starts in the Big Horn Mountains of Wyoming and flows north to join the Yellowstone River at Miles City, Montana. The project is working closely with the Northern Cheyenne Tribe to co-produce knowledge enabling data-driven water management and planning in the Tongue River Basin. Other project partners include the Tongue River Water Users Association, the Wyoming State Engineer's Office, and Montana Department of Natural Resources and Conservation. The project is using a published database of future hydrology data generated using downscaled climate model output from the Fifth Phase of the Coupled Model Inter-comparison Project (CMIP5). The downscaled climate data are used as

input for the Variable Infiltration Capacity model (VIC) at a 1/16th degree resolution (~6 km) to produce daily hydrology estimates from 1950 to 2099. Two future climate scenarios were modelled, one representing business as usual emissions (RCP 8.5) and one representing moderated emissions (RCP 4.5) for 32 different general circulation models (GCMs). The modeled scenarios will be coupled with a river system model which will be used to produce naturalized streamflow estimates to bias correct future hydrology estimates and represent water use and management activities in the watershed. Preliminary analysis of the future climate hydrology data suggests earlier and decreased peak streamflow, but relatively unchanged annual streamflow volumes by 2100. Increased streamflow in September and October by the end of the century also suggest that fall precipitation, which previously fell as snow, may transition to rain in the future, altering the seasonality of streamflow in the watershed, which may require changes in reservoir management.

## **Evaluating Changes in the Seasonality of Peak Streamflow Caused by Hydroclimatic Variability in Montana Using Circular Statistics**

**Nancy A Barth<sup>1</sup>, Steven K Sando<sup>1</sup>**

<sup>1</sup>U.S. Geological Survey Wyoming-Montana Water Science Center

Knowledge of the seasonal properties of annual-peak streamflows is important for planning flood control and response operations and is a key element for the attribution of flood generating mechanisms. A multi-phase Transportation Pooled Fund study is currently underway to evaluate potential changes (nonstationarity) in annual peak-flow records in the Midwest United States caused by hydroclimatic variability. For streamgages with detected nonstationarity in annual-peak streamflow, there is a need to quantify changes in seasonality to better understand effects of climatic change on flood flows. This is particularly important in temperate regions, where floods may be driven by snow, rain, or both. Circular statistics are used to characterize the seasonal properties of annual maximum series for selected U.S. Geological Survey streamgages without regulation or diversion among common 75-, 50- and 30-year trend periods through water year 2020. By using common trend periods, we address mismatched comparisons that may occur because of multi-decadal persistence arising from hydroclimatic variability that has been found in the study region. Additionally, annual maximum series with detected change points (abrupt changes) in the median and/or scale of peak-flow magnitudes are analyzed on either side of the change point to evaluate changes in their circular statistics caused by hydroclimatic variability. This presentation will show circular statistics for paired streamgages with changes in seasonality. These statistics can be used to better understand potential effects of hydroclimatic variability in Montana.

## **Discerning Bedrock Recharge Spatial Variability As A Function Of Topography And Lithology Of Mountainous Watersheds In Montana**

**David Baude, W. Payton Gardner**

University of Montana

In this study we investigate bedrock groundwater recharge and estimate mean residence times across two mountainous headwater catchments in west central Montana as a function of topography and lithology. Groundwater flow and transport processes in mountain systems are rarely constrained to environmental tracer measurement datasets from bedrock wells. Also, determining mountainous groundwater residence time distributions over long timescales remains lacking in mountainous headwater catchment areas. We present a technique utilizing a suite of environmental tracers ( $^3\text{H}$ , CFCs,  $\text{SF}_6$ , and  $^4\text{He}$ ) and lumped parameter models to estimate groundwater mean residence times over a range of timescales from decades to millennia as a function of topography and lithology. We will also determine bedrock recharge rate spatial variability among watersheds. Tracers were sampled from springs and bedrock wells at four well nests located at various topographic positions (i.e., upland hillslope or downslope hollow) within two adjacent catchment areas with differing lithologies in the Lubrecht Experimental Forest, MT. To constrain groundwater recharge temperature, elevation, and excess air dissolved noble gases were also sampled and Markov-chain Monte Carlo analyses were performed to determine noble gas recharge parameter uncertainties. Those uncertainties were then propagated to field tracer measurements and mean residence times to improve its estimates. Stable isotope samples were also collected from well nests and from streams at stilling well locations installed at the outlets of each creek of the catchment areas. Stable isotopes were used to further partition sources of groundwater recharge and streamflow generation for each catchment area. Mass balance mixing models using bulk end-members, average snowpack and summer precipitation  $\delta^{18}\text{O}$  compositions, applied to bedrock wells show a significant proportion of snowmelt compared to summer precipitation, >70%. Downslope wells contain  $^3\text{H}$ , CFCs,  $\text{SF}_6$ , and elevated terrigenous  $^4\text{He}$  indicating a presence of modern (recharged after 1950) and pre-modern water (recharged prior to 1950). Exponential piston flow-piston flow binary mixing models estimate mean residence times of 529 and 6,127 years for wells at the bottom of the Cap Wallace and North Fork Elk Creek catchment areas, respectively. Bedrock groundwater mean residence times ranging from centuries to millennia in headwater catchment areas suggest groundwater flow through deeper bedrock having implications for improving existing conceptual and numerical groundwater flow models that treat bedrock as an impenetrable barrier to flow.

## **Everything is better in 2D: use of a 2-dimensional hydraulic model for indirect discharge estimation and other applications in stream gaging**

**Todd Blythe, Jake Mohrmann, Troy Lechman, Matt Norberg, John Lunzer**

MT Department of Natural Resources and Conservation

Large flood peaks can be downright hard to measure. Hazardous conditions during a flood, limited response time, and limitations of traditional velocity measurement equipment can make physically measuring the peak discharge of a flood impossible. Thus, there has always been the need to indirectly measure a peak discharge after the fact, using an estimated water surface elevation and hydraulic equations for open channel flow. This procedure has been employed in the field of water measurement for nearly a century. It has also been central

to the field of paleo-hydrology, specifically paleo-flood analysis, which seeks to extend our understanding of flood regimes into the near or distant past using paleo-flood indicators. Understanding the flood regime is useful for many areas of river research as well as assessing infrastructure vulnerability to catastrophic events that happened long ago and determining the probability of similar events occurring in the future. In June of 2022, the headwaters and tributaries of the Yellowstone River originating in the Beartooth Mountains of south-central Montana experienced a unique meteorological event that led to unprecedented flooding. DNRC's Stream Gage Program site on the West Fork of Rock Creek near Red Lodge, MT (43D 01900) was operating amid this flooding, and it was clear based on water level values that the peak was over 300% greater than any measured flow at the site. To indirectly estimate the peak discharge, we have developed a method that relies on a calibrated 2D hydraulic model and a 3D channel survey of the bathymetry and surrounding floodplain. We compared different approaches for surveying the target stream reach and assessed the efficiency of each in terms of field and post-processing time, as well as the survey error's impact on the resulting discharge estimate. We present a calibration approach that produces both model parameter probability distributions and a probabilistic final indirect discharge based in multiple model runs. This approach provides a wealth of diagnostic information and was able to indirectly reconstruct the post-flood rating curve for the site to within 5% error. Both the 3D terrain information and the calibrated model have many potential applications that DNRC's Stream Gage Program, and other Water Resources Division modeling projects, will be exploring to produce additional streamflow products at gaging locations.

## **Investigating Hydrologic Connections Between Aquifers and Surface Waters in the East Flathead Valley**

**Andrew L Bobst<sup>2</sup>, James L Berglund<sup>1</sup>, Larry N Smith<sup>2</sup>**

<sup>1</sup>University of Wisconsin-Platteville, <sup>2</sup>Montana Tech

A lack of information on how groundwater and surface waters, such as the Flathead River, are connected has caused recent water management decisions in the Flathead Valley to be contentious. The population of Flathead County is increasing, which is resulting in greater groundwater development. The East Flathead Groundwater Investigation seeks to provide a greater understanding of the interconnection between the area's aquifers and surface water. The Deep Aquifer in the Flathead Valley is an important groundwater source, with wells commonly producing water at hundreds of gallons per minute. The Deep Aquifer is generally overlain by a confining layer composed of glacial till and lacustrine deposits, which is in turn overlain by shallow unconfined sand and gravel aquifers. Field data were collected from summer 2019 to fall 2021 to evaluate the groundwater and surface-water flow systems. Groundwater levels were measured at 144 wells at least monthly. New wells were drilled to improve the monitoring network, provide additional lithologic information, and to conduct aquifer tests. At two sites RotoSonic core was collected to refine understanding of the depositional environments of possible confining units. The surface water network included hourly measurements of stage and flow at 16 surface-water sites, and data from 6 DNRC and 5 USGS gauges. For selected wells environmental tracers (tritium, dissolved gasses, and SF6) were analyzed to aid in understanding the time since groundwater recharge and the degree of aquifer confinement. A detailed 3D model of the distribution of hydrogeologic units and a groundwater budget were developed based on aquifer properties, monitoring data, remote sensing and meteorological information. Groundwater flow models were developed and calibrated based on this information. Stratigraphic interpretation, aquifer testing, environmental tracers and groundwater

modeling indicate that in areas near the base of the Swan Range, and south of Lake Blaine, there is a hydrologic connection between the deep and shallow aquifers. It was not possible to simulate sufficient groundwater inflow to Jessup Mill Pond from the shallow aquifers alone using reasonable values for hydrologic conductivity. Near Jessup Mill Pond and Mill Creek the Rotosonic core shows sandy lacustrine deltaic sediments between the deep and shallow aquifers, The relatively permeable deltaic sediments provide a pathway for water movement from the deep to the shallow aquifers, and then to surface waters. Due to this permeability terrigenic  $^4\text{He}$  was not enriched in the Deep Aquifer in this area. In about 70% of the area, especially away from the Swan Range and nearer the valley center, the shallow and deep aquifers are locally separated by basal till and fine-grained lacustrine deposits. In these more confined areas terrigenic  $^4\text{He}$  was enriched in the deep aquifer. The effectiveness of the confining layers to separate the shallow and deep aquifers varies spatially based on variability in past depositional environments. This more detailed understanding of the groundwater system provides an improved model of the area to guide future groundwater management decisions.

### **Aerobic granular sludge: assessing a novel approach to pharmaceutical removal from wastewater**

**Kylie Bodle, Catherine Kirkland**

Montana State University

Pharmaceutical consumption has increased concomitantly with population growth. A natural consequence of this is increasing pharmaceutical contamination in the environment, due in part to incomplete metabolism by humans, followed by poor removal by conventional wastewater treatment systems. As such, improved wastewater treatment methods are worthy of investigation, as exposure to pharmaceuticals can cause antibiotic resistance gene proliferation as well as numerous other adverse effects on plants, animals, and microbiota. Aerobic granular sludge (AGS) is an emerging wastewater treatment biotechnology that may be capable of enhancing pharmaceutical removal from wastewater. AGS consists of diverse communities of nitrifying, denitrifying, and phosphate-accumulating organisms that self-aggregate into spherical biofilms. The gel-like extracellular polymeric substances (EPS) secreted by bacteria in AGS confer protection from toxins and enhance AGS density, resulting in short settling times and high biomass retention. Furthermore, the EPS in AGS may provide a sorptive medium for organic compound removal. However, the body of literature on AGS-driven pharmaceutical treatment is limited, and therefore more information is needed on how granules respond to a wide range of pharmaceuticals. Current studies are also limited by AGS themselves: most utilize lab-grown AGS, which possesses different properties than AGS grown in full-scale treatment plants. Full-scale AGS has more diverse microbial populations and EPS than lab-grown AGS, traits likely to positively impact pharmaceutical removal. For that reason, this study investigated the effects of three common pharmaceuticals on full-scale AGS. Full-scale AGS' response was then compared with that of lab-grown AGS. This study is ongoing at the time of abstract submission but will be complete in mid-September. In brief, a mixture of three common pharmaceuticals is continuously dosed at environmentally relevant concentrations to test reactors. Pharmaceutical impacts are evaluated by assessing changes in wastewater treatment capacity and internal granule structures throughout dosing. Pharmaceutical removal via biodegradation and sorption are also evaluated.

## **Lysimetry Study of Deep Percolation Beneath Irrigated Fields**

**Ronald Breitmeyer, Shawn Kuzara**

Montana Bureau of Mines and Geology

Across Montana many agricultural areas have converted from flood irrigation to sprinkler or pivot irrigation to reduce water use and labor. Pivot or sprinkler irrigation ostensibly conserves water since application rates can be precisely controlled and tailored to an individual crop need. However, an increasing body of work has shown that the over-watering associated with flood irrigation may serve as an important groundwater recharge source. Reducing this recharge source by conversion from flood to pivot irrigation could have broader impacts to aquifer systems, down-gradient water users and ecological systems. To better understand the changes in potential groundwater recharge associated with irrigation conversion, the Montana Bureau of Mines and Geology Ground Water Investigation Program installed lysimeters and soil-moisture monitoring instruments near Melrose and Edgar, MT. The lysimeters allow direct measurement of percolation beneath irrigated fields while the soil-moisture instruments record water content and soil potential data. At each site, lysimeters were installed below root depth beneath flood irrigated, pivot irrigated, and unirrigated fields. The lysimeters were installed in late fall and early winter of 2022 to capture the 2023 irrigation season. Initial data from the lysimeters indicates higher drainage beneath flood irrigated fields than beneath the pivot irrigated and unirrigated areas. This is consistent with the understanding that flood irrigation has higher potential for producing groundwater recharge. Soil-moisture data from the pivot and unirrigated areas suggest that while not producing percolation at depth, pivot irrigation facilitates deep drainage of precipitation, which in turn provides additional groundwater recharge. Additional data collection and analysis over the next one to two growing seasons will be conducted to further understand these processes.

## **Developing CE-QUAL-W2 Models of Koocanusa Reservoir and the Kootenai River, Montana and Idaho**

**Katherine J Chase<sup>3</sup>, Taylor Dudunake<sup>1</sup>, Laurel Stratton<sup>2</sup>, Seth Siefken<sup>3</sup>, Stewart Rounds<sup>2</sup>**

**<sup>1</sup>USGS ID Water Science Center, <sup>2</sup>USGS OR Water Science Center, <sup>3</sup>USGS WY-MT Water Science Center**

The construction and operation of Libby Dam, a U.S. Army Corps of Engineers project located in northwestern Montana, has altered the natural hydrograph, thermal regime, sediment transport, and nutrient loadings on the Kootenai River. These changes affect Kootenai River fish, including the federally endangered Kootenai River White Sturgeon (*Acipenser transmontanus*), federally threatened Bull Trout (*Salvelinus confluentus*), Burbot (*Lota lota*), and other focal species important to a broad group of stakeholders in the region. Better understanding of the flow and temperature dynamics in Koocanusa Reservoir, impounded by Libby Dam, could inform operations of Libby Dam to optimize flow and temperature in the Kootenai River within operational constraints. To that end, the U.S. Geological Survey, in cooperation with the U.S. Army Corps of Engineers, is developing a CE-QUAL-W2 model of Koocanusa Reservoir and the Kootenai River from Libby Dam downstream to the Canadian border. CE-QUAL-W2 is a two-dimensional hydrodynamic model used to simulate flow, temperature, and water quality parameters. The first phase of the study includes flow and temperature

simulations for temperature management scenarios at Libby Dam. This presentation will describe the climate and hydrology of the bi-national Kootenai River Basin, the measured thermal structure and water budget for the reservoir, the collaboration between USACE and USGS on model inputs and configuration, and some aspects of the development and application of the CE-QUAL-W2 model to Koocanusa Reservoir and the Kootenai River.

### **Examining the roles of beavers and time in driving recovery following stream channel restoration**

**Ben Colman<sup>1</sup>, Alyssum Ahler-Mull<sup>1</sup>, Daylen Egger<sup>1</sup>, Klemensas Krasaitis<sup>1</sup>, Danielle Novotny<sup>1</sup>, Eamon Peterson<sup>1</sup>, Claire Shady<sup>1</sup>, Kory Shoja-Chaghorvand<sup>1</sup>, Shawnalee Voyles<sup>1</sup>, Paul Parson<sup>2</sup>**

<sup>1</sup>University of Montana, <sup>2</sup>Trout Unlimited

Historic placer gold mining and profound impacts on stream ecosystems, including straightened streams, moved to the margins of their valleys and channelized between 10m tall banks. These physical changes transform these ecosystems' hydrology, sediment transport, and ecology. Channel reconfiguration can be necessary to restore stream geomorphology and hydrology, and replanting vegetation can help start the process of revegetating riparian zones. However, revegetation can be slow, taking decades to restore stream reaches to the point where they begin to resemble a reference condition. In North America, American Beavers are increasingly being recognized for the potentially beneficial effects of their dam building, which can accelerate the recovery of floodplain soils and vegetation. To examine the combined effects of time since restoration and colonization by beavers on soil properties and vegetation cover following channel reconfiguration, we studied Ninemile Creek in western Montana, USA. The river was placer mined in the late 1800s into the 1900s, and we studied three reaches that were restored in 2014, 2016, and 2018. We examined vegetation cover, soil characteristics, and the number of beaver structures across all restored reaches in both 2019 and 2021. In 2019, beaver had started recolonizing the 2014 reach, which is also the most upstream reach, and had built seven dams and one lodge. By 2021, they had expanded their dams to 36 and built an additional lodge. By 2021, soil moisture and organic matter were both three-fold higher in the 2014-restored reach than in the downstream reaches, overlapping with values from the reference. Additionally, mean woody vegetation cover was ~5-fold higher in the 2014 reach than the 2016 or 2018 reaches. These results build on literature suggesting that partnering with beaver either intentionally or through happenstance can greatly accelerate the pace of recovery of restored streams in North America.

### **Hydrogeologic Influences on Water Supply in the Big Hole River Near Glen, MT**

**Jenna M. Dohman, Todd Myse, Ann E.H. Hanson**

Montana Bureau of Mines and Geology Ground Water Investigation Program

Drought is a major concern for many river basins, and the Big Hole River is no exception. The Big Hole River is a blue-ribbon trout fishery and an important water resource for the agricultural economy near Glen, MT. Low summer stream flows limit the amount of water available for irrigation and can contribute to late-summer high temperatures which threaten the fishery. Community stakeholders are interested in managing the river

resource so both important economies are sustained. In this study, we seek to improve understanding of how different types of irrigation influence the volume and timing of surficial and groundwater-mediated irrigation return flows, which may be important to low summer flows in the Big Hole River. To better understand the hydrogeologic factors that most influence water supply on the Big Hole River, the Montana Bureau of Mines and Geology Ground Water Investigation Program (GWIP) has been collecting field data near Glen since Fall 2022. GWIP developed a monitoring network that currently includes 43 wells and 16 surface-water sites, which are monitored monthly for water level, stream stage, and discharge where feasible. GWIP installed seven new wells to better define the aquifer(s) and increase the coverage of the groundwater network. We collected water-quality samples at a subset of wells for analysis of inorganic compounds and water isotopes. GWIP is also assessing vertical groundwater gradients using sets of nested wells. Preliminary data show that the groundwater table rises more in areas affected by irrigation than unirrigated areas. Beneath flood fields or adjacent to canals, groundwater rises more rapidly at the onset of irrigation, while near pivot fields the rise is slower. Wells in unirrigated areas, but adjacent to canals, show similar groundwater responses to irrigated areas, suggesting that canal leakage is an important recharge mechanism. This talk will cover preliminary field data and future plans for the GWIP Big Hole River groundwater/surface-water study. Ultimately, data will be used to develop a model of groundwater/surface-water interactions to be used as a water management tool.

### **Beaver dam analogs influence macroinvertebrate communities and fluxes between aquatic and terrestrial ecosystems in headwater streams of western Montana**

**Michelle E Fillion<sup>1</sup>, Benjamin P Colman<sup>1</sup>, Rachel L Malison<sup>2</sup>**

<sup>1</sup>University of Montana, <sup>2</sup>Flathead Lake Biological Station

North American beavers (*Castor canadensis*) engineer stream ecosystems by creating dam complexes that influence geomorphic, hydrologic, and ecological characteristics at a range of scales. The near eradication and slow recovery of beaver populations has had negative effects on aquatic ecosystems, including stream incision and homogenization, lowered water tables, and changes in the composition of riparian vegetation. To restore degraded aquatic ecosystems, managers have increasingly turned to using beaver dam analogs (BDAs), which are human-constructed structures that mimic natural beaver dams. Though BDAs have been shown to decrease incision, raise water tables, and even facilitate beaver recolonization, their influence on macroinvertebrates and the linkages macroinvertebrates provide across aquatic-terrestrial interfaces is not well understood. To examine how BDAs influence aquatic habitat, macroinvertebrate communities, and the riparian insectivores they support, we compared unrestored reference stream segments to BDA-restored segments in three headwater streams in western Montana, with each BDA-restored segment consisting of complexes of 8-14 BDAs. Fieldwork was conducted over three months in both the summers of 2021 and 2022. We surveyed aquatic habitat by measuring wetted widths, thalweg depths, stream surface areas, sediment sizes, and by mapping habitat types. To assess macroinvertebrate communities and fluxes, we used a variety of sampling techniques, including a Surber sampler to collect benthic macroinvertebrates, floating emergence traps for emerging aquatic insects, and pan traps for macroinvertebrates falling into the streams. Finally, to examine the potential influence of BDAs on the number and diversity of riparian insectivores, we conducted spider and bird surveys. Preliminary results show that BDA-restored segments have wider stream widths indicating water retention and pooling. The median

density of benthic macroinvertebrates differed by segment and site, with higher densities in the BDA-restored segment at one site, and slightly lower densities in the BDA-restored segments at the other two sites. Benthic macroinvertebrate diversity was similar across all sites, but BDA-restored segments supported higher median percentages of chironomids, a more tolerant and sessile family often found in slower water, and lower median percentages of Ephemeroptera, Plecoptera, and Trichoptera (EPT), more sensitive Orders typically found in well-oxygenated waters. Similar patterns occurred for emerging insects, with a higher median percentage of chironomids emerging from BDA-restored segments across all three streams and a higher median percent EPT emerging from reference segments across two of the streams. Invertebrates falling into the stream were more variable because inputs included both aquatic and terrestrial organisms, but a higher median percentage of EPT fell back into the streams at all three reference segments. These results suggest that BDA restoration may alter macroinvertebrate communities similarly to natural beaver dams by creating habitat suitable for tolerant macroinvertebrate taxa that can survive in slower-moving water with lower dissolved oxygen. At an ecosystem level, an increase in tolerant taxa at BDA-restored stream segments has the potential to increase site-wide diversity by supporting a variety of macroinvertebrate communities through increased habitat heterogeneity while also retaining and supplying water to lower stream reaches to sustain downstream habitats and communities.

## **Tracking trends in selenium concentrations through the Upper Columbia River Basin**

**Madison Foster, Ashley Bussell, Meryl Storb, Travis Schmidt**

US Geological Survey WY-MT Water Science Center

A legacy of coal-mining activities in the Elk River valley (British Columbia, Canada) has increased selenium concentrations in downstream waters, including Koochanusa Reservoir (Montana, USA). While selenium is an essential micronutrient, enriched concentrations can be toxic to aquatic life. Selenium loads in the Elk River have increased over 400% since 1984 and yielded 12 tons of selenium in 2022. Additionally, selenium concentrations remain elevated downstream and are increasing in the Upper Columbia River Basin. However, it is unclear how these trends are influenced by hydrologic conditions and changes to analytical methods and detection limits. Furthermore, many water quality sampling sites in the Upper Columbia River Basin do not have streamflow data, which complicates understanding how streamflow variability influences these trends. We will present flow-normalized trends in selenium concentrations on the Elk, Kootenay, and Columbia Rivers in Canada. Site locations on the Columbia and Kootenay Rivers range from being upstream of Elk River inflows to over 400 river miles downstream and water quality data records at these sites range from the 1970s to 2022. Flow estimates at each site will be derived from nearby streamgages and interpolated based on watershed area. We will use the QWTREND time-series model to identify systemic changes in selenium concentrations by estimating the effects of flow variability on concentrations, while accounting for changes in method detection limits, among other parameters. Our results will describe how far selenium may travel through the Kootenai and Upper Columbia River Basins and the degree to which mining activities impact local and downstream water quality, independent of hydrologic conditions and changing analytical methods.

## **Comparative Observations of Mountain Aquifer System Dynamics in western Montana and Colorado**

**Payton Gardner<sup>1</sup>, Nicholas Thiros Lawrence<sup>2</sup>, David Baude<sup>1</sup>, Kelsey Jencso<sup>1</sup>, Zachary Hoylman<sup>1</sup>, Kenneth H Williams<sup>2</sup>**

<sup>1</sup>University of Montana, <sup>2</sup>Berkeley National Laboratory

Mountain aquifers represent an important source of upland storage and the recharge location for regional groundwater flow paths that help recharge adjacent low-land aquifer systems, yet the groundwater dynamics of these important systems remain under-investigated. Here, we summarize results on mountain aquifer characterization efforts across multiple watersheds in western Colorado and Montana using hydrologic and environmental tracer methods. Multi-level groundwater wells have been installed across the different watersheds and a variety of landscape positions with differing climate and subsurface geology. Borehole geophysics, core logging and slug tests have been used to characterize subsurface structure and hydraulic properties at our drilling locations. Continuous water-level and temperature logs provide information on seasonal hydraulic dynamics. Environmental tracers (CFC, SF<sub>6</sub>, 3H-3He, stable noble gas isotopes, stable isotopes of water) collected in wells and adjacent streams are used to provide information on timing, location and volume of groundwater circulation. Results indicate that mountains host active groundwater systems with strong seasonal responses to changing infiltration and evapotranspiration dynamics. Measured groundwater ages in these deep bedrock systems are characterized by a mixture of young and old water, with mean ages that span 100-1000 years, depending upon landscape position and geologic setting. Models of surface and subsurface flow are highly sensitive to subsurface hydrogeologic properties, and specific subsurface configurations are required to reproduce observed water table dynamics and groundwater mean ages. This work suggests that the deep critical zone including the saprolite and bedrock groundwater systems are an important, but often under explored control on upland watershed dynamics in mountainous systems, and set controlling boundary conditions for recharge to regional groundwater systems.

### **Year Three of Monitoring Montana Waters (MMW): A Flathead Lake Biological Station program supporting watershed monitoring.**

**Jared D Glass, Rachel Malison**

Flathead Lake Biological Station, Monitoring Montana Waters

Flathead Lake Biological Station (FLBS) launched Monitoring Montana Waters at the start of 2021 to support water quality monitoring in Montana. Founded in 1899, FLBS is the second oldest biological research station in the country. The mission of FLBS is to serve the Flathead Lake region, the state of Montana, the nation, and the world by advancing a cutting-edge research, monitoring, education & outreach platform for limnology, ecology, and environmental science at Flathead Lake. MMW was created to support the collection of more water quality monitoring data throughout Montana. MMW supports water quality monitoring by providing scientific, technical and financial support to citizen-led watershed groups. MMW works very closely with MT-DEQ's VMLAS program and the MSU Extension Water Quality Program to support volunteer efforts

throughout Montana. MMW supports citizen-led groups to ensure that scientifically credible methodologies are used in all aspects of their monitoring efforts (e.g. sample collection, handling, chain of custody, instrument calibration). An important aspect is helping groups develop their monitoring plans and narrow down objectives to ensure they are able to answer why they are monitoring (e.g. understanding the effects of agriculture would focus more on sampling Nitrogen and Phosphorus while measuring the effects of mining would focus on heavy metals). MMW also provides in-person, on the ground training in collection methods. This year we worked with MT-DEQ and MSU extension to host a water quality training workshop which allowed 26 individuals from 21 groups to come together and receive in-person training at FLBS. We provided workshops, hands-on outdoor training stations and group-learning sessions at this 3-day event in May 2023. MMW also provides funding to groups to pay for sample analyses at the FLBS Freshwater Research Laboratory and Gear funding to assist with the cost of sampling gear (e.g. water meters, YSI, Flow meters, ect). All data that is generated from funded groups must be uploaded to DEQ EQuIS database, so it is publicly available for everyone to use. Our overarching goal is to help better understand and protect the world-renown waters of Montana which also feed into some of the largest watersheds in the nation. More details about the MMW program, groups, and resources can be found at our website at [bit.ly/flbsmmw](http://bit.ly/flbsmmw). This is now MMW's third year, and the program has continued to grow, with 11 groups receiving laboratory or gear funding support in 2023. This program is led by Dr. Rachel Malison, with the support of Jared Glass, our 2023 MMW Big Sky Watershed Corps Member. Please reach out to us with any questions or if you would like to discuss monitoring efforts ([mmw@flbs.umt.edu](mailto:mmw@flbs.umt.edu), 406-872-4518). If you are interested in sampling in 2024 we recommend reaching out as soon as possible to start the process. Ideally groups start drafting documents the fall before initiating sampling. Funding applications are due March 1st each year.

## **40 Years of Water Quality and Biological Monitoring at the Confluence Clark Fork Superfund Complex - The Case for Weight of Evidence Analysis**

**Joe Griffin**

Montana Technological University

The upper Clark Fork Superfund Complex is comprised of three gargantuan sites, Silver Bow Creek/Butte Area, Anaconda Smelter and Mill Town Reservoir/Clark Fork River. The Complex is commonly referred to as “the largest in the nation.” Major cleanup work in the watershed began in the early 1990s and will continue for at least another decade. Under Superfund authority and law, the measure of success in that massive cleanup of mining damages to the Clark Fork and its five tributaries is meeting Montana's strict water quality standards based on a total recoverable (unfiltered) fraction. There is an enormous body of water quality data, extending from the early 1990s to the present, that answers the question “where are we now” by that measure of success. In this presentation, I suggest it is time to recognize the limitations imposed by strict adherence to those standards and turn to a weight-of-evidence and reference-reach approach that also integrates 40 years of biological monitoring with water chemistry data for a more pragmatic and useful measure of success.

## **Mapping Optimal Restoration Sites for Persistence of Greenback and Colorado River Cutthroat Trout**

**William Hamilton<sup>1</sup>, Travis Schmidt<sup>1</sup>, James Roberts<sup>2</sup>**

<sup>1</sup>U.S. Geological Survey, WY-MT Water Science Center, <sup>2</sup>US Geological Survey, Great Lakes Science Center

In Rocky Mountain National Park (ROMO), climate-driven changes in temperature and hydrology raise concerns about the persistence of habitats of Colorado cutthroat trout (*Oncorhynchus clarkii plueriticus*; CRCT) and greenback cutthroat trout (*O. c. stomias*; GBCT). CRCT are a species of concern and GBCT are listed as a federally threatened species. Recent findings reveal a shrinking range of wild GBCT populations. Both species are major attractions for anglers visiting the park, and ROMO is the only National Park Service unit within the historic range of both species. Water temperature is a key parameter to persistence of cutthroat trout, with low temperatures limiting recruitment and growth, and high temperatures resulting in reduced growth and higher mortality. ROMO is interested in reclaiming cutthroat trout habitat, but a changing climate makes long-term suitability of current and reclaimable habitat unclear. In a warmer climate, colder, high-elevation settings become more important thermal refugia for trout, but high-resolution data that locates suitable thermal refugia is limited. Using new and historic data we created a dataset of air and water temperature at 120 sites across ROMO from 1996-2019. Using the SSN package in R we developed high-resolution models to predict water temperature in stream-lake networks throughout the 415 square-miles of ROMO. The models indicate air temperature, drainage area, and aspect to be most important for predicting water temperature in ROMO. Using these high-resolution GBCT and CRCT habitat suitability models, we mapped predictions of average water temperature across stream segments. These maps may be used by ROMO resource managers to make informed decisions based on current thermal habitat, and will act as a basis for predicting future thermal habitats under different climate scenarios.

## **Detecting and Monitoring Cold- and Warm-Water Inputs to the Lower Big Hole River Near Glen, MT**

**Ann E. H. Hanson, Jenna M. Dohman**

Montana Bureau of Mines and Geology

Elevated river temperatures during late summer can be a concern to river ecosystems – potentially affecting fish, macroinvertebrates, and nutrient cycling. The lower Big Hole River in southwestern Montana consistently has river temperatures greater than 70°F (21.2°C) during late summer. Groundwater, which remains cooler than the surface water during the summer, can provide cold-water inputs where it discharges to a river. Conversely, some solar-heated surface-water return flows may provide warm inputs. As part of a local groundwater/surface-water study near Glen, MT, the Montana Bureau of Mines and Geology Ground Water Investigation Program

(GWIP) is investigating cold- and warm-water contributions to the lower Big Hole River using thermal infrared imagery and temperature loggers. Ongoing efforts during Summer 2023 include float trips utilizing a handheld thermal camera to scan the river banks during low-flow periods looking for contrasts in water temperature. Other observable and measurable indicators, such as saturated sands along banks, iron precipitates, and redox conditions, are being used to confirm groundwater discharge. Size, subsurface temperature, and water quality parameters are collected at each site visit. Temperature loggers are being deployed to investigate differences in temperature signatures among surface water, groundwater discharge sites, and groundwater in the study area. This talk will discuss findings from the Summer 2023 temperature survey of the lower Big Hole River. Preliminary field work shows both cold- and warm-water inflows from saturated banks to the river. All of these inflows have lower pH, lower dissolved oxygen (DO), and lower redox compare to the river suggesting a groundwater source and/or hyporheic interaction with groundwater. Iron staining is visible on the riverbanks at these locations. Some observed surface-water inputs have warmer inflows and higher conductivity compared to the river indicative of solar-heated surface-water return flows. Understanding the size and location of cool and warm inflows to the river is important for understanding overall river temperature changes along the river, and may provide useful information for water managers.

## **Patterns of aquatic insect emergence from irrigation canals in the lower Gallatin watershed, Montana**

**Nate M Heili, Wyatt F Cross**

Montana State University

Human demand for water has altered the hydrology of Earth and as a result, artificial aquatic waterways are pervasive across mixed-use watersheds. Despite their ubiquity, artificial waterways have been overlooked from ecological exploration. Irrigation canals are a common type of artificial waterway and are essential for agricultural production in the state of Montana. Previous literature indicates irrigation canals influence natural hydrologic processes (i.e., groundwater recharge and instream return flow), but less is known about their distribution on the landscape and how they function as aquatic habitat and affect ecosystem processes. The objective of this study was to map and collect spatial statistics (i.e., length and surface area) of the canal network in Gallatin valley, MT to assess their contribution to water-to-land energy transfer through aquatic insect emergence. We quantified spatial and temporal patterns of aquatic insect emergence from three canals using floating emergence traps during the 2022 irrigation season (June-October) and compared community biomass, structure, and timing of emergence. We observed a median daily biomass flux of 9.29 mg dry mass m<sup>-2</sup> day<sup>-1</sup> and production increased through the summer peaking during August. In general, sites closer to the headgate (i.e., point of water diversion) were more diverse but sites farther away had more individuals emerging and, in some cases, higher biomass. Our preliminary results suggest that individual ditches had distinct emergence events, implying asynchronous resource availability for mobile insectivore predators. Aquatic insect emergence from canals represents an overlooked water-to-land energy transfer and demonstrates the need to understand how ditches influence ecosystem processes in order to achieve holistic water management in the state of Montana.

## **Montana Department of Agriculture: A GIS Method for Agricultural Chemical Groundwater Monitoring Well Site Selection**

**Brett Heitshusen**

Montana Department of Agriculture, Sustainable Agriculture Section

Monitoring for agricultural chemicals in groundwater is most often reactionary to known contamination events or focused in regions with geographic attributes specifically vulnerable to leaching from agricultural activities. Access to many of the wells utilized in the Groundwater Protection Program's permanent monitoring well network (PMWN) have come from the opportunistic expansion of monitoring, where monitoring has been requested by concerned citizens or other state agencies. This has led to a lack in reliable land use and geographic conditions between monitoring wells, and a low correlatability between monitoring well environments and groundwater sample analytical results. The ACSR model uses a dynamic confluence window to compare the agricultural land use, crop type history, soil depth and soil saturated conductivity around a point to identify areas that are representative of the average agricultural conditions of a WBDHU12, Project Area, and the PMWN. Using the resulting heat maps, new monitoring wells can be developed with a level of consideration for how a given location fits into the agricultural environment of the region as well as a new sites relatability to the existing permanent monitoring well network.

## **Evaluating the relative influence of soil water potential, soil moisture, and vapor pressure deficit of semi-arid vegetation dynamics**

**Kayla R Jamerson<sup>1</sup>, Kelsey G Jencso<sup>1</sup>, Zachary H Hoylman<sup>1</sup>, Anna Sala<sup>2</sup>, Ashley Ballantyne<sup>3</sup>**

<sup>1</sup>Montana Climate Office, University of Montana, <sup>2</sup>Division of Biological Sciences, University of Montana, <sup>3</sup>Global Climate and Ecology Laboratory, University of Montana

Knowledge of vegetation's response to water availability and atmospheric demand is critical to understanding the impact of climate change on semi-arid ecosystems. However, limited field-based research has been conducted to assess the relative importance of these drivers and previous research has simplified the assessment of soil water availability by relying on soil volumetric water content (VWC) as a primary control on plant growth, agnostic of soil textures' influence on plant available water. To address these gaps, we compared remotely sensed indicators of vegetation response to field based measurements of VWC (at 8in depth), relative humidity and temperature (used to calculate the vapor pressure deficit, VPD) and soil temperature from 52 sites in Montana. Soil samples were collected at each site and were used to generate continuous time series of soil water potential ( $\Psi_{\text{soil}}$ ). We utilized statistical analysis to assess the relationship of our biophysical metrics to satellite-derived estimates of vegetation health and vigor, including the Enhanced Vegetation Index (EVI), near-infrared reflectance vegetation index (NIRv), and solar-induced fluorescence (SIF). Results from this analysis suggest that  $\Psi_{\text{soil}}$  plays a central role in driving seasonal vegetation dynamics in semi-arid regions, while VPD emerges as a secondary driver in the absence of  $\Psi_{\text{soil}}$  limitations. Finally, anomalies in subsurface moisture were the dominant driver for explaining anomalies in vegetation response. These findings emphasize the importance of soil water potential as the first order control on vegetation water stress across semi-arid landscapes.

## **Enhancing the Upper Missouri River Basin's Drought Early Warning System**

**Kelsey Jencso, Zachary Hoylman, Kyle Bocinsky, Kevin Hyde, Colin Brust**

Montana Climate Office

Montana is a headwaters state - its two major river basins drain to almost two thirds of the land area of the Conterminous United States. Whether for drought detection, flood prediction, water supply estimates, or natural resource management, too few watersheds in Montana have been monitored for meteorological and soil moisture information in support of decision-making. Here, we discuss the development of a drought and flood early warning system that is being built upon the Montana Mesonet. Since 2016 the Montana Mesonet has grown to a network of 94 stations that are supported through federal, state, tribal and private partnerships. A recent contract from the U.S. Army Corps will support the installation of an additional 205 stations in the next 6 years. Data from each station is available online at 5-minute intervals ([climate.umt.edu/mesonet](http://climate.umt.edu/mesonet)). In this presentation we will discuss applications of MT Mesonet data for the development of a Drought Early Warning System in the Upper Missouri River Basin ([drought.climate.umt.edu](http://drought.climate.umt.edu)), validation of gridded weather and remote sensing data, and rangeland management and precision agriculture approaches for optimization of production. Quantifying even small changes in water availability is significant for Montanans and downstream users who make decisions that balance risks and costs - the development of watershed networks such as the Montana Mesonet can help to navigate the waters ahead.

## **Water Quality, Mixing, and Groundwater Age in an Urbanizing Agricultural Intermountain Basin, Gallatin Valley, Montana**

**Skye Keeshin<sup>1</sup>, Stephanie A Ewing<sup>1</sup>, Andrew G Hunt<sup>2</sup>, Tom Michalek<sup>3</sup>, Robert A Payn<sup>4</sup>, W. Payton Gardner<sup>5</sup>**

<sup>1</sup>Montana State University, <sup>2</sup>USGS, Denver Federal Center, <sup>3</sup>RESPEC, Bozeman, <sup>4</sup>Montana State University, <sup>5</sup>University of Montana

Intermountain basins in the western US rely on mountain snowmelt for groundwater recharge, which in turn maintains the long-term aquifer storage that provides a critical source for dry-season river flows. Aquifer recharge and the timing of instream flows have potential to be transformed by climate change, irrigation diversions with consumptive use and leaky ditches, or reduction in permeable landcover by urbanization. The Gallatin Valley is an intermountain basin in the headwaters of the Missouri River that is subject to all of these potential mechanisms of changes in water resource availability, either due to issues with water quantity or quality. Nutrient impairment affects over 200 miles of streams in the Gallatin. The rapidly growing city of Bozeman at the heart of municipal development in the valley is anticipating water shortages within a decade if consumption increases at predicted rates. This projected shortage has led to exploration of new water resources including pipelines from resources outside the local watershed and well fields extracting from the intermountain basin aquifer. Here, we present work seeking the understanding of groundwater age, flow path dynamics, and surface water-groundwater connection in the Gallatin Valley alluvial aquifer that is necessary

for characterizing this aquifer's role in the availability of surface and subsurface water resources for humans and ecosystems. Between 2017 and 2023, we performed longitudinal stream surveys and groundwater sampling across seasons and in variable drought conditions. Dissolved  $^{87}\text{Sr}/^{86}\text{Sr}$  isotopic ratios and  $^{234}\text{U}/^{238}\text{U}$  activity ratios ( $^{234}\text{U}/^{238}\text{U}$ ) in groundwaters and surface waters suggest source and mixing relationships. The first full suite noble gas measurements in the Gallatin Valley provide groundwater age and recharge conditions throughout the aquifer. The presence of excess  $^4\text{He}$  in the alluvial aquifer at both the range front and in the lower valley indicates connection to premodern waters. Groundwater age at one point in the underlying Tertiary aquifer appears to be many hundreds of thousands of years. Major and trace ions indicate contaminant sourcing and geochemical evolution of waters. These geochemical methods illuminate the connections between hydrogeologic processes and nutrient contamination of groundwater and streams in the Gallatin Valley.

## **Comparison of stream morphological metrics in reference and managed catchments across Western Montana and Northern Idaho**

**Craig Kendall<sup>1</sup>, Josh Erickson<sup>2</sup>, Andy Efta<sup>2</sup>, Eric Archer<sup>3</sup>**

<sup>1</sup>USDA Forest Service- Flathead National Forest, <sup>2</sup>USDA Forest Service- Northern Region, <sup>3</sup>USDA Forest Service- Helena- Lewis & Clark National Forest

In the Northern Region, hydrologists and fisheries biologists often consider management-induced changes in hydrographs (timing and volume) in response to forest canopy removal and presence of road networks. The working assumption is that such changes and conditions can impact streams indirectly through morphological shifts. However, this assumption has seen limited testing in the context of contemporary forest management and resource protection measures. As a cursory step, we compared channel morphology metrics (specifically bankfull width, bankfull width to depth ratio, and bank angle) in reference and managed streams across Western Montana and Northern Idaho using the PACFISH/INFISH Biological Opinion (PIBO) dataset. We used Linear Mixed Effects Regression Model (LMER) techniques and covariates to test for statistical differences between the reference and managed groups. The results indicate no statistically significant ( $\alpha = 0.05$ ) differences between the two groups. This analysis has some limitations but will aid in the development of guidance for National Environmental Policy Act (NEPA) and Endangered Species Act (ESA) analysis and compliance.

## **Reducing Toxics in the Upper Columbia River Basin of Montana through a new Pesticide Stewardship Partnership Program (PSPP)**

**Rachel L Malison**

Flathead Lake Biological Station, University of Montana

The Flathead Lake Biological Station/UM was recently awarded a 5-year grant from the EPA Columbia River Basin Restoration Funding Assistance Program to create a Pesticide Stewardship Partnership Program (PSPP)

for the Upper Columbia Basin portion of Montana (CRB-MT). PSPPs are voluntary programs that rely on local partnerships to monitor pesticide levels and enact solutions to protect water quality while still managing pests and maintaining crops. Despite the enactment of the Clean Water Act in 1972, the threat of pesticides to surface waters remains today and there is no pesticide monitoring program in place in Montana. Though pesticides target pests, weeds and fungal diseases, they are equally effective at killing non-target organisms. We do not have baseline data to determine what the risks from pesticides currently are in state surface waters, or to be able to determine if actions implemented in the future to reduce pesticides will make a difference. One of our first steps will be to engage partners to design and carry-out water monitoring for pesticides. We continue to look for more groups and volunteers to assist with collecting water quality samples. Our PSPP will build a network to develop and leverage partnerships that engage multiple government agencies, stakeholders, producers and the general public in the CRB-MT. The PSPP will meet priorities identified by the EPA, including 1) Agriculture best practices to reduce toxics, 2) green infrastructure to reduce stormwater and improve water quality, and 3) to improve community education and outreach to help the public take actions to reduce toxics in the basin. We are partnering with the MT-Depart. of Ag to analyze water samples, increase pesticide collections, install a permanent pesticide container recycling station, and develop education and outreach materials. We will also work with MSU-Extension to conduct field-based research to engage irrigators. We plan to partner with and award funding to Conservation Districts, Weed Districts and other groups to ensure the best development of trainings and tools. We will partner with the City of Missoula to build green infrastructure projects to treat stormwater runoff. The third priority, providing community education and outreach is critical, and planned actions tie together the greatest group of participants. This work will allow the public to take actions to reduce toxics in the basin. Work will also be done in partnership with the Kootenai Tribe of Idaho and Confederated Salish and Kootenai Tribes to sample food webs and fish tissues for pesticides. As the lead institution, UM and PI Malison will provide coordination, planning, and grant management to ensure that a collaborative and cohesive effort to reduce pesticides is undertaken throughout the Upper Columbia River Basin of Montana and the Kootenai Basin of Idaho. We hope that everyone interested in engaging in this important effort will reach out as the program launches. A website hosted by FLBS will provide program information. Please email Dr. Rachel Malison with questions: [rachel.malison@umontana.edu](mailto:rachel.malison@umontana.edu) or call 406 872-4518. Janelle Housman will join the program soon as the Research Coordinator and she can be reached at [janelle.housman@flbs.umt.edu](mailto:janelle.housman@flbs.umt.edu).

## **Landscape Influences on Microclimate and Forest Growth Cessation in a Semi-arid Montane Forest**

**Fin Malone, Zachary H Hoylman, Kelsey Jencso**

University of Montana, Montana Climate Office

As climate change impacts the severity and frequency of drought, knowledge of hillslope-to-watershed scale ecohydrology is becoming increasingly necessary to inform appropriate conservation, restoration, and management of forested ecosystems. In mountain environments, spatial patterns of water and energy organize

forest productivity at plot, hillslope, and watershed scales. These hydrometeorological patterns are impacted by gradients in elevation, aspect, and local topographic convergence and divergence. In water-limited systems, such patterns of moisture may be first-order drivers of intra-annual tree growth. However, there is limited field-based research characterizing how seasonal limitations of forest growth may vary across complex terrain. In 2016, continuous soil moisture, vapor pressure deficit, temperature, and radial growth were collected at 27 Douglas-fir (*Pseudotsuga menziesii*) sites within the Lubrecht Experimental Forest, MT. Using these data, we assessed the influences of topographic position, elevation, and aspect on local temperature and moisture microclimates. These landscape and microclimatic predictors were then compared to the observed timing of tree growth cessation. Trees located in low topographic positions, high elevations, and north-facing aspects were correlated with decreased temperature and greater moisture, which generally led to later growth cessation. However, we also observed a curvilinear phenomenon where saturated soil conditions also contributed to early cessation in convergent topographic positions. Overall, average microclimatic measures predicted the complex timing of growth cessation across the watershed better than static landscape proxies. These findings contribute to critical knowledge of landscape scale vegetation responses to changes in water availability, important for predicting the ramifications of climate change on forest growth.

### **Pathways of nitrate processing across agricultural riparian corridors characterized through geochemical analyses of water from shallow aquifers and streams**

**Caitlin M Mayernik<sup>1</sup>, Stephanie A Ewing<sup>1</sup>, Robert A Payn<sup>1</sup>, Michael D DeGrandpre<sup>2</sup>**

<sup>1</sup>Montana State University, Land Resources and Environmental Sciences, <sup>2</sup>Chemistry Department, University of Montana, Missoula, MT

Nitrate loading to terrestrial and aquatic systems in response to increasing demands on food production threatens human health and ecosystem integrity. Relative to land cover area, riparian ecosystems are disproportionately important to inorganic nitrogen export from watersheds, yet we have limited understanding of the fundamental processes influencing biogeochemical pathways in these systems. Our research investigates the hydrologic transport and biogeochemical transformation of nitrate in agricultural riparian ecosystems. For this study, we selected riparian corridors managed as pasture along small streams draining an extensively cultivated terrace landform in central Montana, USA. In this area of the Northern Great Plains, upland groundwater concentrations exceed 20 mg N L<sup>-1</sup>, twice the EPA public drinking water standard. These highly conductive upland aquifers are perched on impermeable shale and drain to fluvial riparian corridors and stream channels. We examine spatiotemporal patterns in two years of water chemistry data collected from stream channels and riparian groundwaters across three ~700-m stream reaches to infer the potential drivers of riparian corridor biogeochemical processes. Nitrate concentrations in riparian waters vary within and across stream reaches (0-13 mg N L<sup>-1</sup>) yet are consistently lower than those of terrace groundwater (20-30 mg N L<sup>-1</sup>) and adjacent stream waters (4-18 mg N L<sup>-1</sup>). Dissolved inorganic carbon concentrations are higher in riparian waters than terrace groundwater inflows and adjacent stream waters, and vary inversely with nitrate and dissolved oxygen concentrations, suggesting influence of heterotrophic nitrate reduction. Variations in nitrate and dissolved inorganic carbon concentrations within and across reaches indicate sites where heterotrophic reduction processes may be more limited and alternate pathways dominate. Additionally,

terrace and riparian soils derived from weathered shale supply sulfate to riparian corridor waters. Sulfate-chloride concentration ratios reflect weathering versus biogeochemical processes. Sulfate concentrations and sulfate-chloride ratios indicate sites of sulfate reduction where nitrate concentration is decreased, and others of sulfate production despite decreased nitrate concentration. Evidence of nitrate reduction co-occurring with sulfate production suggests processes such as autotrophic denitrification may exist. Sulfate reduction processes appear more prevalent at one reach relative to the other two reaches likely due to subsurface structure that facilitates transport of solutes to reaction sites and communication between these reaction sites and the stream channel. Riparian corridors vary in their extent of subsurface connection to terrace groundwater inflows and stream waters, the depth of riparian soils to riparian aquifer, and vegetation management. These characteristics influence biogeochemical processing and are evident in the spatial and temporal variation in solute concentrations observed within and across riparian corridors. We explore differences in solute concentrations as a function of variation in these character traits to infer the heterogeneous riparian processing pathways that mitigate consequences for downstream water quality.

### **Partner Engagement Across Eco-Hydrologic Projects in the American West: A Case Study in the Tongue River Basin of Montana and Wyoming**

**Megan Moore<sup>1</sup>, Theodore Barnhart<sup>1</sup>, Shanny Spang Gion<sup>2</sup>, Jason Whiteman<sup>3</sup>, Todd Blythe<sup>4</sup>, Nick Taylor<sup>1</sup>, Jay Alder<sup>5</sup>**

<sup>1</sup>USGS WY-MT Water Science Center, <sup>2</sup>University of Idaho, <sup>3</sup>Northern Cheyenne Nation, <sup>4</sup>Montana Department of Natural Resources and Conservation, <sup>5</sup>USGS Geology, Minerals, Energy, and Geophysics Science Center

Climate change affects natural resources across the American West. In particular, water resources have experienced changes because of multiple factors including shifting precipitation patterns, rising air and water temperatures, and drought. Natural resource managers require information and data to make decisions around water availability for public use and ecosystem functions. A mismatch often exists between the information available (data and models) and the information managers need to make timely and effective decisions. The Tongue River 2100 project is one of five eco-hydrologic projects spanning Montana, Wyoming, Washington, North and South Dakota, which emphasize connecting and supporting managers with water-related information and decision tools. Using the Tongue River 2100 project as an example, we highlight the partnerships developed to enable water-management planning and knowledge co-production between the primary partner, the Northern Cheyenne Tribe, and other partners such as the Tongue River Water Users Association, Montana Department of Natural Resources, and the Wyoming State Engineer's Office. Through these partnerships and collaboration, we aim to provide actionable science to managers, practitioners, and community members. Our work provides a framework for partner engagement through engagement plans, metrics, and evaluation to ensure products and deliverables are usable and useful for partners. We offer lessons learned and insight for others looking to work with partners in different water resource contexts.

## **Assessing Hydrological Connectivity of the Upper Teton Alluvial Aquifer, Choteau, MT**

**Evan Norman, Todd Blythe**

DNRC Water Sciences Bureau

The upper Teton River watershed (Teton County, Montana) is known for its flashy nature and transport of glacial deposits across perched floodplains that act as natural infiltration galleries. The hydrology and geology of the Teton have been studied in-depth over the past few decades; however, the flow regime of the Teton Watershed is significantly altered by agricultural irrigation and storage of water in off-channel reservoirs. In 2017, the Teton River Distribution Project was initiated to help deliver water to users in this hydrologically complex region. Over the last 5 years, the project has been successful in distributing surface water to users via the natural aquifer by establishing target flows at key locations and employing real-time stream gages. However, the distribution project has been lacking a complete understanding of the groundwater dynamics in the local aquifer. DNRC began the Teton Groundwater Investigation in 2020 to understand 1) groundwater and surface water connections of the alluvial aquifer 2) the source, volume, and timing of discharge to spring creeks and 3) estimates of increased recharge and shallow aquifer interactions of the Teton River. The aquifer is significantly recharged by the Teton River above and below the Springhill Reach, which is a segment of the river that flows over a localized thickening of the alluvial aquifer between Eureka Reservoir and the town of Choteau, MT. Other sources of recharge are irrigation return, precipitation, and bedrock inflows (Patton, 1991). The saturated alluvial aquifer thickness ranges from 10 to 40 feet with an estimated 50,000 acre-feet of groundwater storage. Water levels near Choteau can be within 2 feet of ground surface during runoff or when freezing conditions produce ice jams that induce groundwater recharge, however these water level increases quickly dissipate. Synoptic surface water surveys showed that the Teton River has gains and losses of up to 6 and 7 cfs per mile, respectively. Specific electrical conductivity and temperature were used to describe groundwater and surface water connections and contributions of annual runoff to the aquifer. DNRC currently operates 10 non-real-time and real-time stream gages and collects water levels from a network of 20 wells in the upper and lower Teton River watershed. This surface and groundwater data is accessible via the DNRC Stream And Gage Explorer (StAGE) and is used to manage inflow into the Springhill Reach to maintain water availability for more senior downstream water uses. The integration of real-time groundwater monitoring will proactively manage inflows and outflows from a natural storage reservoir and the overall water resources in the Teton Valley Aquifer.

## **Coupling Groundwater Simulations with Geodetic Forward Models to Parameterize the Bedrock in a Snow-dominated Mountain Watershed**

**Brett Oliver<sup>1</sup>, Payton W Gardner<sup>1</sup>, Hilary R Martens<sup>1</sup>, Zachary Hoylman<sup>2</sup>, Donald Argus<sup>3</sup>, Adrian Borsa<sup>4</sup>**

<sup>1</sup>University of Montana, <sup>2</sup>Montana Climate Office, <sup>3</sup>NASA Jet Propulsion Laboratory, <sup>4</sup>Scripps Institution of Oceanography

We propose a novel method to estimate the role of bedrock diffusivity in the terrestrial water budget of mountainous watersheds, an important but understudied freshwater reservoir in mountainous regions like Western Montana. Seasonal changes in terrestrial water storage cause deformation to the Earth's crust that is within the observational capacity of GNSS instruments. We couple finite difference groundwater simulations with geodetic forward models of crustal displacement to investigate the ability of geodetic deformation to

constrain subsurface hydrologic properties. We use MODFLOW-2005 to simulate groundwater storage and flow and LoadDef to forward model crustal displacement caused by the change in terrestrial water storage calculated by each groundwater simulation. We perform theoretical sensitivity analyses by simulating changes in deformation as a result of different subsurface properties for a single, synthetic seasonal recharge function. Initial results indicate that the timing and magnitude of vertical crustal displacement are affected by the bulk bedrock hydraulic diffusivity. Varying values of hydraulic conductivity and hydraulic storativity create unique signatures in crustal displacement. This method could improve the bulk parameterization of bedrock within mountainous regions with adequate GNSS network density. Our modeling framework offers a new tool to parameterize the subsurface at the watershed scale for numerical groundwater simulations using geodetic observations, which is challenging in mountainous watersheds where extremely limited groundwater data is available.

## **Conceptualizations of Ecological Drought in Montana and Implications for Management**

**Sale Rhodes<sup>1</sup>, Sarah P Church<sup>1</sup>, Jamie McEvoy<sup>1</sup>, Tonya Haigh<sup>2</sup>, Brennan Radulski<sup>1</sup>**

<sup>1</sup>Montana State University, <sup>2</sup>University of Nebraska-Lincoln

Increasing demand for water resources amidst decreasing water supply in the arid Mountain West has led to more frequent and more severe drought events. Changing climates, precipitation patterns, and temperature trends exacerbate this imbalance, leading to new drought concerns. Ecological drought is an emergency drought concern representing the impact that drought events have on ecosystem functions and services. The concept of ecological drought is holistic, demonstrating the interconnectedness between many ecosystem functions as well as their influence on humans; for example streamflow influences aquatic habitat, riparian vegetation, and water quality. However, little is known about how ecological drought is understood or managed in Montana. In this talk I will present the results from 26 semi-structured interviews we conducted with Montana scientists and managers to explore primary concerns, monitoring strategies, and response plans for ecological drought. Our results present how this drought typology is understood by ecosystem managers across local, state, and federal scales and offer insight about the indicators these scientists and managers use to address impacts of ecological drought. These results suggest that ecological drought impacts determine interviewees' understanding, monitoring, and planning or management (eg. stream gages are used to monitor surface water and forest health is used to monitor fire risk). This finding points to siloes in ecosystem management across Montana rather than holistic thinking about social-ecological systems that could help inform responses to the threat of ecological drought. These results present current conceptualizations of ecological drought in Montana and generate questions about how to address increasingly frequent and impactful ecological drought events. This talk will ask if there is an opportunity to coordinate management across ecosystem concerns and ecological services to better manage natural resources across Montana. Ecological drought represents a present and significant threat to natural resources and the communities reliant upon them and requires intentional and cross-cutting management. This talk will be relevant for anyone interested in drought management, adaptation, social-ecological systems, and ecological transformations.

## **Leveraging stable water isotopes and synthetic aperture radar to assess the complex hydrology of snow-fed agricultural lands in Southwestern Montana**

**Lila A Rickenbaugh<sup>1</sup>, Eric Gagliano<sup>2</sup>, Eric Sproles<sup>1</sup>, Timothy Covino<sup>1</sup>, Rosemary Carroll<sup>3</sup>, Cascade Tuholske<sup>1</sup>**

<sup>1</sup>Montana State University, <sup>2</sup>University of Washington, <sup>3</sup>Desert Research Institute

As many critical agricultural regions around the world rely on water stored in mountainous snowpack for irrigation, our current and future ability to grow food is threatened by more frequent, severe, and extended snow droughts. As such, water resource managers will need more efficient and accurate methods to characterize the snowmelt cycle and forecast water availability. Focusing on a montane catchment in Southwestern Montana, we integrate in-situ and remotely sensed data to assess the relative contributions of groundwater and current season's snowmelt to irrigation supply. Utilizing stable water isotope ratios (H2 and O18), we compare weekly samples of stream water at low elevation to monthly samples of snow and groundwater. Samples range in elevation from 1,475 m to 2,555 m. We find that diverted water is predominantly composed of groundwater at the outlet. To understand the timescale on which snow contributes to stream water we analyze backscatter data from Sentinel-1 Synthetic Aperture Radar (SAR). This provides approximate dates of snowpack warming, ripening, and importantly, runoff onset at discrete locations in the watershed. We find that the onset of snowmelt is occurring later in areas of the study catchment that are sparsely vegetated due to previous wildfire. Combined, these analyses provide estimates of where and when irrigation water originated for agricultural land in the Paradise Valley. While our work focuses on a local region in Montana, the efforts and approaches used are potentially applicable globally for agricultural regions that rely on snowmelt for irrigation.

## **Monitoring restored wetland water quality and quantity**

**Hannah Riedl, Steve Carpenedo**

Montana Department of Environmental Quality

Functional wetlands provide numerous ecosystem services, including water storage for increased late season flows, groundwater recharge, nutrient and sediment retention, erosion control, and critical habitat for most of Montana's plants and wildlife. Estimates of nutrient attenuation in wetlands vary widely but are reported to be as high as 80%. Approximately 1/3rd of Montana's original wetlands have been lost since the mid-1800s. Restoration and protection of wetlands is essential for remedying the nutrient and sediment pollution that impairs up to 40% of river miles assessed by the MT Department of Environmental Quality. Beginning in 2022, the Nonpoint Source and Wetlands program began monitoring five wetland restoration sites to determine their nutrient and sediment load reductions. This presentation will provide an overview of the study design, share preliminary results from one wetland, and provide an opportunity to identify potential partners. Demonstrated wetland restoration effectiveness is required for continued financial support for project implementation and to generate landowner participation. Lessons learned from this monitoring will inform better wetland restoration projects in the future and support integration of wetlands into issues like point source pollution treatment and hazard mitigation.

## **Climate Change Across Aquatic-Terrestrial Boundaries: How Changes in Air and Water Temperature Affect Giant Salmonfly Emergence**

**Alzada Roche<sup>1</sup>, Lindsey K Albertson<sup>2</sup>, Christine E Verhille<sup>2</sup>, Alisha Shah<sup>3</sup>**

<sup>1</sup>WGM Group, Montana State University, <sup>2</sup>Montana State University, <sup>3</sup>Michigan State University

Aquatic invertebrates experience variable temperature conditions throughout their life history, especially during the vulnerable life stage transition from aquatic to terrestrial habitats during emergence. Due to climate change, summer water and air temperatures have been rising, whereas spring water temperatures remain consistent from year-to-year due to the moderating influence of snow melt. Giant salmonflies (*Pteronarcys californica*) depend on spring water temperature cues to time their large, synchronous emergence in early summer, but it is unknown how variable temperatures after this springtime cue affect life-history traits. Using a laboratory experiment, we tested how changes in temperature in the weeks before and after emergence affect emergence timing, emergence success, and adult lifespans. We found that with each degree of warming during the weeks preceding emergence, the timing of emergence was 3.3 days earlier. However, emergence success was unaffected by higher water temperature within our test temperature range (13-23°C). On land, adult lifespans were shortened by increased air temperatures, especially when water temperatures during the juvenile stage had also been increased. The predicted lifespan was almost five times longer at the coldest air and water temperature combination than at the warmest (28 vs 6 days). However, even the shortest lifespan observed is not likely to prevent successful reproduction, since salmonflies can mate and oviposit within days of emergence. Our results indicate that although thermal changes in the weeks before and after emergence are not likely to limit salmonfly reproduction, shifting water and air temperatures could have consequences for riparian consumers by changing the timing and duration of the nutrients provided by these large-bodied aquatic insects.

## **Ecosystem Restoration of Elbow Coulee, design, construction and monitoring**

**Robert Sain, Jason Drake, Tanner Tompkins**

Kroenke Ranches

Previously presented Elbow Coulee phases 1 and 2 at the Montana AWRA; this presentation will sum up the Elbow C initiative with Elbow C. Phase 3 and discuss the entire eight miles of Elbow Coulee as an ecosystem restoration success with on-going monitoring via drone and trout, fish passage, PIT tracking.

## **Development of a Surface-Water Index of Permanence to assess surface-water availability for ecohydrological refugia in the upper Missouri River basin**

**Roy Sando<sup>1</sup>, Patrick Wurster<sup>1</sup>, Lindsey Thurman<sup>1</sup>, Alynn Martin<sup>2</sup>, Kyle McLean<sup>1</sup>, John W. Jones<sup>1</sup>, Anteneh Sarbanes<sup>1</sup>, Erin Poor<sup>1</sup>**

<sup>1</sup>US Geological Survey, <sup>2</sup>Texas A&M University

Surface-water availability has major implications for both the environment and society in the 21st century. With climate change, increased drought severity, and altered water and land use, it is predicted that future water availability will continue to decline in many areas, including much of the western U.S. An understanding of where and when water will be available at multiple spatial and temporal scales is crucial for the planning and management of wildlife health, recreation, and energy development. Currently, indices describing water presence and permanence exist for specific surface-water components (for example, streams and wetlands or waterbodies); however, a general surface-water permanence index that considers multiple major surface-water components is lacking. To address this gap, the USGS is working on combining remote-sensing products and modeled streamflow permanence outputs to develop an index designed to represent holistic surface-water conditions in the upper Missouri River basin from 1990-2022. This presentation will show preliminary results from this work and discuss general and specific spatial and temporal patterns in surface-water permanence in the study area. Topics covered will include regions of observed and estimated surface-water expansion and contraction, loss and gain of seasonal surface water, and Surface-Water Index of Permanence (SWIPE) results for basins of interest.

## **Collaborative Science Opportunities in the Mining-Affected Transboundary Kootenai River Watershed, United States and Canada**

**Melissa Schaar, Meryl Storb, Travis Schmidt, Ashley Bussell**

US Geological Survey, Wyoming-Montana Water Science Center

Mining-affected transboundary watersheds pose complex and often contentious challenges for researchers tasked with collecting data and/or providing scientific interpretations to inform policy and management decisions. How can scientific organizations overcome these challenges and collaborate to provide relevant and timely information for stakeholders? We will explore this question using a complex case example in the mining-affected transboundary Kootenai River Watershed. We will discuss strategies to overcome challenges and the potential opportunities for collaborative science. The transboundary Koocanusa Reservoir (also known as Lake Koocanusa) is within the international Kootenai (or “Kootenay” in Canada) drainage basin, is bisected by the border between the United States and Canada, and is impounded by Libby Dam upstream from Libby, Montana. Selenium concentrations have been measured by the USGS and others at concentrations above water-quality and aquatic-life standards in Koocanusa Reservoir. One source of selenium is waste rock and tailings storage from mining for metallurgical coal in the Elk River Valley, BC, Canada. In the absence of a central coordinating body, collaboration among international, Federal, State, local, and Indigenous governments has been complicated. Additionally, issues of data transparency and the lack of standardized data collection methodologies create inefficiencies for contributing agencies. Outspoken stakeholders, public opinion, and funding constraints often divert the central scientific endeavors and divide researchers in their

efforts. These barriers can be overcome by a bilateral coordinating body chartered by the International Joint Commission or jointly by the US and Canadian Federal governments. Strategies for scientific collaboration that facilitate focused scientific efforts to answer the most relevant scientific questions in the absence of a unifying coordination body are discussed. Examples of proposed and successfully implemented partnerships with lessons learned are presented.

## **USGS Water Temperature Data in Montana – Collection, Access, and Application**

**Seth Siefken**

US Geological Survey

The U.S. Geological Survey (USGS) collects real-time water temperature data at more than 2,000 locations across the United States, including 65 locations in Montana. These monitoring stations provide high-quality water temperature data that are utilized by USGS projects, partner agencies, independent researchers, and the general public. The presentation will provide an overview of (1) data collection methods and quality control, (2) methods of accessing the data through the web browser and the USGS dataRetrieval R package, and (3) example applications of water temperature data in Montana. Example applications of water temperature data will include an overview of an ongoing water quality modeling project on Lake Koocanusa and the Kootenai River where USGS water temperature data are being used for model calibration.

## **Vermilion River Restoration Effectiveness Monitoring: Year One and More to Come**

**Nicole Stine, Rod Caldwell, Melissa Schaar**

U.S. Geological Survey

The Vermilion River is a major perennial, fourth order tributary to the lower Clark Fork of northwestern Montana. This river is critical spawning and rearing habitat for migratory Bull Trout (an Endangered Species Act-listed species) and is known to support resident Bull Trout. Historic placer, dredge mining and clearcutting in the upper portion of the Vermilion River drainage have degraded the riverine habitat. Hydraulic degradation has increased the magnitude of flooding in the lower drainage, which, has caused high sediment loads, decreased channel complexity, and limited floodplain access. Excess sediment, channel instability, and the dominance of immature riparian vegetation in the lower 12 miles of the river are of particular concern due to the river's designation as critical Bull Trout habitat. Vermilion River stream and floodplain restoration has been managed by the U.S. Forest Service since 2012. It is anticipated that restoration will continue with more phases planned for completion over the next 10 years. The US Geological Survey, in collaboration with the US Forest Service, Sanders County, Avista Corp., and other partners, is investigating the effectiveness of U.S. Forest Service restoration techniques. The Vermilion River Restoration Effectiveness Monitoring Project, which includes multiple phases will span approximately 5 years providing a unique opportunity to monitor and potentially determine the effectiveness of stream and watershed restoration with goals to improve and sustain aquatic habitat for Bull Trout and other aquatic species. Overall, the results of this project will inform adaptive management of restoration activities throughout the lower Clark Fork Watershed and across the state of Montana. Phase 1 of this project began July 2023, and includes the monitoring network design, an uncrewed

LiDAR and thermal imagery survey, and establishment of the monitoring network. Temporal monitoring of the interaction of groundwater and surface water in the near-stream environment will be conducted in later phases. Future phases of this project will include evaluating water quality and biological monitoring with data collection efforts to include nearby reference streams, and pre-restored reaches of the Vermilion River. The preliminary results of Phase 1 and discussion of future work phases will be discussed.

### **Groundwater quality on the Fort Peck Reservation:**

**Meryl B Storb<sup>1</sup>, Martina Wilson<sup>2</sup>, Sheree J Watson<sup>1</sup>**

<sup>1</sup>US Geological Survey WY-MT Water Science Center, <sup>2</sup>Fort Peck Tribes

A three-decade evaluation of nitrogen extent, magnitude and sources related to land use Cooperative studies between the U.S. Geological Survey and the Fort Peck Tribes (Assiniboine, Sioux) began in 1979 to evaluate the extent, magnitude, and source of nitrate (NO<sub>3</sub>) in shallow groundwater aquifers that were commonly used as domestic and stock water sources. Initial studies revealed most sampled drinking water wells (84%) in the Flaxville aquifer had concentrations exceeding the Environmental Protection Agency (EPA) drinking water standards (10 mg L<sup>-1</sup>). Isotopic analysis revealed most NO<sub>3</sub> sourced from soil organic nitrogen (N), linking nitrate in groundwater to non-point source agricultural practices of crop-fallow dryland farming, with a smaller source related to animal wastes from poorly sealed stock wells. Dryland farming practices of crop-fallow rotation leaves part of the farmland uncultivated, and weeds are chemically suppressed. Fallow was practiced to conserve soil moisture and was the dominant practice from 1960 through the 1990's. Following these initial studies in the 2000's, recommendations were made to farmers to shift from fallow to continuous cropping, perennial, and pulse crops to try to decrease N sourced into soil and groundwater. Hypotheses based on age of the groundwater aquifers (6-30 years) and changes in agricultural practices to continuous cropping in the 2000's predicted a decrease in groundwater NO<sub>3</sub> concentrations around 2020. A recent re-evaluation performed between 2019-2021 generally revealed not much has changed regarding NO<sub>3</sub> contamination in the Flaxville and underlying shallow aquifers as most of the wells re-sampled still exceed EPA drinking water standards. However, there are nuances related to location differences in specific regions of the aquifer, as some localized areas have shown decreased concentrations while others have increased. Current isotopic analysis reveals NO<sub>3</sub> from non-point source soil organic N continues to be the primary source, with small local contributions from animal wastes.

### **Membrane Technology as a Promising Solution for Water Security and Challenges**

**Amos Taiswa**

Montana Tech

Membrane technology continues to be a critical area of research that enables access to safe drinking water around the world. Membrane filtration reportedly contributes >50 % of the total world water treatment volume. Despite its advancement, there are emerging challenges over time. Here, we focus on exploring existing

advancements and technologies where membrane technology has played pivotal roles not limited to wastewater treatment. Finally, a short survey on persistent fouling problems will be explored as well as solutions studied in our previous work and other researchers.

## POSTER PRESENTATION ABSTRACTS

### **Simulating the influence of climate change on patterns in recharge of mountain aquifers in snow-dominated headwaters**

**Abaye G. Abebe<sup>1</sup>, Robert A. Payn<sup>1</sup>, Stephanie A. Ewing<sup>1</sup>, Eric A. Sproles<sup>1</sup>, Payton W. Gardner<sup>2</sup>**

<sup>1</sup>Montana State University, <sup>2</sup>University of Montana

Climate change in semi-arid mountainous regions has potential to influence groundwater resources by altering the patterns in recharge of mountain aquifers that ultimately provide critical water resources in the form of dry season stream flow. Conventional distributed watershed models have historically prioritized on accurate prediction of flood risk over base flows. Therefore, only recent advances in coupling surface and groundwater models (e.g., SWAT-MODFLOW) are likely to provide the perspective on subsurface processes necessary to understand the influence of climate change on the lower summer flows driven by mountain groundwater storage. A critical first step to predicting the potential response of aquifer behavior to climate change is to understand the potential changes in the timing, location, and volume of aquifer recharge induced by: (1) changes in snowmelt patterns, (2) shifts in precipitation from snow to rain, and (3) shifts in partitioning from deep percolation to evapotranspiration with warming temperatures. We present a series of sensitivity analyses with the distributed watershed model SWAT designed to explore how these potential consequences of climate change may influence the spatial and temporal distribution of mountain aquifer recharge, with later goals of coupling these near-surface process models with the groundwater model MODFLOW to understand the propagation of changes in recharge to dry season stream flow. We particularly focus on the potential for these hypothesized changes in recharge to differ with elevation and landscape position. The driving data and extent of numerical experiments are based on the Hyalite Creek catchment near Bozeman, Montana, a typical snow-dominated semi-arid mountainous headwater in the western intermountain US. Our numerical experiments are first designed to assess whether shifting of the snow line or more general change in snowmelt dynamics is a stronger controls on the timing and location of recharge. We also report on numerical experiments designed to parse whether the shift in precipitation from snow to rain will have a stronger effect on recharge at lower or higher elevations, as well as the relative importance of changing snowmelt patterns and changes in form of precipitation. Finally, we conduct numerical experiments to assess the potential for the changes in evapotranspiration with temperature to have stronger influence on recharge in wetter or drier areas of the catchment. This work contributes a theoretical perspective on the specific mechanisms by which climate change is most likely to influence the capacity of headwater catchments to store critical dry-season water resources in mountain landscapes.

## **A Hydrologic and Nutrient Mass Balance on Ben Hart Creek, Montana**

**Nick Banish, Drew Shafer**

Gallatin Local Water Quality District

Nutrient enrichment caused by human activity is a major threat to waterways within the Gallatin Valley. This study aims to improve the understanding of mass loadings of nitrate-nitrogen (N), soluble reactive phosphorus (SRP), and Chloride (Cl), a wastewater tracer, from one spring creek into the E. Gallatin River.

The study site is a 6.3 km reach of a groundwater-fed spring creek in the Gallatin Valley, Montana. Ben Hart Creek (BHC) is underlain by Quaternary-age braid plain alluvium (Qabo) and receives most of its baseflow from groundwater, however, two major irrigation ditches flow into the stream along the study reach. Using discharge estimates and samples of stream water chemistry, a hydrologic and dissolved constituent mass-balance was conducted during three separate sampling events (March 2022, July 2022, January 2023) to quantify the principal inputs and export of water and dissolved materials. Estimated dissolved material loads from BHC into the E. Gallatin ranged from 78.4 kg/d to 98.2 kg/d for N and were highest during the March 2022 sampling, while the lowest N loads were observed during the June 2022 sampling, concurrent with the summertime growing season. SRP loads ranged from 0.49 kg/D to 1.39 kg/D and were ~ 3-fold higher in winter than summer. Cl loads varied from 568.3 kg/D to 732.2 kg/D. Irrigation ditches were a major component of surface water and nutrient inputs into BHC. Shallow groundwater in the study area was characterized using riparian wells (n = 10), instream piezometers (n = 5) and upland wells (n = 6). Groundwater N (mean = 0.56 mg/L) was low compared to the stream ecosystem (mean = 1.61 mg/L) and the difference was statistically significant (t-test,  $P < 0.001$ ). Similarly, some physicochemical conditions were also different between these two compartments; groundwater was typically low in dissolved oxygen (mean = 4.97 mg/L), compared to stream concentrations (mean = 10.01 mg/L), and the difference was statistically significant (t-test,  $P < 0.001$ ), partially supporting the notion of redox-gradient controlled N speciation at the groundwater/surface water interface. This study underscores the importance of BHC as a source of dissolved material loads to the E. Gallatin River. Identifying and quantifying the principal inputs of dissolved materials and wastewater tracers to this spring creek ecosystem is beneficial to the development of pollution mitigation and implementing management practices that aim to reduce nutrient loads to the E. Gallatin. The Gallatin LWQD aims to work with the MDEQ to have BHC listed on the 303(d) list of State Impaired Waters.

## **Towards Understanding in the Upper Clark Fork River: Assessing Spatial and Temporal Changes in Macroinvertebrate Diets and Role in Energy Flow Food Webs**

**Jadyn M Bellander, Jose A Sanchez, Wyatt F Cross**

Montana State University

Large-scale mining of heavy metals remains a pervasive disturbance in the western US and represents the primary source of metal pollution in freshwater ecosystems globally. The Upper Clark Fork River (UCFR) in Montana was subjected to nearly 100 years of heavy-metal mining and was polluted with an estimated 14.5 million m<sup>3</sup> of tailings and heavy metal sludge. In 1982 mining practices were discontinued, and the Clark Fork River was declared part of the nation's largest EPA superfund site. Efforts to understand the impacts

of legacy mining and rehabilitation of the system have led to a focus on assessing recovery of ecological communities. However, less attention has been focused on understanding of how these heavy metals flow through the food web via diet and assimilation and the repercussions for higher trophic levels (e.g., fish). The diets of macroinvertebrates can provide insights into how resources and metals move up a food web. Linking the diets by classifying different macroinvertebrates by their functional feeding group (FFG) and performing the corresponding gut content analysis can reveal the major sources and proportion of the different metals that move through the food web. We quantified the dietary composition of *Hydropsyche* spp. (Order Trichoptera) and Chironomidae (Order: Diptera), two of the most abundant macroinvertebrates of the UFCR with different feeding behaviors. Our preliminary analysis demonstrates how the relative proportion of dietary components change over a spatial and temporal gradient, and how these categories may influence the movement of metals through the food web. This information, in combination with metal concentrations of dominant resources, will be critical for estimating the annual flux of metals through invertebrates to fish.

### **MCO Climate Extension: Tribal Engagement**

**Kyle Bocinsky<sup>1</sup>, Maureen McCarthy<sup>2</sup>, Paige Johnson<sup>1</sup>**

<sup>1</sup>Montana Climate Office, <sup>2</sup>Desert Research Institute and Montana Climate Office

Since 2018, the Montana Climate Office has developed a suite of activities focused on enhancing the usability of MCO and Montana Mesonet climate data and services. Broadly termed “Climate Extension,” we have built relationships with users of climate data and information in Montana, including outreach supporting agriculture, forestry, recreation, urban and rural climate resilience planning, and other climate-sensitive issues. A particular focus of MCO Climate Extension has been to partner with Native nations in Montana in support of their needs as related to climate and drought monitoring and education. One key component of this work is our ongoing partnerships with Tribal nations in hosting Montana Mesonet weather, soil moisture, and snowpack monitoring stations. In this poster, we highlight three other recent examples of MCO Tribal engagement. In the Native Drought Resilience project, the MCO is partnering with the Confederated Salish and Kootenai tribes of the Flathead Reservation to implement several components of their recently updated Climate Change Strategic Plan, including enhancing weather and air quality monitoring on the Reservation. Meanwhile, the MCO supported the Fort Peck Assiniboine and Sioux tribes in revising their Tribal Hazard Mitigation Plan, which for the first time included projections of future hazards related to climate change, including drought, flooding, and wildfire risk assessments. Finally, the Native Climate project is an initiative to better serve Tribal agricultural producers across the western US. The MCO hosts the Native Climate Data Fellow who is developing a climate data resource guide for Tribal agriculture extension agents.

## **The Aquifers of the Lower Clark Fork: Lincoln and Sanders Counties Aquifer Characterization, Northwest Montana**

**Camela Carstarphen, Sara C Edinberg**

Montana Bureau of Mines and Geology

The hydrogeologic framework of aquifers in Lincoln and Sanders counties was characterized as part of the Montana Bureau of Mines and Geology's Ground Water Assessment Program. Data from geologic maps, water-well logs, and field measurements/observations were used to map the aquifers and compile hydrogeologic cross-sections. This is part of a broader effort that will also describe the groundwater-flow systems and groundwater quality. The area is characterized by a series of intermontane valleys framed by Precambrian Belt Supergroup bedrock. The valleys are filled with unconsolidated to semi-consolidated alluvial and glacio-fluvial deposits. The alluvial deposits are present along the modern (Holocene) and late-Pleistocene flood plains of the Clark Fork River and its tributaries. This alluvium is underlain by thick, and in some places very well-sorted, Glacial Lake Missoula flood deposits. A deep sand and gravel that may pre-date Glacial Lake Missoula underlies the glacial deposits in places. Shallow unconfined aquifers occur in Holocene alluvial deposits associated with modern rivers and tributaries; these aquifers are up to 30 feet thick. In the lower Clark Fork, a series of reservoirs have submerged the modern alluvial deposits. Late-Pleistocene alluvium forms a prominent aquifer along the Cabinet Gorge Reservoir at Heron; this aquifer is at least 120 feet thick, unconfined, and water-level and isotope data suggest it is hydraulically connected to the reservoir. In the Plains area, the surficial aquifer is composed of Holocene and late-Pleistocene alluvium. Productive sand and gravel sets occur between 15 and 35 feet below ground surface. Below the alluvial aquifer, the glacial deposits – consisting of permeable sand and gravel layers interfingered with less permeable silt and clay – form a sequence of confined to semi-confined 'intermediate' aquifers that range in thickness from 200 to 500 feet. In the Heron area, thick clay-rich lake deposits separate the glacial flood gravels from the late-Pleistocene alluvial aquifer; the clay deposits are as much as 150 feet thick in some areas. The older (pre-glacial) sand and gravels form a deep alluvial aquifer of unknown thickness. This aquifer is present in the Plains area and has a different water-quality and isotope signature than the overlying intermediate and shallow aquifers. The Belt Supergroup forms a fractured-rock aquifer around the valley margins that exhibits variable well yields and water quality. The mountainous, higher elevation, fractured-bedrock is a source of groundwater recharge to the basin-fill aquifers, moving mountain snowmelt to lower elevations, however low yields limit its potential as an aquifer in some areas.

## **Lodge Pole Groundwater Quality Assessment Fort Belknap Reservation**

**Caitlyn Cliff, James Swierc**

Aaniiih Nakoda College

The community of Lodge Pole is located on the southern part of the Fort Belknap Reservation, on the northern edge of the Little Rocky Mountains. Lodge Pole Creek flows north with headwaters near the Zortman mine along the drainage divide in the mountains. Mining activities have resulted in significant impacts to surface and groundwater quality near the mines. Potable water in Lodge Pole is obtained from wells. Some wells are shared between residents; their houses are connected to one well. Wells are generally installed into the alluvium

within the Lodge Pole Creek valley. Some residents are located away from local wells and have cisterns for water connections to their housing. Those residents rely on hauling water to fill their cistern(s). Although well water is available to some houses, numerous residents rely on purified water for consumption (drinking and cooking), leaving residents with no other option but to purchase their purified water. This project was developed to obtain data on surface and groundwater resources, and to see if the water quality results meet drinking water standards. The data will support future development of the resource and determine the suitability of the water as a long-term drinking water source. Water quality sampling was conducted from accessible wells in the preferred area, and from local streams. The well system includes several monitoring wells installed by the USGS for studies in 1987 and 1988. Water quality samples were analyzed at Energy Laboratories in Helena, Montana using standard methods. Samples were analyzed for major ions, nutrients, and trace elements. Water levels were collected in monitoring wells, with datalogging transducers used for long-term data. The water levels in house wells were collected using water level meters. The water levels were used to prepare a groundwater surface map for the alluvial aquifer in the area. The water levels show that the aquifer receives recharge from the streams during spring runoff. Water quality data shows that the stream is not connected to the local groundwater system downstream from Lodge Pole. This is attributed to the presence of glacial deposits covering the area. This is an ongoing research project, and additional data will be included later. The water quality data results show that the secondary drinking water standards have been exceeded for Total Dissolved Solids (TDS) and Sulfate. One conclusion is to recommend water treatment to reduce the TDS and Sulfate in private water systems.

### **Dimensionless impulse framework for investigating hydrogeomorphic response to flooding in northern Yellowstone National Park**

**Zack P DeLuca<sup>1</sup>, Andrew C Wilcox<sup>1</sup>, Lyman Persico<sup>2</sup>**

<sup>1</sup>University of Montana Geoscience, <sup>2</sup>Whitman College

Flood-induced geomorphic change has been linked with metrics representing fluvial forces or energy, such as stream power (the product of the specific weight of water, slope, and discharge,  $\Omega$ ) gradients and unit stream power ( $\Omega$ /channel width) magnitude. Ideally metrics used to explain geomorphic change would account for not only peak-flow magnitude, but also flood duration and channel bed-material caliber. To evaluate the effects of the June 2022 flooding in northern Yellowstone National Park (YNP), we calculated cumulative flood impulse, a metric that incorporates flow duration exceeding the channel bed-surface incipient-motion threshold, based on critical Shields stress, grain size, slope, and hydraulic radius. The June 2022 flood, which had an annual exceedance probability on the order of 0.002, was driven by an atmospheric river, rain-on-snow event that resulted in extensive valley-bottom geomorphic change and damage to roads that connect northern YNP to nearby population centers. We evaluate the hydrogeomorphic response of the Gardner River and assess whether cumulative flood impulse predicts geomorphic change of a riverscape subjected to an historic flood. We quantify

topographic change using digital elevation models of difference (DoDs) created from pre-flood (fall 2020) and post-flood (fall 2022) lidar. Further, we calculate flood impulse using HEC-RAS modeling, supported by post-flood channel surveys to measure bathymetry, grain size, and high-water surface elevations. Hydraulic modeling shows that the threshold of bed mobility was exceeded for 23 days during the June 2022 flood, with variability between confined and unconfined reaches. Impulse was highest in straight, confined reaches between bends upstream of areas with significant geomorphic change. DoDs show that in confined bends up to 8 m of lateral erosion in banks with more than 10 m of total relief occurred; in unconfined valley reaches, more than 1 m of vertical aggradation occurred in avulsed, single-thread channels; and some reaches experienced little net change. Results indicate that the cumulative impulse framework may be a useful tool for investigations of geomorphic change resulting from floods. Our work applies impulse to large-scale geomorphic change and informs understanding of riverscape response to floods.

## **Water Quality in Unionville, MT**

**Angelique Frier, Madeline McKeefry, Jennifer McBroom**

Lewis and Clark Water Quality Protection District

In the spring of 2019, ten private potable wells were sampled in the area of Unionville, MT which is located in the mountainous area south of Helena. This 2019 study was conducted as a class project from Carroll College with oversight from the Lewis and Clark County Water Quality Protection District (WQPD). The purpose of the current study is to provide additional data on groundwater quality and build upon the previous sampling project completed in 2019 in Unionville. In addition, residents will be provided with more information about potential contaminants. Specifically, WQPD wanted to consider bedrock type and focus on granite bedrock while considering contaminants such as nitrates, arsenic, uranium, and radionuclides. Five of the original ten wells from 2019 were resampled, and five new wells were sampled in the area. The project was divided into two sampling periods to see if variation occurs seasonally. With the first sampling period being at the end of April 2023 and the second at the beginning of September 2023. The project is set to be completed by the end of September 2023.

## **Progress Toward a Low-Cost Multispectral Imager for River Algae Monitoring**

**Shannon M Hamp, Charlie D Nicholson, Riley D Logan, Joseph A Shaw**

Montana State University

Filamentous algal blooms add to the accumulation of benthic organic matter and ultimately contribute to the depletion of dissolved oxygen in riverine ecosystems. While filamentous algal blooms disrupt benthic conditions and deplete dissolved oxygen, they also indicate damaging nutrient enrichment and can be related to water quality through metrics such as chlorophyll a (chl a) abundance. The second prototype of a low-

cost multispectral imager is presented for routine remote sensing of Cladophora nuisance algae in narrow rivers that are not spatially resolved by satellites. The goal is to identify algal blooms and estimate the chl a and phycocyanin content from a network of low-cost imagers that can be mounted on trees, posts, or other convenient objects at key river locations. The imager uses four Arducam monochrome cameras and a Raspberry Pi embedded computer. The multispectral channels are implemented with four, separate bandpass filters centered at 560, 670, 680, and 850 nm, based on data gathered with an airborne hyperspectral imager on the Upper Clark Fork River in southwestern Montana USA. This presentation summarizes the design and calibration of the multispectral imager as well as the field measurement methods and corresponding results from data collection on the Gallatin River in southwestern Montana.

## **Data Map for Wells and Springs Visited during the Park-Sweet Grass Characterization Study, Ground Water Characterization Program: Montana Bureau of Mines and Geology**

**Megan N Heath**

Montana Bureau of Mines and Geology

The Montana Bureau of Mines and Geology (MBMG) Ground Water Characterization program staff visited 516 groundwater sites, including 469 water wells and 47 springs, between 2012 and 2018 as part of the Park-Sweet Grass Groundwater Characterization study. This area encompasses all of Park and Sweet Grass Counties, excluding Yellowstone National Park. There are about 8,500 recorded wells in the area; visited sites were selected to obtain representative data from all aquifers. These data will be used to create maps and reports describing the hydrogeologic framework, groundwater flow system, and groundwater quality of the area. The data map shows the distribution of wells and springs visited and sampled, and will include a link to download all the basic data for this study area. Measured field data typically include a static-water level, temperature, pH, dissolved oxygen, redox, and the specific conductance; wells with limited access may not include the full suite of field parameters. Where possible, wells were pumped until the parameters reached stabilization (typically 30 minutes or three well volumes) to ensure measurements were representative of aquifer conditions. Samples for laboratory analysis were collected from 140 wells and springs and analyzed at MBMG's analytical lab. The analysis included major ions, trace metals and stable water isotopes. Monthly groundwater levels were measured from a subset of 73 wells between 2012 and 2018; 25 of those are part of the statewide monitoring network (GWAAMON). Locations for most sites were determined using handheld GPS; sites in the Paradise Valley that were measured monthly have improved location and elevation data from lidar (<https://montana.maps.arcgis.com/apps/MapSeries/index.html?appid=55cc886ec7d2416d85beca68d05686f4>) and the GWAMMON sites have survey grade GPS latitude, longitude, and elevations. Data from each visited site can be accessed via the Ground Water Information Center database (<http://mbmaggwic.mtech.edu>) or the appendix of this map.

## **Using machine learning to uncover spatial patterns of streamflow drought mechanisms in the Contiguous U.S.**

**Aaron Heldmyer, Roy Sando**

US Geological Survey

Hydrologic drought presents a complex, multi-dimensional challenge for the stewardship of water resources across the continental United States (CONUS). While advancements in remote (from aircraft or satellite) and at-site monitoring of water resources continue to emerge, many basins within CONUS still lack adequate water resources data for characterizing and predicting the spatio-temporal extent, persistence, and severity of hydrologic drought. To address this need, the U.S. Geological Survey (USGS) has launched an effort aimed at characterizing and predicting hydrologic drought at national and regional scales. As part of this effort, the USGS has developed random forest classification models to predict hydrologic drought for 2,647 basins across CONUS monitored by USGS stream gages with at least 40 years (1980-2020) of daily streamflow record. The models are driven by gridded daily meteorologic and hydroclimatic data and developed using both fixed and variable (moving 30-day window) drought thresholds. In this study, we apply a donor-based transfer method for these random forest models to pseudo-ungaged locations for the purpose of understanding regional variations in the mechanisms of hydrologic drought. In the donor-based method, the models are first clustered using variable importance values to classify them into distinct hydrologic drought regime categories. These clusters are then characterized using static basin characteristics (e.g., elevation, drainage area) to assign pseudo-ungaged locations to a cluster on the basis of basin similarity, thereby establishing a pool of “donors” within the cluster. Finally, a prediction is made by running the random forest model input data for the pseudo-ungaged location through the donor models and combining the weighted outputs. The strengths and limitations of this method are presented along with regional patterns in dominant mechanisms of hydrologic drought throughout the CONUS.

### **Drought Monitoring in Montana: Science, Application and Partnerships**

**Zachary Hoylman<sup>1</sup>, Kyle Bocinsky<sup>1</sup>, Michael Downey<sup>2</sup>, Troy Blanford<sup>3</sup>, Arin Peters<sup>4</sup>, Colin Brust<sup>1</sup>, Kevin Hyde<sup>1</sup>, Kelsey Jencso<sup>1</sup>**

<sup>1</sup>Montana Climate Office, <sup>2</sup>Montana Department of Natural Resources and Conservation, <sup>3</sup>Montana State Library, <sup>4</sup>National Weather Service

Water scarcity and its adverse impacts on communities worldwide underscore the urgency of accurate drought assessments. This is especially true in Montana, where strong seasonality of moisture availability, changes to climate and increasing demand for water all contribute to considerable drought impacts. The Montana Climate Office (MCO) is committed to addressing these issues through a science-application-partnership nexus,

designed to meet the diverse needs of Montanans. In this presentation we describe recent peer-reviewed science that directly informs drought monitoring applications (developed by the MCO) used across the state. More specifically, these scientific analyses confront complexities that arise due to climate change and address the need for enhanced soil moisture drought identification in Montana. To do so, we leverage critical information collected by the Montana Mesonet, a growing, collaborative, state-of-the-art monitoring network, as well as state (DNRC, State Library, etc) and federal (NWS, NOAA, etc) partnerships necessary for functional monitoring programs. In summary, these efforts represent the MCO's dedication to scientific objectivity, practical implementation, and collaborative engagement that is required to meet Montana's drought monitoring needs.

## **The Montana Mesonet: Status and Development**

### **Kevin Hyde**

Montana Climate Office

Near real-time climate monitoring supports many critical needs: water resource management, drought assessment, emergency warning and management, and agricultural production, among others. Initiated by the Montana Climate Office of the University of Montana in 2016, over 145 climate monitoring stations now populate the Montana Mesonet. The MT Mesonet, a network of closely spaced climate monitoring stations, is composed of two sub-networks, the Agrimet and the Hydromet. Agrimet stations meet the guidelines of the American Society of Agricultural and Biological Engineers and produce data sufficient to support agricultural production decisions. Hydromet stations closely adhere to the guidelines of the World Meteorological Organization and produce data required for more technically demanding applications and for long-term assessment of climate trends. Both station types produce common atmospheric measurements – temperature, relative humidity, insolation, wind speed and direction, and barometric pressure – with comparable accuracy, with the exception of precipitation. Hydromet stations produce metrics with higher precision and reliably capture high precision precipitation data year-round. Other differences include recording and reporting frequency, wind measurement height, and the inclusion of cameras at Hydromet sites. Both sub-networks utilize soil sensors of comparable accuracy and precision in soil monitoring arrays extending 91-100cm into the soil profile. The soil sensors measure volumetric water content, temperature, and electrical conductivity. This poster presents maps of the distribution of MT Mesonet stations across the state and the on-going development of the Hydromet sub-network under the Congressionally funded Upper Missouri River Basin Project administered through the US Army Corps of Engineers. Additionally, this poster presents illustrations of the similarities and differences between the Agrimet and Hydromet sub-networks.

## **Low Level Pesticide Attenuation in Agricultural Riparian Reaches of the Judith River Watershed**

**Carl A Krause<sup>1</sup>, Stephanie A Ewing<sup>1</sup>, Caitlin M Mayernik<sup>1</sup>, Brett Heitshusen<sup>2</sup>, Jona Verreth<sup>3</sup>, Kelsey<sup>3</sup>Powers, Robert A Payn<sup>1</sup>**

<sup>1</sup>Department of Land Resources and Environmental Sciences, Montana State University, <sup>2</sup>Groundwater Protection Program, Montana Department of Agriculture, <sup>3</sup>Analytical Laboratory, Montana Department of Agriculture

Montana's groundwater protection program at the Montana Department of Agriculture (MDA) has documented low levels of a suite of pesticides (including herbicides, fungicides, and insecticides) in agricultural areas across the state. In the Judith River Watershed (JRW), a variety of pesticides has been applied over time to non-irrigated spring and winter wheat production systems on terrace landforms, and herbicides are used to manage summer fallow periods. In this work, we evaluate pesticide fate and transport in the JRW. To test where transport, sorption and degradation of these compounds may occur, we examine pesticide concentrations along flow paths from terrace groundwater through two riparian reaches (A and B) where distinct hydrologic connection and nitrate attenuation have been observed. We compare concentrations of pesticides detected in these two riparian reaches with data from an adjacent permanent monitoring well (M1) sampled since 2000 by the MDA, and use laboratory column experiments to study sorption processes that may slow transport or facilitate degradation. In 2023, samples collected from the M1 well, riparian spring lines, riparian wells, and stream channels were analyzed by the MDA Analytical Laboratory. Across all sites, 32 compounds were detected at levels of 0.0010 to 1.3 ppb, ~100 to 1,000,000 fold lower than regulatory limits. Samples collected at sites within and across reaches vary in terms of both concentration and composition of pesticides detected, yet the observation of shared pesticide detections between reaches is consistent with pesticides used in wheat production. Pesticide compounds observed in M1 were not identical to those observed in the riparian spring lines, suggesting more variation of pesticide compounds within terrace groundwater than has been observed for nitrate. This may result from both spatially variable application patterns and sorption or degradation processes with pesticide transport in the terrace aquifer. At the same time, terrace groundwater (both M1 and spring lines) had higher concentrations of several pesticide compounds relative to riparian groundwater and stream water, suggesting attenuation in riparian zones. At Site A, pesticides detected in both the riparian groundwater and stream water mostly had concentrations below quantification limits, whereas at site B, pesticide concentrations were often higher and more variable. This is consistent with greater attenuation of nitrate at site A and suggests that contact with riparian substrate results in lower dissolved pesticide concentrations in riparian groundwater and stream water. While ecological and human health effects of low-level pesticide transport and persistence are not well documented, this work shows that beneficial effects of riparian zones likely extend beyond nutrient attenuation.

## **Effects of residue management on snow retention and subsequent belowground water storage in a small plot study near Bozeman, MT**

**Wyatt Kray, Stephanie A Ewing, Jack W Poole, Ryan Barnes, Perry R Miller, Robert A Payn, Eric A Sproles, Niko Hinz**

Land Resources and Environmental Science, Montana State University, Earth Sciences, Montana State University

As climate in the Western US shifts towards warmer winters, wetter springs, and hotter summers, determining the effects of shifting patterns of water delivery from rain and snow is increasingly important. In Montana, rangelands and agriculture have a key role to play as mediators of water storage from both snow and rain that in turn supports both plant productivity and aquifer supply and turnover. By investigating how the interaction of climate and land management influences soil water, we can inform decisions about the sustainability of land management practices. In this work, we use UAV-based LiDAR, along with point observations of snow, to understand how differing stubble practices affect snow capture and resulting soil water storage. To begin exploring stubble height effects during spring 2023, we characterize snowpack over time in replicated small plots split for short (15 cm) and tall (45 cm) stubble heights as part of an ongoing cropping systems study at the Post Experimental Farm, near Bozeman MT. We collected LiDAR data sets for the extent of the farm on four dates between February and June. We also collected cores for snow depth and snow water equivalent (SWE) data (one point per plot) and compared these results to evaluate variability of potential water supply from snow as a function of stubble height and snow distribution dynamics. On ground measurements of snow depth and SWE demonstrate significant differences between tall and short stubble plots, favoring tall stubble plots, during the months of February and early March. No difference is seen in late March, potentially due to melting of the snowpack and erratic snowfall patterns. Using the LiDAR data, we characterize snow drift patterning and variability to improve the accuracy of snow depth observations by difference relative to the snow-free image. These data findings add insight to controls on snow distribution and provide opportunities to examine landform scale patterns in snow variability. In addition, we compare water storage in snow, coupled with rainfall through the springtime period, to the water subsequently (May-June) stored below ground in soils measured by Electrical Resistivity Tomography (ERT). Our results inform future studies of how residue management regulates water storage in Montana's non-irrigated cereal production systems and takes initial steps to characterize snow drift and variability in agricultural settings.

## **Analyzing Creek Realignment Effects on Stormwater Management in the Grant Creek-Mullan Road Area**

**Angela C Lucero, Amelia Tallman, Cam Stringer**

NewFields

The City of Missoula is evaluating storm water management for areas of future development in the Grant Creek area as part of the Mullan BUILD Project. NewFields is updating the numerical groundwater flow model and predictive simulations to include both ancestral Grant Creek locations as possible preferential flow areas and the proposed Grant Creek realignment design. The groundwater flow model simulates the cumulative effects of the use of sumps to manage stormwater for existing and future development during 2-year and 100-year Grant Creek flood events paired with 2-year and 100-year storm events. The updated model should better simulate the

influence of major storm events on the shallow groundwater system in the Grant Creek area thereby making it a useful tool for the City of Missoula to use when making future development decisions.

### **Patterns of nutrient limitation along the Gallatin River near Big Sky during August 2023: Results from nutrient diffusing substrate experiments**

**Christy S Meredith<sup>1</sup>, Nathan Gong<sup>2</sup>, Gabrielle Starr Metzner<sup>2</sup>**

<sup>1</sup>Montana Department of Environmental Quality, <sup>2</sup>Carroll College

In 2022, the Gallatin River segment MT41H001\_021 from the Yellowstone National Park Border to Spanish Creek, was listed by the Montana Department of Environmental Quality (DEQ) as being impaired due to excessive algae growth, which was supported by photos and videos from the public. Water quality data indicated that nitrogen and phosphorous concentrations were below levels where nuisance algae growth typically occur. These findings have prompted a five-year research effort by DEQ to understand nutrient dynamics and other factors contributing to algae growth in this segment. As part of this effort, experimental approaches that quantify algal response to nutrient additions, called “nutrient diffusing substrates” (or NDS), can provide strong evidence as to what nutrient is limiting to algae growth. Polystyrene cups filled with agar of known nutrient conditions are covered in a silica disc and placed in the river for at least 22 days, and the resulting algae growth within different treatments is compared to understand if growth is limited by nitrogen, phosphorous, both nitrogen and phosphorous, or neither nitrogen or phosphorous. We placed NDS at five key sites along a longitudinal gradient of the Gallatin River starting on August 7, 2023. These included one site near the Yellowstone border, two sites above the tributary of West Fork entering the river near the town of Big Sky, and two sites below the tributary of West Fork. Sites were chosen that had similar flow and light characteristics in order to control for these environmental factors. We investigated how chlorophyll a and Ash Free Dry Weight (dry biomass) differed by treatment and site. Here we present these findings and discuss potential implications.

### **Distinguishing the effects of selenium forms and concentrations on bioaccumulation and lethality to aquatic insect communities in stream mesocosms.**

**Molly Moloney, Madison Foster, Ashley Bussell, Travis Schmidt**

United States Geological Survey Wyoming – Montana Water Science Center

Mines in the Elk River Valley in British Columbia have been active since the 1880s. These mines have caused elevated selenium levels in surface waters flowing into the United States. While selenium is essential for life, its accumulation in food webs can be toxic to wildlife. This study aims to investigate the bioaccumulation rates and potential toxic effects of two water-soluble inorganic selenium compounds, selenate (Se 6+) and selenite (Se 4+), on benthic communities in stream ecosystems. Selenite is generally more bioavailable and is more toxic at lower concentrations, but the interactive effects of selenium forms and concentrations on accumulation are poorly understood. Selenite and selenate will be added at varying concentrations to 36 stream mesocosms. Each mesocosm represents a small-scale stream ecosystem comprised of rocks, native water, algae, and invertebrates. Each experimental stream will receive selenite or selenate, or a mixture of both (1:10 ratio

selenite: selenate) for 30 days. Total selenium concentrations in treatments will range from 0.5 ug/L to 100 ug/L. Each treatment will be duplicated, whereas the control (near zero total selenium) will be quadrupled. Sediment, algae, macroinvertebrates, and adult aquatic insect samples will be collected to quantify accumulated total selenium. Additionally, dissolved selenium, selenium species, and ancillary water-quality parameters (specific conductance, temperature, pH, etc.) will be collected regularly in all exposed water. This poster will highlight relevant background information on the experimental design and analysis plan.

## **Understanding Groundwater-Surface Water Interactions in Western Montana**

**Matthew T Nichols, Herbert M Valett**

University of Montana

The proposed research will use ecological stability theory to investigate how hyporheic zones influence nutrient and metal transport across differing hydraulic gradients of the Upper Clark Fork River (UCFR), located in western Montana. Two Research Elements (RE I and II) are proposed to 1) understand how hyporheic zones influence nutrient and metal concentrations and subsequently 2) dictate algal responses. Investigators will deploy piezometers and manometers in the headwaters of the UCFR to elucidate groundwater (GW) flow paths. By measuring the hydraulic gradient (dh/dl; sensu Lee and Cherry 1979), it will be possible to identify which reaches of the UCFR experience upwelling and downwelling, as well as those that are 'stationary' (i.e., no appreciable GW or surface water (SW) input). In addition, water samples will be collected concurrently from GW and SW piezometer wells to analyze nitrate, ammonium, soluble reactive phosphorus, and metal concentrations (RE I). Algal standing crop (as chlorophyll-a; mg/m<sup>2</sup>) will be measured across three sub-reaches (upwelling, downwelling, and stationary) to ascertain hyporheic influence on primary production (RE II). This study aims to shed light on the intricate role hyporheic zones play in dictating ecosystem resilience. Results from the proposed research will provide state and federal agencies with a greater understanding of potential groundwater contamination and hyporheic mediation of nutrients and metals in the UCFR. Broader implications of the proposed research include addressing these water quality issues, educating and training undergraduate students, and contributing towards ongoing research of state-agencies who are developing effective restoration techniques for the UCFR.

## **Subsurface Characteristics of Prairie Riparian Corridors Dictate Water Quality Patterns**

**Jack W Poole<sup>1</sup>, Stephanie A Ewing<sup>2</sup>, Trevor P Irons<sup>3</sup>, Robert A Payn<sup>4</sup>, Caitlin M Mayernik<sup>4</sup>, Joseph A Shaw<sup>5</sup>, Riley D Logan<sup>5</sup>, Eric A Sproles<sup>6</sup>, Wyatt Kray<sup>2</sup>**

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The green revolution of the 1960s ushered in a new era of farming, with extensive application of nitrogen-

based (N) fertilizer to increase crop yields. Increasingly intensive N fertilization, at rates that now exceed crop uptake, has led to loss of N to groundwater and surface water draining agricultural systems. This has raised health concerns for humans and ecosystems that depend on these water resources. In the Judith River Watershed (JRW) of Central Montana, chronically high and increasing nitrate concentrations in shallow groundwater have motivated decades of research. This work has quantified nitrate leaching from dryland agricultural soils, with limited water holding capacity due to soil thickness, as well as transport of high nitrate waters from shallow terrace aquifers, into adjacent uncultivated riparian corridors. In these riparian corridors, which are managed as pastures, nitrate attenuation occurs as a function of riparian and upland hydrologic connection to streams. Here we assess the riparian character thought to control these hydrologic connections across two contrasting 700m reaches of emergent creeks located near the town of Moccasin, Montana. We hypothesize that these reaches differ in their attenuation of nitrate loading due to distinct terrace groundwater contributions, as well as contrasting character of hydrologic connection between the riparian aquifer and the stream channel. We test this hypothesis using shallow geophysical surveys, drone-based observation of vegetation and topography, and ground surveys of vegetation and groundwater levels at 15 shallow well locations. Electrical resistivity tomography (ERT) surveys were conducted along transects at both reaches to characterize subsurface soil physical properties and water content based on ground observations from riparian wells and soil pits. ERT imaging in the reach with less direct spring flow contribution from terrace groundwaters indicates distinctly delineated shallow aquifers, represented by cobble substrate with higher resistivity values, that likely support pervasive pathways of groundwater movement connecting the riparian corridor to the stream channel. In the reach with more direct spring flow contribution from terrace groundwater, ERT imaging indicates cobble aquifer material is often present at greater depths, and in disconnected pockets, resulting in distinct vegetation community composition and seasonal greenness patterns recorded in ground observations and hyperspectral imaging. Locations where ERT imaging indicates hydrologic connection in this second reach have more limited influence, based on groundwater and stream concentration patterns, and are offset by abundant surface spring line inflows counteracting the riparian attenuation that does occur. Our findings illustrate how the interaction of geomorphic, hydrologic, and ecological processes combine to determine the capacity for attenuation of nitrate loading by riparian groundwaters.

## **Data Driven Irrigation Scheduling for Water and Nitrogen Use Efficiency**

**Meghan Robinson<sup>1</sup>, W. Adam Sigler<sup>1</sup>, Clain Jones<sup>1</sup>, Kent McVay<sup>1</sup>, Jasmine Neupane<sup>2</sup>**

<sup>1</sup>Montana State University, <sup>2</sup>University of Missouri

Water is the primary limiting resource for crop production in semi-arid climates, and water management will be critical for the future of sustainable agriculture. Nitrogen is an important limiting resource for crop production as well, and its plant-available form nitrate is susceptible to leaching below the root zone with deep percolation. Soil water management is an important mechanism for controlling water and nitrogen use efficiency and is particularly relevant in irrigated systems where the quantity and timing of supplemental water applications are decided by producers. Increasing soil water content with irrigation can result in higher crop yields but also increases the risk of runoff, deep percolation, and associated nitrogen loss. We expect that implementing data-driven irrigation scheduling based on soil moisture conditions can reduce water and nitrogen losses. To explore interactions among soil water holding capacity, weather, and irrigation management decisions, we are

conducting research with cooperating producers growing seed potatoes (*Solanum tuberosum*) in the Gallatin Valley and barley (*Hordeum vulgare*) on the Fairfield Bench. Soil moisture sensors were used to monitor soil water content over the summer 2023 growing season, and water samples from lysimeters were collected biweekly to assess nitrate concentrations in soil water. Field measured soil water content data were used to calibrate Hydrus soil water flux models which were then used to predict deep percolation under actual irrigation management and hypothetical irrigation scenarios of interest to cooperating producers. Model predictions on deep percolation will be combined with observed nitrate concentrations from lysimeters to estimate nitrate leaching from study fields. Initial field work in these irrigated systems suggests that on thinner soils, risk of deep percolation may extend much later into the growing season than in dryland systems. For thicker soils or soils with higher water holding capacity, initial observations suggest deep percolation risks are minimal even during wet years, however, runoff, especially on compacted soils, can still be extensive. Preliminary modeling results suggest that under similar quantities of total irrigation, soil moisture-based irrigation scheduling produces less deep percolation than fixed date irrigation, representing the potential for improved water and nitrogen use efficiency, as well as downstream water quality.

### **“Who’d you get?!”: Creating and Disseminating Benthic Macroinvertebrate Trading Cards as an Education and Outreach Project**

**Drew Shafer, Nick Banish**

Gallatin Local Water Quality District

A goal, as outlined in the Gallatin Local Water Quality District’s (GLWQD) 5-year strategic plan (FY20-24) is to ‘Improve public awareness and understanding of local water quality, water resources and the District.’ We achieved this goal through benthic macroinvertebrate sampling and the distribution of ‘BMI Trading Cards’. We sampled five sites, on three river systems, three separate times and sent our samples to River Continuum Concepts LLC. for laboratory sorting, taxonomy, analysis, high-resolution photographs, and BMI diversity indices. The BMI indices along with field water quality measurements were used to gauge general water quality for each site. Using the photos, laboratory analyses, and field measurements, we created trading cards with high-res photos and statistics of the macroinvertebrates we captured. Sites were chosen based on proximity to parks, foot traffic, and locations not previously sampled by the GLWQD with hopes of future interpretive signage and/or a ‘Nature Play Space’ for families and children to capture and examine their own specimens.

### **Cumulative Human Health Risk from 19 Contaminants in Montana Groundwater**

**Adam Sigler<sup>1</sup>, Margaret J Eggers<sup>1</sup>, Nicklas Kiekover<sup>1</sup>, Paul Bradley<sup>2</sup>, Robert Peterson<sup>1</sup>, Albert Parker<sup>1</sup>, John LaFave<sup>3</sup>**

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The most common approach to assess human health risk from drinking water is to evaluate whether individual

contaminants are greater than a threshold. Our team is completing a Montana statewide assessment of cumulative human health risk from drinking groundwater, considering 19 contaminants (antimony, arsenic, barium, beryllium, boron, cadmium, chromium, copper, fluoride, lead, manganese, molybdenum, nickel, nitrate+nitrite, selenium, strontium, thallium, uranium, zinc) with a cumulative risk quotient (concentration addition model) approach. Our selection of contaminants and thresholds is informed by recent work by USGS. We conducted our analysis based on eight-digit hydrologic unit code watersheds (HUC8s), using data from the Montana Bureau of Mines and Geology, GWIC database. This novel approach required significant data curation and pre-processing to maximize data used, while excluding data with reporting limits too high to be meaningful relative to thresholds. We calculated risk quotients based on median and mean contaminant concentrations by HUC8, but focus on median based results here. We calculated cumulative risk (CR) using two sets of thresholds, the first based on the solely health based EPA Maximum Contaminant Level Goals (MCLGs) as well as health advisory values, and the second based on EPA Maximum Contaminant Levels (MCLs), which incorporate technical and economic feasibility for public water supply implementation. A CR value greater than 1 indicates water quality unsuitable for human health for lifetime consumption. The GWIC database includes groundwater data for all 96 HUC8s that intersect Montana. Using the solely health based thresholds and requiring a minimum of five unique well results per 19 analytes per HUC8, 59 HUC8s had sufficient data and 44 (75%) of those had a CR greater than 1. Arsenic, lead, and uranium make the largest contribution to CR across basins when applying the solely health based standards. Plumbing fixtures are typically expected to be more important sources of lead in drinking water than aquifers, so we are investigating the high lead concentrations in the GWIC groundwater data. Using the MCL based thresholds, the number of HUC8s with a CR value greater than 1 decreases to six (10%) a much smaller percentage due to arsenic and uranium MCLs that are much higher concentrations than the MCLGs (MCLG values of zero were implemented as the lowest reporting limit values of 0.0001 µg/L for As and 0.01 µg/L for U). Using the MCL thresholds, the contaminants making the largest contributions to CR are: fluoride, arsenic, lead, uranium, and nitrate (in decreasing order of importance). Our sensitivity analysis revealed that increasing the minimum required result per analyte per HUC8 reduced the number of HUC8s with sufficient data but had minimal effect on the percentage of HUC8s with CR > 1 (requiring 10 results per contaminant per HUC8 decreased the HUC8 count to 50 with 78% CR >1; requiring 15 results decreased the HUC8 count to 39 with 77% CR >1). Our findings underline the importance of private well owner education programs, such as MSU Extension's Well Educated program, that helps people test, understand, and address issues with their well water.

## **Potential effects of water temperature on patterns of aquatic insect emergence in Gallatin Valley streams**

**Lillian M Strong, Nate M Heili, Wyatt F Cross**

Montana State University

Water temperature is a principal variable in freshwater ecosystems influencing biotic communities and ecosystem processes such as energy flow. Water temperature regimes are changing due to anthropogenic factors such as climate change, water use, and development which could have localized impacts for freshwater organisms and their life histories. Aquatic insects are an integral component of aquatic food webs transferring

energy to higher trophic levels and they support terrestrial food webs through the process of insect emergence. Stream temperature is one of the most important environmental cues for aquatic insects to begin their emergence process. How warming stream temperatures may influence the magnitude and timing of aquatic insect emergence across various temperature regimes is not well understood. In this study, we measured water temperature at five streams within the Gallatin Valley watershed between June and September. We also deployed floating emergence traps on 4-6 day intervals during the same time to quantify community biomass, structure, and timing of aquatic insect emergence. We predicted that warmer temperatures would result in an increase in biomass of more tolerant species (i.e., Diptera) and a decrease in biomass of less tolerant species (i.e., Ephemeroptera, Trichoptera, and Plecoptera). For each taxon we expected emergence timing to be asynchronous based on spatial variation in temperature. In general, our preliminary results suggest that Trichoptera and Diptera were more successful at emerging in warmer temperatures than Plecoptera and Ephemeroptera. As the Gallatin Valley continues to change from population growth and development, it is critical to inventory existing conditions, such as water temperature and insect emergence, in order to predict future scenarios across changing conditions. This project is a part of a larger effort to understand the patterns of aquatic insect emergence in natural streams compared to irrigation ditches to provide a more holistic understanding of water management in the Gallatin River watershed.

## **Prioritizing Restoration through the Lens of Floodplain Connectivity: A Case Study in Coupling 2D Hydraulic Models and Relative Elevation Models**

**Sarah P Washko, Reid Camp, Tyler Rockhill, Michael Briggs**

Cramer Fish Sciences

2D hydraulic models are often used to aid in planning for specific restoration design. However, expanding the use of hydraulic models to pre-design and assessment phases can open the door to more targeted planning and prioritization. In this study we paired a large scale 2D hydraulic model with relative elevation data to characterize the magnitude, duration, and extent of inundation across several flow events. We then created and implemented a framework to prioritize and rank discrete floodplain areas for future restoration projects. The study area included the lower 16 miles of the mainstem of Asotin Creek and its floodplain near Asotin, Washington. We developed a 2D hydraulic model using HEC-RAS (v6.3.1) using topo bathymetric LiDAR as the terrain. We compiled and analyzed an extensive hydrograph dataset to determine common recurrence interval flows and climate change impacts. For each flow scenario, we ran the hydraulic model to generate a baseline of contemporary water surface elevations (WSE). We then created a relative elevation model from the LiDAR and delineated the valley bottom based purely on topographic indicators. In addition, we delineated all anthropogenic confining features within the valley bottom including levees, dikes, roads, and bridges. The intersection between the 10-year recurrence interval flow WSE and the valley bottom was used to characterize floodplain connectivity. Areas that overlapped by >50% were defined as connected, <50% were partially connected, and 0% were disconnected. For areas that were partially or wholly disconnected, we determined whether anthropogenic or natural features were the primary cause (e.g., channel incision). Within the modeled domain, 57% of the floodplain area was connected, 24% was partially connected, and 19% was disconnected. Among the disconnected areas, 71% were restricted by anthropogenic features and 29% by natural causes or features. We created a prioritization framework based on results of the hydraulic model, floodplain connectivity

evaluation, and management considerations to rank locations most suitable for future floodplain restoration projects. The final ranked list provides a road map for floodplain restoration in Asotin Creek over the next decade or longer. This novel evaluation approach of combining the hydraulic model and REM precludes the need for generating many proposed condition hydraulic models during initial planning phases for large-scale floodplain restoration projects.

## **Long term trends in nutrients and attached algae levels in the Clark Fork River**

**Vicki J Watson, Claire Utzman**

University of Montana

Impacts of excess algae growths in the upper Clark Fork River have been a concern since the 1970's. Increased nutrient loading associated with population growth and increased use of nutrients by a pulp mill on the river resulted in growing concerns in the 1980's. A Voluntary Nutrient Reduction Program was signed by stakeholders in 1996. Elements of the VNRP were eventually included in a nutrient TMDL for the river's mainstem, and numeric nutrient and algae standards were adopted -- some of the first in the nation. Monitoring of nutrient loads and levels and of algae levels has continued, producing one of the longest records in the world. Snapshots of some of those results are presented. Note that major reductions in point source loads have occurred at wastewater treatment plants in Missoula, Butte and Deer Lodge as a result of these efforts.

## **Examining the influence of nutrients and colloidal metals on metal accumulation in the base of a river food web**

**Dylan T White<sup>1</sup>, Rafael Feijo de Lima<sup>1</sup>, Molly Moloney<sup>2</sup>, Ashley Bussell<sup>2</sup>**

<sup>1</sup>University of Montana, <sup>2</sup>US Geological Survey Wyoming-Montana Water Science Center

The base of the food web in many mid-order streams is periphyton, the mixture of algae, bacteria, and fungi growing on submerged surfaces. In streams such as the Clark Fork River in Montana that have elevated heavy metal concentrations, periphyton can also serve as an important source of these contaminants to higher trophic levels. As such, understanding the factors that drive metal accumulation in periphyton is crucial to understanding exposure of the food web to metals and metalloids (hereafter collectively referred to as metals). Elevated nutrients in streams can drive the formation of algal blooms, however, the influence of the resulting increase in algal biomass on metal accumulation in periphyton is poorly understood. The forms of metals accumulated by periphyton are typically considered to be dissolved solutes, which we quantify by measuring the metals in filtered water samples. However, the filter sizes commonly employed are in the range of 220 to 700 nm, which will allow some fraction of colloidal particles (1 to 1000 nm) to pass through the filter, in addition to truly dissolved solutes (< 1 nm). Thus, it is unclear the extent to which colloidal particles or truly dissolved solutes drive the accumulation of metals in periphyton. To assess how elevated nutrient concentrations and different metal size fractions affect metal accumulation by periphyton, we conducted an experiment using stream mesocosms. We used two source waters, one from the Clark Fork at Deer Lodge, MT that had high metal concentrations and one from the Clark Fork at Turah, MT with lower metal concentrations. To examine the role

of nutrients and metal concentrations in driving accumulation, we used either ambient or elevated nitrate and phosphate concentrations in both source waters, yielding four treatments: Low Metals Ambient Nutrients, Low Metals Elevated Nutrients, High Metals Ambient Nutrients, High Metals Elevated Nutrients. To examine the accumulation of metals in different size fractions, we filtered Deer Lodge water with tangential flow filtration into three size fraction treatments: Suspended Particulate Matter (SPM; 0.45 – 80  $\mu\text{m}$ ); Colloidal (1 – 450 nm); and Truly Dissolved (< 1 nm), which was then spiked with metal salts to match the concentrations in the Colloidal water. We used four replicate mesocosms for each treatment, which were dosed with 4 mL per minute of treatment water in recirculating mesocosms for 15 days before being processed and analyzed for metal concentrations, algal pigments, and organic matter content. We found that periphyton in the Colloidal treatment had elevated concentrations of As, Cd, Pb, Zn, Se, and V compared to the Truly Dissolved and SPM treatments. In both treatments with elevated nutrients, algal pigments were higher, but periphyton concentrations of As, Cu, Fe, V, and Pb were lower relative to the ambient nutrient treatments. These results suggest that colloidal metals may be important in driving accumulation in periphyton, and that elevated nutrients may reduce the concentration of metals in periphyton by stimulating algal growth and diluting metal concentrations.