

## **Modelling Transport of Selenium in Lake Koocanusa**

Seth Siefken, Meryl Storb, Madison Foster, Johanna Blake, Travis S. Schmidt

Lake Koocanusa is a transboundary reservoir impounded by Libby dam in northwest Montana. The reservoir extends upstream into British Columbia where its major tributaries—the Kootenay, Elk, and Bull Rivers (which account for 87% of lake inflow) enter the lake and have their headwaters. Globally significant metallurgical coal mines in the Elk River Valley discharge mine wastes into downstream waters, including Lake Koocanusa and the Kootenai River. While previous investigations documented that 95% of the selenium loads to Lake Koocanusa were from the coal mines, and that most of the selenium passes through the reservoir into the Kootenai River below Libby Dam, little is known about the physical processes that control selenium transport in Lake Koocanusa. To better understand how selenium is distributed in the reservoir over space and time, a mass balance of selenium was calculated for the reservoir, and a solute transport model was used to estimate daily selenium concentrations along the length of the reservoir. The mass balance indicates about 90% of the selenium moves through the reservoir on annual timescales; however, about 10% has been retained in the reservoir over the last 10 years (13,500 kg). The transport model indicates that advection and diffusion are the primary controls on the distribution of selenium in the reservoir and are more important controls than other processes such as lake turnover. These results imply that Lake Koocanusa is a selenium sink with some selenium moving into sediments or the food web, the latter indicating potential risks to fish and wildlife.

## Seasonal Groundwater-Elevation Variations and Potentiometric Surfaces in the Tobacco Valley, near Eureka, Montana

Tyler Storey, Andrew Bobst, and Ali Gebril

In the Tobacco Valley, near Eureka, growing water demand and regulatory requirements to mitigate depletion of the Tobacco River drive the need to understand interactions between surface waters and the aquifer system. These concerns led to a groundwater investigation by the Montana Bureau of Mines and Geology (MBMG) Ground Water Investigation Program (GWIP). As part of that investigation, we examined seasonal groundwater elevation patterns in Water Year 2023 (WY2023), classified hydrograph signal types, and mapped potentiometric surfaces to aid in understanding groundwater responses to potential recharge sources, groundwater flow directions, and hydraulic connectivity between aquifers.

The Tobacco Valley aquifer system consists of highly heterogeneous glacial sediments. The study area contains several glacial lakes and is bordered on the west by Lake Koochanusa. The area is underlain by Belt bedrock, with valley fill deposits of glacial till, glacial outwash, deltaic sediments, lacustrine sediments, and modern alluvium. A network of 105 wells was monitored during WY2023 (typically monthly). These hydrographs were analyzed for characteristic seasonal patterns. Potentiometric surface maps for April (late dry season low) and July 2023 (post-snowmelt high) were constructed using measured groundwater elevations. Our conceptual model of the groundwater system, including lithologic and water budget data (streamflow losses, lake infiltration estimates, etc.) were used to interpret the recharge and discharge processes underlying the observed patterns.

Six hydrograph types were identified, and they reflect distinct controls: 1) Tobacco River proximal wells showed subtle ~1 ft spring rises synchronized with river stage; 2) lakeside shallow wells showed steady declines (~4–6 ft) with minimal recharge; 3) wells near Lake Koochanusa exhibited ~50 ft seasonal fluctuations mirroring reservoir operations; 4) in the Phillips Creek area there was a ~24 ft spring rise attributable to focused stream infiltration during snowmelt; 5) sites distributed across the study area showed a smaller ~2–8 ft spring rise; and 6) wells with flat hydrographs, mixed signal behavior, strong pumping influences, or otherwise atypical patterns were classified as no clear signal. Potentiometric surfaces revealed regional east to west flow toward Lake Koochanusa, a groundwater ridge near Phillips Creek, and a persistent southern groundwater ridge caused by a bedrock structural high. Water levels in shallow wells near Sophie, Moran, and Tetrault Lakes were ~20 ft higher than the regional water table, showing vertical disconnection from the deeper regional system.

These results highlight strong horizontal connectivity between groundwater and major surface-water features, while also showing localized vertical separation. The identified patterns improve conceptual understanding of recharge and discharge mechanisms and informed development of a transient groundwater model, now being calibrated. The calibrated model can guide water resource planning and help balance groundwater development with existing surface-water rights.

## Hydrogeology Framework of Gallatin and Madison Counties

Carstarphen, Camela A.<sup>1</sup>, Crowley, Jeremy<sup>2</sup>

Gallatin and Madison counties span about 6,200 mi<sup>2</sup>, in southwestern Montana. Gallatin County has experienced steady population growth, reaching 126,409 according to the most recent census, contributing to an increasingly urban landscape. Madison County, while also growing, remains largely rural with a population of 10,059. This regional expansion, coupled with a growing dependence on groundwater, raises important questions about water availability and long-term sustainability—questions that require aquifer mapping and long-term groundwater data to answer.

To support this need, the Montana Bureau of Mines and Geology (MBMG) conducted a groundwater characterization study between 2008 and 2012, visiting 1,188 wells across both counties. A key component of this effort was developing a hydrogeologic framework to identify the geologic units that form aquifers—either individually or in combination. The hydrogeologic framework provides the basis for analyzing groundwater flow patterns, groundwater levels, aquifer productivity, and groundwater-quality. This analysis incorporated over 20,000 well log lithology records and regional geologic mapping to identify well completions and aquifer characteristics.

Wells in the study area are completed in a variety of geologic units including geologically young alluvium, consolidated sedimentary rocks of various ages, igneous rocks and older fractured bedrock units. These units form aquifers organized into three primary types: basin-fill aquifers (unconsolidated sand, gravel and clay that include recent alluvial deposits), sedimentary bedrock aquifers (sandstones, shales, and limestones with both primary and secondary porosity) and fractured bedrock aquifers that depend on fracture flow for groundwater movement. Aquifer characteristics—yield and depth—were organized by the major basins in the region: Jefferson, Upper Madison, Lower Madison, Hebgen, Gallatin and Bridger.

In total, 83percent of wells in the study area were completed in the basin-fill aquifers. The combined thickness of Quaternary (Qs) and Tertiary (Ts) basin fill ranges from about 6,500 ft in the Gallatin Valley to as much as 10,000 ft in the Jefferson, Ruby, and Beaverhead Valleys. Qs thickness typically ranges from 20-80 ft, with greater depth observed in central Gallatin Valley, lower Madison and Jefferson Valley and alluvial fans near Sheridan, Montana area. For all of the wells completed in Qs and Ts deposits, the median depth is 126 ft and the median driller reported yield is 30 gallons per day (gpm).

The remaining 17 percent of wells are completed in sedimentary and fractured-bedrock aquifers, with most wells completed in fractured bedrock consisting of Precambrian metamorphic rock, which are also the most widespread in surface outcrop. Wells in bedrock aquifers average 200 ft in depth, and yield a median of 16 gpm.

Most wells are used for household (domestic) purposes, with value varying across basins likely (80—94%). The higher percentage is in Bridger Basin (94 %) with the Jefferson and Lower Madison basins the two lowest (80%). Despite the lower number of wells reported as irrigation and public water supply use, the USGS estimates that in Gallatin and Madison counties, public water supply and irrigation are responsible for most of the groundwater. Domestic withdrawal is estimated at 2 million gallons per day; 10 percent of USGS total daily estimate of all use (~16.5 million/gallons/day, from 2019 data)

<sup>1</sup> Montana Bureau of Mines and Geology

<sup>2</sup> University of Montana

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## The Montana Bureau of Mines and Geology Live and Interactive GIS Data Hub Site

Camela Carstarphen, Yiwen Li, John Sanford

Montana Bureau of Mines and Geology (MBMG) maintains large databases of geologic and hydrogeologic data. The continued focus for the GIS Department is to make sure all the data in these databases are not just available in tabular fashion, but also as spatial geodatabases available to staff and to the public in GIS format. The translation of our data into ArcGIS Enterprise databases began in February 2022, and the department has made significant strides in creating public GIS data previously only available in tables, presently housed in our GIS Data Hub Site.

The GIS Data Hub Site is a hub for all things GIS for the MBMG, serving as the one-stop shop for all web maps, analytical dashboards, and story maps, along with direct download access to the MBMG GIS data. The Hub Site releases are organized by discipline (Geology, Geohazards, Water Resources, Energy Resources, and Mineral Resources). This allows users to easily find the data they need, download it quickly, or simply learn about our various projects.

The Ground Water Assessment Program (GWAP) has released web maps to accompany traditional publications. Recent examples include 1) the Statewide Principal Aquifer Map by Crowley and others, 2) the Montana Precipitation Isotope Network data by Carstarphen and Li, and 3) the Lincoln and Sanders Counties characterization Data Map by Carstarphen and Li (<https://gis-data-hub-mbmg.hub.arcgis.com/pages/020ad343eab741c1b2d5ca14852a95cf>).

Lincoln and Sanders Counties, located in Northwestern Montana, are facing the pressures of population growth and rising demand for water resources. In western Montana, groundwater recharge is primarily driven by snowpack accumulation, making it a winter dominated recharge system. The region's precipitation history reveals a pattern of surplus followed by deficit, and since 2018, data from the Cabinet Mountains SNOTEL site show consistent negative departure from normal precipitation levels.

The pressure of increased growth and changing precipitation patterns brings up questions of groundwater sustainability; questions that require long-term climate and groundwater data sets to answer.

To address this need, the Montana Bureau of Mines and Geology (MBMG) established the Ground Water Assessment Program (GWAP), designed to monitor long-term trends in groundwater storage and water-quality, and to map regional aquifers across the state. This mapping serves as a foundation for evaluating changes in ground water storage using long-term precipitation and groundwater data.

As part of the GWAP's groundwater characterization effort (2018-2024), the MBMG collected extensive groundwater, surface water and precipitation data in Lincoln and Sanders Counties. Program staff visited 667 sites including: groundwater (590 water wells, 23 springs, 1 mine adit), surface water (31 streams, 16 lakes, and 2 canals), and precipitation (4 monitoring stations). Visited wells were selected from more than 13,000 well records in the Ground Water Information Center (GWIC) database for the two counties. This included two years of hourly data collection at a well (GWIC 81347) and a nearby staff gage (GWIC 320133) at Crystal Lake (Thompson Chain of Lakes, Lincoln County), where declining lake levels have sparked local concerns about groundwater sustainability.

This work, combined with long-term groundwater elevation (GWIC 85274), precipitation and snow water equivalent (SWE) data from SNOTEL, is used to calculate statistical anomalies. These anomalies help quantify how precipitation and groundwater levels have varied over different timeframes (e.g. monthly, annually), and identify the primary drivers of observed trends.

Lake and well water-level data at Crystal Lake show an annual fluctuation with a spring "high" and a winter "low" and display a recent downward trend over the monitoring period. However, a past water level from June 1989 (water elevation of 3353 ft) is one foot lower than a June 2022 (3354 ft). Precipitation and groundwater anomalies indicate that groundwater head is well correlated ( $R^2 \geq 0.8$ ) with shifts in precipitation at annual time scales and longer. This suggests that groundwater levels in the region are largely governed by long-term precipitation patterns and recent declines in precipitation are the dominant factor behind falling lake and groundwater levels. Looking ahead, climate models predict increased precipitation across much of the western United States. However, rising temperatures may alter how and when that precipitation occurs—potentially shifting it from snow to rain and affecting groundwater recharge dynamics. As a result, the future of Montana's groundwater resources remains an active and essential area of research.

Soil moisture storage drives hydrological processes, ecosystem dynamics, and its responsiveness to climatic and anthropogenic changes makes it an early indicator of drought. Despite its importance, soil moisture recharge remains poorly understood due to complex interactions between antecedent soil moisture conditions, precipitation dynamics, and land characteristics. For example, a brief, high-intensity precipitation event could lead to increased runoff that limits soil moisture recharge, or it could trigger infiltration through preferential pathways that transport large volumes of water deep into the soil. Thus, soil moisture recharge has proven particularly challenging to characterize and quantify. In water-limited systems, a key question remains: *how impactful or “effective” is a precipitation event for improving water availability (use and storage)?* To address this question, we leverage a high-frequency dataset of *in situ* precipitation and multi-depth soil moisture observations from the Montana Mesonet in order to (1) determine the antecedent soil moisture and precipitation event conditions that promote effective precipitation and (2) identify the dominant flow processes (diffuse or preferential flow) associated with effective precipitation events across different soils. This research aims to identify key drivers and processes associated with effective precipitation and their spatial variability. Knowledge of these factors and their variability will provide important information for understanding and predicting drought and the potential impacts to vegetation across Montana’s diverse ecosystems.

This project seeks to quantify regional evapotranspiration (ET) in the Sierra Nevada Mountains of California from geodetic estimates of total water storage. ET is the second largest hydrologic flux for most terrestrial watersheds, but its quantification is especially difficult at regional scales. Current methods of direct ET measurement are range limited or expensive, making them impractical for regional-scale investigations. Remote sensing and ET models are often used for regional studies, but they rely on assumptions about vegetation type and homogeneity, which may not accurately represent ET in complex mountainous terrain. Here, we explore the use of geodetic techniques to quantify changes in total water storage, from which regional ET can be inferred using a mass balance approach. Direct measurements of surface displacement are processed to isolate hydrologic loading, which are then combined with streamflow measurements and estimates of precipitation to compute ET. The mass balance methodology can also be used to assess the scale of mountain block recharge (MBR), groundwater flow from the mountains to the valley, and constrain the contribution of MBR to the overall water balance of the Sierra Nevada, and its effect on ET estimates. Preliminary results indicate that ET estimates are within the range of modeled estimates, but MBR is likely a significant term in the regional mass balance causing an overestimation of ET using the mass balance method. Regional-scale ET and MBR estimates in mountainous areas with complex topography, independent of climate models, represent an advance for almost all water-related fields.

## Abstract

Acid mine drainage (AMD) poses significant environmental challenges due to its high acidity and metal content, particularly iron. This study explores the use of iron recovered from AMD in Truetown, Ohio, as a sustainable and cost-effective adsorbent for arsenic removal from water. The recovered iron was characterized and tested for its ability to adsorb arsenic through batch isotherm studies and continuous-flow column experiments. Key parameters, such as adsorbent mass and solution pH (ranging from 3 to 12), were systematically varied to assess their effects on adsorption performance.

The results indicated that arsenic removal efficiency increased with higher adsorbent dosage and was highly dependent on pH, with optimal performance occurring in the neutral to slightly acidic range. The adsorption behavior was modeled using both Langmuir and Freundlich isotherms. Additionally, the performance of the AMD-derived iron was compared to that of a commercial adsorbent, Bayoxide® E33. This research highlights the dual benefits of valorizing AMD waste while improving water treatment technologies.

One third of Montana's population relies on private wells for domestic drinking water. Testing water quality and maintaining these water supplies is the homeowners' responsibility but there are many obstacles to homeowners taking action. Obstacles include understanding: that testing is important; what to test for; how to test; and how to interpret results. There are also financial obstacles to testing and to implementing solutions.

In February of 2025, our team and coauthors published a journal article on cumulative human health risk associated with Montana groundwater. The results of that article have been translated into an interactive map on the Well Educated program website to inform well owners, county environmental health offices, county Extension agents, and others about what analytes are most important to test private wells for across the state based on county and watershed. Flyers about the health risks associated with exposure to each analyte as well as information about well maintenance and water quality testing are also available on our website (<https://waterquality.montana.edu/well-ed/>).

For 20 years, the MSU Extension Well Educated program has been guiding Montana well owners through testing and understanding their water quality. The Well Educated program has been orchestrated in partnership with a private lab which has offered competitive pricing, but testing costs are still an obstacle to many homeowners.

In 2023 and 2025, our team piloted a new clinic-based private well testing approach. This included analyzing private well samples on MSU campus, which is parallel to the approach of other leading Extension private well testing programs across the US. Pilot efforts indicate that on campus sample analysis has the potential to dramatically reduce testing costs for education-based private well testing, which could increase testing accessibility for Montana well owners.

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Rachel Suhs (Missoula Valley Water Quality District) AWRA 2025 Abstract

## At What Data Resolution R Trends Meaningful? A Groundwater Elevation Analysis

The Missoula Aquifer is an EPA designated sole-source aquifer, providing drinking water and irrigation to over 90,000 households across several communities in the Missoula valley. The Missoula Aquifer is an unconfined aquifer of coarse alluvial sedimentary layers primarily recharged by the Clark Fork River and discharges into the Bitterroot River and lower reaches of the Clark Fork River. Its thickness ranges between 110 to 140 feet and has an average saturated thickness of 50 to 120 feet. The Missoula Valley Water Quality District has been monitoring the aquifer since 1995 via a growing network of monitoring wells, now numbering 44 wells. However, the water levels have been monitored on a variety of time scales via hand measurement and pressure transducers. Initially, the wells were monitored quarterly from 1995 to 2020. Beginning in 2020, wells were monitored monthly by hand, and starting in 2021, hourly by pressure transducer.

What can a dataset with differences in data resolution tell us when looking back in time and looking forward? The data set was aggregated to quarterly (1995-2024), monthly (1995-2024 & 2021-2024), and daily (2021-2024) to conduct the Mann-Kendall Test and Sen's Slope analysis. The results of the analyses were then compared across the different data resolutions. The comparison of these trends helps us to define what is a "good" long, term dataset, how to best maintain it moving forward, and how to conduct meaningful analysis with it.

The Greenfields Irrigation District (GID) overlies the Greenfields Bench aquifer near Fairfield, MT. This shallow alluvial terrace aquifer supplies drinking water for the City of Fairfield, the Tri-County water system, and over 400 private residences. At the request of the GID and the Sun River Watershed Group, the Ground Water Investigation Program (GWIP) at the Montana Bureau of Mines and Geology (MBMG) is conducting a study to investigate interactions between the GID irrigation infrastructure/practices and the alluvial groundwater system. The purpose of the project is to understand the groundwater response to potential changes in the canal delivery system, irrigation practices, and the potential effects of these changes on groundwater recharge.

Irrigation water is diverted from Gibson Reservoir into an extensive canal network that serves over 80,000 irrigated acres. Leakage from the canal system provides groundwater recharge to the shallow aquifer. In the last four years, the mean annual water levels in the reservoir have been lower than average. Furthermore, excess water flows through the canal system and discharges to Muddy Creek, contributing to erosion issues. Below-average snowpack, lower reservoir levels, and the discharge of unused irrigation water into Muddy Creek result in shorter irrigation seasons, thereby decreasing recharge and lowering groundwater levels. Water shortages are widespread in the aquifer; in response, the City of Fairfield implements seasonal water restrictions for all users. In 2025, groundwater levels had declined to the point that many residents had to haul water for domestic use. In the future, the GID plans to install a series of reregulation ponds that will store water closer to the point of use, thereby improving water delivery efficiency and decreasing the amount of unused irrigation water discharged to Muddy Creek.

The MBMG established a monitoring network that includes 76 wells and 28 surface-water sites. Field data will be used to construct a groundwater budget and numerical flow model. The model will simulate groundwater response to potential changes in the irrigation delivery system and the effects on groundwater recharge. This will provide stakeholders with information to make informed water management decisions, such as optimizing water efficiency while maintaining and potentially increasing groundwater recharge to the aquifer.

# Hydrologic Connectivity in a Gravel-Bedded River: UAV and SWOT Observations from the Clark Fork River

## Abstract

Hydrologic connectivity is essential for maintaining water quality, floodplain resilience, and ecosystem health. When connectivity within a system is disrupted, aquatic habitat, groundwater recharge, sediment deposition, and other processes may be impacted. Understanding these dynamics is critical to support effective water management, habitat restoration, and climate adaptation strategies. This is particularly true for gravel-bedded rivers, as these dynamic landscapes are of high ecological importance and have been understudied in past years. As a result, the interaction between lateral and vertical connectivity, and how geomorphic features influence connectivity patterns, is poorly understood, particularly in unconfined, multi-threaded reaches where these complexities are most pronounced. One such example is the Kelly Island reach of the Clark Fork River in Missoula, MT, a dynamic multi-threaded floodplain that is shaped by seasonal flows and geomorphic complexity. This study seeks to investigate hydrologic connectivity in this system by drawing comparisons between unmanned aerial vehicle (UAV)-based topographic and thermal mapping with the Surface Water and Ocean Topography (SWOT) mission's satellite-scale observations. These datasets are also complemented by data from pressure transducers, in-water temperature sensors, and USGS gaging records to track temporal variability in water levels. Study findings will provide new insights into how seasonal variability and geomorphic features shape hydrologic connectivity in gravel-bedded rivers, enhance our understanding of connectivity processes in dynamic systems, and support water resource management and conservation efforts. Additionally, we hope to demonstrate the value of integrating field, UAV, and satellite datasets to study river–floodplain dynamics across spatial and temporal scales.

# Empowering Pesticide Stewardship: MT PSPP's Outreach Strategy to Protect Montana's Waters

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*Pesticide Stewardship Partnership Program*

*Flathead Lake Biological Station*

**Abstract:** The Montana Pesticide Stewardship Partnership Program (MT PSPP), based at the Flathead Lake Biological Station, works to reduce pesticide pollution, improve water quality, and promote education and engagement. This collaborative network—including residents, tribal nations, farmers, watershed groups, government agencies, and local organizations—supports efforts to protect water resources in Western Montana. MT PSPP was launched in 2023 through a five-year EPA Columbia River Basin Restoration grant. The first year focused on program development, partnership building, and drafting a Quality Assurance Project Plan (QAPP) to guide pesticide monitoring in Montana's portion of the Upper Columbia River Basin. These foundational efforts reflect the program's commitment to voluntary, locally driven stewardship, and science-based decision-making. Building on this groundwork, MT PSPP is now expanding its network, conducting field-based monitoring, and deepening engagement with agricultural producers, tribal communities, urban stakeholders, and more. The program continues to align with EPA priorities—reducing toxics through agricultural best practices, green infrastructure, and community education. Together, we aim to improve the health of the upper Columbia River Basin, recognizing that protecting the headwaters benefits ecosystems downstream.

The program's approach includes water quality monitoring, community education, sustainable land management, fish and food web monitoring, science communication, green infrastructure projects, and more. Education and outreach are key to connect individual actions to broader ecosystem outcomes and supports voluntary stewardship. This supports the goal of reduced pesticide pollution and improved water quality. A core outreach component is watershed science—explaining how everyday land-use decisions, such as pesticide application, can influence water quality.

Outreach is tailored to diverse audiences and promotes practical strategies to reduce pesticide pollution, including pest monitoring and identification, encouraging beneficial insects, selecting low-risk or organic products, minimizing spraying, preventing runoff and drift, establishing buffer zones, planting native vegetation, and adopting integrated pest management techniques. Workshops, conferences, and coordination with PSPP partners foster collaboration and consistent messaging. These efforts support broader water resource management goals by reducing nonpoint source pollution and protecting aquatic ecosystems.

MT PSPP's outreach is designed to promote and support voluntary behavioral changes. Shared messaging and partner engagement are key in achieving this. By empowering partners to share materials, reinforce stewardship messages, and offer their expertise to stakeholders, the program expands its reach and builds community capacity. Looking ahead, MT PSPP will integrate monitoring data into outreach and deepening engagement across Montana.

**How many hydrogeologists can dance on the head of a pin: Examining the controversial history of groundwater management at the Butte Superfund Site using more than 35 years of stream and groundwater data.**

Joe Griffin, Montana Technological University, Affiliated Faculty

James Madison, Montana Bureau of Mines and Geology, Associate Professor

Nearly two decades ago, the U.S. EPA implemented a remedial strategy for the contaminated alluvial aquifer at the Butte Priority Soils Superfund Site. Exercising its federal authority, the EPA designated the alluvial aquifer along Silver Bow Creek as *technically impracticable* (TI) to restore to drinking water standards due to persistent secondary contamination sources and aquifer heterogeneity. In compliance with Superfund law, the remedy prioritizes human health through institutional controls and protects aquatic life by continuously capturing and treating contaminated groundwater (*in perpetuity*) before it reaches Silver Bow Creek.

The remedy has involved multiple components, including removing the Colorado Smelter tailings—a major source of stream contamination **directly** impacting the creek. However, EPA controversially chose not to remove the Parrot Tailings, despite their role in generating a severe groundwater contamination plume (copper 1,000 ppm), because the tailings and the resultant plume were located far from the creek.

Using over 35 years of comprehensive groundwater and surface water-quality data, we apply a novel cumulative gain-loss analysis to evaluate the interaction between aquifer and stream systems to critically assess whether EPA make the right decision to leave waste in place and rely on capture and treatment to manage surface water/groundwater interaction at this large and complex Superfund site.

## Evaluating Managed Aquifer Recharge (MAR) in Montana

Ginette Abdo, Andrew Bobst, Ann Hanson, Mary Sutherland, Cole Denver, and John LaFave

The Montana Bureau of Mines and Geology (MBMG) is evaluating the potential for Managed Aquifer Recharge (MAR) in Montana. MAR is the intentional recharge and storage of groundwater to improve the reliability of water supplies, enable drought preparedness, and enhance ecosystems. Two MAR methods are being evaluated: 1) Surface infiltration, accomplished by ponding, spreading, or diverting surface water and/or modifying stream channels to enhance infiltration into unconfined aquifers, and 2) Aquifer storage and recovery (ASR), which involves injecting water into confined/semi-confined aquifers for later recovery. This evaluation addresses the hydrogeologic suitability of each method.

Surface infiltration suitability was evaluated using a GIS-based multi-criteria decision analysis (MCDA) to evaluate pertinent hydrogeologic characteristics. The analysis incorporated four criteria: geologic unit/aquifer, depth to groundwater, soil permeability, and topographic slope. The final suitability map (Hanson and others, 2024) provides a statewide perspective on where conditions are most favorable for surface infiltration and where additional data collection and analysis may be warranted.

The ASR suitability analysis was focused on the deep aquifer in the Flathead Valley. The suitability approach also used MCDA, incorporating three criteria: 1) the thickness of unconsolidated sediments below the confining layers, 2) the available drawup (depth to water), and 3) vertical confinement. The resulting suitability map (Bobst and others, in review) showed that 26% of the area is highly suitable for ASR, providing a first step in identifying locations for further evaluation of potential ASR projects.

Other related MBMG work includes a feasibility study for both surface infiltration and ASR in the Upper Big Hole Valley above Wisdom, a comparison of results between the statewide surface infiltration suitability mapping and focused suitability maps using site-specific data, and an evaluation of the potential for ASR in the Gallatin Valley.

Climate change is a direct threat to the health of forest ecosystems, with loss of hydraulic function being an important pathway towards tree mortality. Individual vulnerability to this change will depend on tree-specific environmental conditions that cross physiological thresholds determined by their hydraulic traits. These traits develop over time via the growth of new tissues, and are in part influenced by the same local conditions that may someday result in their failure. However, local hydroclimates are often highly variable, due to topographic effects on atmospheric aridity and soil water supply, resulting in the potential for diverse vulnerabilities to exist within the same landscape. The question remains: *which trees are most vulnerable to drought stress, and where?* Here, I present preliminary findings and an approach to address this question at the hillslope scale. First, I establish a rationale for the likely existence of spatially organized differences in tree hydraulic strategies via the landscape arrangement of seasonal hydroclimates and constraints on Douglas-fir growth. Second, I address a need for improved methodology for measuring two key hydraulic traits, capacitance and vulnerability to embolism, of which current methods are limited in their ability to capture small, but physiologically relevant differences. Third, I propose the evaluation of (1) the interrelations among field-monitored local hydroclimates, growth dynamics, and hydraulic traits, and (2) how trees with different seasonal and annual responses may fare under a changing climate. This research aims to elucidate fine-scale patterns in forest hydraulic vulnerability that may confine forest refugia during rapid climate change.

Widespread use of nitrogen fertilizers has significantly altered the global nitrogen cycle, resulting in nitrate accumulation in and loss from soils, with adverse effects on human and ecosystem health. Although gradients in oxygen availability have been inferred across structural units within soil profiles, the resulting gaseous N losses and nitrate leaching remain poorly characterized in detail. Here we present results of a simulation of benchtop soil column experiments to capture the temporal variability of nitrate production and loss dynamics. We model the benchtop soil column using MESAS (Multiresolution Estimation of StorAge Selection) modeling framework (Harman & Xu Fei, 2024), which simulates concentrations of N in outflow of the column as a function of transit time distribution and first-order reaction kinetics. This benchtop experiment will inform future modeling efforts of non-irrigated cereal production at the well-studied sites of the Judith River basin (Moccasin, MT). At these sites, soils have well-developed structures that allow for complex flow patterns and redox environments. Our modeling approach will allow us to efficiently simulate nitrate concentrations and associated patterns of change in nitrate stable isotopes and anticipate observations using microfluidic collection and sensing that will test pore-scale predictions developed with these approaches.

An overview of the  
Montana Board of Water Well Contractors

Thomas Palin <sup>(1)</sup> and James P. Madison<sup>(2)</sup>

The Montana Board of Water Well Contractors (BWWC) was established in 1961 under the Montana Water Well Contractors Act to regulate the construction, maintenance, and abandonment of water wells throughout the state. Created under the authority of the Montana Code Annotated Title 37, Chapter 43, the board operates within the Department of Natural Resources and Conservation (DNRC) and is tasked with licensing water well drillers and contractors, enforcing construction standards, and protecting Montana's groundwater resources. As the demand for environmental monitoring grew, the BWWC added monitoring well standards in 2006, codified in Subchapter 36.21.8 of the Administrative Rules of Montana. These standards were introduced to prevent contamination, ensure accurate data collection, and maintain aquifer integrity—especially in areas used for environmental assessments and remediation. The board consists of four licensed contractors appointed by the Governor, including representatives from the Bureau of Mines and Geology, the Department of Environmental Quality, and the DNRC itself. The BWWC's creation was driven by the need to ensure that water wells are constructed safely and responsibly, given Montana's reliance on groundwater for domestic, agricultural, and industrial use. The board's duties include adopting rules for well casing materials, sealing and grouting procedures, cleaning and disinfecting protocols, and abandonment standards to prevent contamination and preserve hydrostatic pressure. It also oversees the licensing process, including examinations, continuing education, and enforcement of professional conduct among contractors and drillers. One of the board's key responsibilities is overseeing the submission of well logs, which are detailed records of each well's construction and geological profile. According to Montana Code Annotated 85-2-516, drillers are required to submit a well log within 60 days of completing a well. These logs must include location data, construction details, and lithologic descriptions, and they must be submitted using forms approved by the board. The logs are filed with the Montana Bureau of Mines and Geology (MBMG), which maintains the Ground-Water Information Center (GWIC)—a public database that supports water resource planning, research, and environmental monitoring.

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## Using Multiple Environmental Tracers to Understand Groundwater Net Exchange and Quality in the Upper Clark Fork

Understanding the interactions between groundwater and surface water is crucial for the management of water resources and remediation. In this project, groundwater-stream water exchange will be mapped longitudinally by measuring environmental tracers in the stream and fitting a numerical model of tracer transport in the river that considers groundwater net exchange to these data. The Upper Clark Fork River is being synoptically sampled for a suite of environmental tracers ( $^{220,222}\text{Rn}$ ,  $\delta^{18}\text{O}$ ,  $\delta\text{D}$ , CFCs and  $\text{SF}_6$ ), pH, discharge, dissolved oxygen, specific conductivity, and major and minor chemistry including heavy metals. Concentrations of radon, CFCs, and  $\text{SF}_6$  will be used to estimate net groundwater exchange and mean age, using a newly developed stream transport model that considers groundwater net exchange and age distribution. The remaining tracers will be used to estimate discharging groundwater quality. Sampling is taking place along the reach of the stream between the Warm Springs State Wildlife Management Area near Anaconda, MT and Goldcreek, MT, an area which has seen extensive remediation but not the expected rebound in fish population. Our anticipated results will advance our understanding of the evolution of water-chemistry post-remediation along with the hydrological processes that affect water management and ecosystem health. This knowledge will in turn improve water management strategies in a changing climate and global population that is running short of water for personal, municipal, industrial and agricultural use.

Preliminary data review indicates higher groundwater concentrations in the river at irrigation-influenced low flow compared to peak flow, increasing through Deer Lodge, MT, and tapering where the valley constricts. Initial review of stream water samples shows that heavy metals (Cu, Cd, Cr, Pb and Mn) are more elevated at peak flow than irrigation-influenced low flow, except for arsenic. Copper concentrations increase downstream, peaking near Deer Lodge before tapering toward the valley terminus.

## Make the Vadose Zone Great Again: The Gold Creek Return Flow Pilot Study

Throughout Montana, the past 50 years have brought a widespread conversion from gravity-based flood irrigation to pressurized sprinkler systems. Flood irrigation is relatively **inefficient** because crops can only take up a small proportion of the water applied to the field. Modern sprinklers are highly **efficient** because they allow irrigators to apply precise quantities of water to crops, boosting production while requiring less water. However, this efficiency often comes at a cost. Flood irrigation water that is not used by plants seeps into the soil, recharging the shallow aquifer and often percolating back to the stream during low flow months. By contrast, there is far less non-consumed water on sprinkler-irrigated fields, meaning that less water is available to contribute to late season return flows. This tradeoff is known as the paradox of irrigation efficiency.

To address this challenge, an experimental study was developed in the Gold Creek drainage within the Upper Clark Fork Watershed in 2024. This experimental study seeks to explore whether pivot sprinkler irrigation can be operated in a manner to maximize soil water storage and deep percolation during spring runoff, and then return to highly efficient sprinkler operation when stream flows are lower later in the season. Ultimately, can pivot sprinkler systems be operated in a manner to achieve the best of both worlds within the paradox of irrigation efficiency? Can we make the vadose zone great again?

# Geologic and Hydrologic Controls on Salinity in Intermittent Prairie Streams of Central Montana-Distinguishing Natural Salinity Processes from Potential Oilfield Impacts

Matthew Smith<sup>1,2</sup> · Elizabeth Meredith<sup>1</sup> · Marcia Schulmeister<sup>2</sup>

## Abstract

Oil production-associated brine contamination to small creeks and shallow aquifers presents an ecological health risk to aquatic life, wildlife, livestock, agriculture, and humans. North Willow Creek (NWC) in central Montana has been identified by Montana Department of Environmental Quality (DEQ) to be impaired for aquatic life and irrigation by salinity (e.g. 29,000  $\mu\text{S}/\text{cm}$ ). The NWC watershed is host to multiple oil and gas fields. This study evaluated the source of salinity in NWC and its adjacent alluvial aquifer for the possibility of historic oil-production related salt contamination and salt sourced by natural processes. During Spring and Fall of 2023, field geochemical parameters were measured, and major ion and isotopic analyses were conducted on stream water from NWC, nearby Flatwillow Creek (FWC), and the Musselshell River. Associated shallow alluvial groundwater was sampled at each location along the reach of NWC and FWC. Additionally, precipitation samples were collected to develop a local meteoric waterline to assist in analysis of the relative dating of the study waters. The results were compared to historical water quality in the deeper Tertiary through Cretaceous aquifers and in the Pennsylvanian and Mississippian petroleum-associated aquifers within the study area. Findings reveal that NWC surface waters and groundwaters are predominately sodium-magnesium-sulfate-type waters of modern origin, while the deeper bedrock aquifers are sodium-sulfate-carbonate-chloride dominated.  $\delta^{34}\text{S}-\text{SO}_{4(\text{aq})}$  and  $\delta^{18}\text{O}-\text{SO}_4$  in NWC and the shallow groundwater system are much lighter than those typically observed in bedrock samples, suggesting minimal bedrock contributions to the stream. A linear relationship between  $\delta^{18}\text{O}$  and  $\delta^{34}\text{S}$  in surface and groundwater suggests primarily reduced sulfur oxidation and is consistent with ORP and  $\text{HCO}_3^-$  measurements. Finally, LMWL analysis of the NWC groundwater and surface water date the water as modern, directly related to recent climatic events. The study demonstrates that the source of elevated salts of NWC and its aquifer is a result of natural processes of evapoconcentration and dissolution of soluble salts in the shales and sandstones. The stream salinity is exacerbated by the use of stock dams and ponds installed along an intermittent NWC, preventing the efficient flushing of salts out of the NWC watershed.

# **Application of Surrogate Technology to Predict Near-Real-Time Metal Concentrations and Loads in the Upper Clark Fork and Select Tributaries**

By Lindsey R. King, Christopher A. Ellison, and Gregory D. Clark

U.S. Geological Survey, WY-MT Water Science Center, Helena, MT

This presentation describes current data collection activities in the U.S. Geological Survey (USGS) Clark Fork Long-Term Monitoring program, which has been ongoing since 1985 following nearly a century of extensive mining, milling, and smelting of copper, gold, silver, and lead ores in the Silver Bow Creek and Warm Springs Creek drainages of the upper Clark Fork Basin in western Montana. Over time, mine and smelter tailings have eroded, mixed with stream sediment, and been transported downstream and deposited in stream channels and on floodplains. USGS is evaluating how continuous data from six USGS monitoring stations measuring streamflow, water temperature, specific conductance, and turbidity relate to laboratory measurements of total and dissolved metal concentrations. Using the statistical relation between turbidity and total metals and the relation between specific conductance and dissolved metals facilitates the use of water-quality sensor data to estimate total and dissolved metal concentrations continuous. Continuous estimates of total and dissolved metal concentrations can offer great insight into the fate and transport of metals through the system than the six to eight discrete samples collected each year. A statistical relation developed for each metal could also allow identification of periods of elevated metal concentrations, thereby improving the timing and efficiency of sampling efforts. Developing and using these relations could enable near-real-time estimation of total and dissolved metal concentrations and loads providing high-resolution spatial and temporal data that more accurately describes instream conditions, which can be related to aquatic-life standards. Preliminary models relating turbidity to total metal

concentrations are examined, along with their limitations. Potential opportunities for further analysis, particularly for predicting dissolved metal concentrations from continuous specific conductance data are an objective for future analyses. Overall, this work can improve understanding of the toxicity of trace elements at high temporal frequency from historic mine tailings that has driven a coordinated effort by State, Federal, and private entities to characterize the water quality and effect on the aquatic resources in the Clark Fork Basin.

## Time-Traveling Plant Sweat: The search for more accurate ET estimates

Hannah Haugen, MT DNRC

The Montana DNRC currently uses the Blaney-Criddle method with legacy climate databases and county-wide agricultural statistics to estimate evapotranspiration (ET) values. While useful in situations with limited information, the technique is imprecise and unlikely to give an accurate estimate of ET at the field scale. Today, we have access to an abundance of relevant information to improve our ET estimates, especially satellite remote sensing data that gives us a record of the actual state of a crop through time. However, data alone cannot solve all issues with ET estimation. For example, DNRC responsibilities include estimating ET pre-1973, long before high-quality satellite data was available. Models using satellite data to learn how a field responds to meteorological inputs can help bridge the gap between historical time periods and today's data availability. This talk presents OpenET data as a modern source of ET estimates, compares OpenET estimates to results from the existing DNRC methodology, and introduces the Soil Water Inverse Modeling (SWIM) project as an important tool for the application of modern data to historical ET estimation problems.

## Investigating patterns of nitrogen and phosphorous on the Gallatin River near Big Sky: Implications for algae patterns and water quality modeling

Christy Meredith, Gabrielle Metzner, Troy Clift, and Torie Haraldson

DEQ is investigating drivers of algae growth on the Gallatin River near Big Sky, Montana. Extensive nutrient and algae data collection occurred from 2023 to 2025. Sampling is focused on 1) understanding temporal and spatial (i.e., longitudinal) patterns of nitrogen and phosphorus (N and P), and 2) quantifying algal biomass and algal diversity. Results indicate that the spatial distribution of total P and total N is highly correlated with amount of suspended sediment and increased during spring and summer storm events. Some of the highest values were observed in the section directly upstream of the confluence with the West Fork Gallatin River tributary. Bioavailable P (soluble reactive phosphorous-SRP) and bioavailable N (nitrate) also increased in response to storm events. However, across seasons, spatial pattern of SRP most correlated with proximity to the P-rich geology of tributary drainages. SRP values ranged from 2 to 9 ug P/L during summer baseflow conditions. Nitrate concentrations showed little discernable pattern during summer base flow owing to most sites having values below the detection limit of 5 ug N/L. However, night and winter sampling revealed an increase downstream of the West Fork (up to 36 ug N/L at night and 80 ug N/L during winter) due to contributions from the West Fork and an area of groundwater upwelling at the start of the canyon near the West Fork confluence. These sources increase the flow in the Gallatin River by 14% and 50%, respectively. During summer low flow periods, the dominant species and biomass of algae changed along the longitudinal gradient in response to these nutrient dynamics. Total algae biomass and prevalence of *Cladophora* was highest within the portion three miles downstream of the West Fork, where nitrate concentrations were also highest. However, the extensive long-stranded *Cladophora* blooms observed in previous years (e.g., 2018, 2019) did not occur during the study. These data may serve as a baseline for understanding future trends and will inform a modeling effort to explore how nutrients and environmental factors affect the Gallatin's algae patterns.

Paleolimnological records provide no evidence of long-term eutrophication of three lakes in Glacier National Park (Northern Rocky Mountains) despite ongoing environmental changes

Brooke G. Bain-White, Ashley P. Ballantyne, Cale A.C. Gushulak, Peter R. Leavitt, James J. Elser

Enrichment of remote mountain lakes with growth-limiting nutrients by way of climate change, atmospheric deposition, and watershed disturbances has the potential to increase primary production and algal biomass and alter the relative and absolute abundances of phytoplankton groups. Through paleolimnological investigations, we sought to identify periods and causes of nutrient enrichment and their effects on algal abundance and community composition in three lakes in the Northern Rocky Mountains within the boundary of Glacier National Park (Montana, USA). We collected sediment cores from Lake McDonald (42-cm), Saint Mary Lake (61-cm), and Bowman Lake (20-cm) that were dated using  $^{210}\text{Pb}$  and  $^{137}\text{Cs}$  radioisotopes and analyzed for carbon, nitrogen, phosphorus, metals, and algal and cyanobacterial pigment concentrations. We found regional signals of nitrogen and phosphorus enrichment, but no evidence of contemporary increases in total algal abundance, inferred based on concentration of pheophytin a, a marker of total lake production, in any of these lakes. Watershed disturbances punctuate these chronologies and are identifiable in the chemical records.

# Peak Streamflow Trends in Montana Associated with Hydroclimatic Variability with Applications for Determining Future Flood Risk

By: Nancy A. Barth<sup>1</sup>, Monica Conlin<sup>2</sup>, and Douglas Brugger<sup>2</sup>

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

<sup>2</sup> Montana Department of Natural Resources and Conservation, Helena, Montana

A multi-phase Transportation Pooled Fund study led by the U.S. Geological Survey (USGS) is currently underway to evaluate potential changes (nonstationarity) in annual peak-flows in the north-central United States caused by hydroclimatic variability among four discrete trend periods through water year 2020. In Montana, the peak-flow nonstationarities detected in the 50- and 75-year trend periods are mostly downward, in association with mostly upward monotonic trends in temperature and the ratio of potential evapotranspiration to precipitation. Peak-flow change points also are predominantly downward and concentrated in the 1970s and 1980s, which indicates important consistency among the longer trend periods (50-, 75-, and 100-years). For the 100-year trend period, some likely upward monotonic trends were detected among streamgages in mountainous regions and more commonly in the mountainous headwaters of the Missouri and Yellowstone Rivers. Conversely, downward trends were detected among streamgages in the lower Yellowstone River Basin. Furthermore, decreases in the annual center of volume duration (COVDUR) were detected among streamgages with upward peak-flow trends in the Missouri and Yellowstone River Basins, which could indicate that the snowmelt runoff period is compressing in those mountainous headwaters. Conversely, COVDUR increased

for those streamgages with decreasing peak-flow trends, which could indicate an expanding snowmelt runoff period for those streamgages in the lower Yellowstone River Basin.

Regulatory floodplain mapping assumes stationarity in peak flows. However, managing flood risk in the face of climate trends is extremely complex and requires flexible and adaptive approaches that take nonstationarity into account. The Montana Department of Natural Resources and Conservation will use the results of this USGS study to map potential increases in flood risk for communities with increasing peak flows. This presentation will include an overview of non-regulatory flood risk products that can account for nonstationarity in identifying flood risk.

## MT AWRA Meeting - Abstract

CSKT Bison Range: Interactions Between the Jocko River and Adjacent Shallow Aquifer Prior to Channel-Floodplain Restoration. Adam Johnson, Brian Hogenson, Tabitha Espinoza

### Draft Abstract

For several decades, the Confederated Salish and Kootenai Tribes (CSKT) have worked to restore the floodplain and channel of the Jocko River on the Flathead Indian Reservation. A river reach along the CSKT Bison Range was historically leveed and channelized to accommodate agricultural development. These activities resulted in channel incision, floodplain disconnection, reduced complexity of aquatic habitat conditions, and water table declines. Currently, the Tribes are re-naturalizing a 2.5-mile portion of the river channel and floodplain. New channel locations within historical meander sequences, and increased channel complexity, will provide fisheries benefits and wildlife habitat enhancements. The Tribes developed a floodplain groundwater monitoring network to help characterize baseline hydrologic conditions prior to the restoration and to allow for comparisons with post-restoration conditions. The network consists of 13 purpose-built monitoring wells and several unused domestic wells that were located in the area. The majority of wells have been surveyed and instrumented with datalogging pressure transducers. An unconfined shallow aquifer is present within 10 feet of the floodplain surface. Deeper aquifer sediments are under confined conditions as evidenced by flowing artesian wells on and near the floodplain. Preliminary mapping shows that shallow groundwater flow is generally parallel to the river, and that surface water likely recharges the floodplain aquifer. Groundwater levels exhibit varying degrees of seasonal fluctuations due to changes in stream flows and associated groundwater recharge. Water levels in monitoring wells respond to changes in river discharge, and patterns of water level change vary based on well location. Findings indicate a moderate to high degree of hydraulic communication between the river and the shallow aquifer. The overall pattern of shallow groundwater temperatures consists of highs from July to September and lows in February and March. This pattern is generally consistent with variations in air and surface water temperatures. Observed aquifer temperature fluctuations point toward streamflow losses (groundwater recharge) throughout the study reach. These results are consistent with the water table map. The degree to which river temperatures affect groundwater temperatures is under investigation. Although the seasonal temperature pattern holds for most wells (highs in summer and lows in winter), the timing and magnitude of temperature fluctuations varies across the floodplain. Preliminary analysis of temperature patterns suggests variable groundwater flow path lengths and influences from multiple flow paths at a given location. Following restoration, the CSKT anticipate alterations in river interactions with the floodplain aquifer, modified groundwater flow paths, shallower groundwater elevations, increased groundwater storage, and modified subsurface water temperatures. A more connected river-floodplain system will likely improve hyporheic zone functionality. CSKT staff will continue to monitor groundwater levels and temperatures during and after the channel-floodplain restoration. This information will facilitate comparisons of baseline and post-restoration hydrogeologic conditions, and will help guide restoration and revegetation efforts across the floodplain.

## Legacy and Prospect: Critical Mineral Insights from the Upper Clark Fork River

Johanna M. Blake, Michelle E. Fillion, Madison J. Foster, Travis S. Schmidt, Chloe J. Zampetti,

Identifying the locations and concentrations of critical mineral resources in the United States has become a national priority. One promising approach involves quantifying critical mineral concentrations in stream sediments and biofilms—microbial communities that accumulate on bed sediments—particularly in historically mined regions. The Upper Clark Fork River near Butte, Montana, offers a compelling case study due to its legacy of silver, gold, and copper mining, milling, and smelting. Despite extensive reclamation efforts, elevated concentrations of critical minerals persist in both stream sediments and biofilms throughout the Upper Clark Fork watershed. This study documents concentrations of critical minerals, including arsenic (12–122 mg/kg), copper (62–531 mg/kg), cadmium (0.74–5.99 mg/kg), and zinc (259–1,360 mg/kg), which are elevated in both sediment and biofilm samples in the Upper Clark Fork River. Rare earth elements (REEs) such as lanthanum (29.5–53.9 mg/kg), cerium (56.6–99.3 mg/kg), and yttrium (14.8–30.3 mg/kg) are notably higher in sediments upstream and downstream of a reclamation pond complex, but not immediately downstream—suggesting multiple, spatially distinct sources within the watershed. In some locations, sediment concentrations exceed EPA aquatic life benchmarks by up to 10 times, and light REEs exceed chondrite-normalized values by over 100 times. These findings indicate that stream sediments and biofilms may serve not only as environmental indicators but also as potential secondary resources, offering opportunities for cost recovery that could support ongoing restoration efforts. Geochemical data are presented spatially and analyzed using fingerprinting techniques to identify potential sources of critical minerals. Additionally, this watershed serves as a natural prototype for evaluating biofilm uptake of critical minerals, offering insights into their potential role in passive resource capture and environmental monitoring.

## MT AWRA 2025 – Presentation Abstract

### **Title: Understanding social learning in collaborative water resources research: A case study of the Upper Clark Fork Working Group**

Scholars recognize the existence of complex “wicked problems.” Collaborative approaches in water resource management, policy, and planning are suggested as best practices to address these problems. By engaging multiple groups, collaboration facilitates shared dialogue and connection between divergent interests. Collaborative models are also increasingly used within water resources research to better understand a topic and improve application of research; examples include interdisciplinary science and co-production.

An important process and outcome of collaborative partnerships is social learning. Through social learning, individuals build new relationships and understanding with each other, which in turn enhances a group’s social capital – defined as norms of trust and connectedness. Past research recognizes the power of social learning, with social capital, to support a group’s adaptive capacity and ability to sustain long-term partnerships. However, there is a lack of examination on if and how social learning emerges in water resources research collaboratives. Additionally, there have been few studies that look at the capacities and outcomes research collaboratives engender.

This study sought to understand if and how social learning emerges in the Upper Clark Fork Working Group (UCFWG), a collaborative research group focused on studying and addressing riverine metals contamination in Montana. This presentation will highlight the results of semi-structured interviews with participants of the UCFWG and other watershed actors. We will report on the following findings: 1) if and how social learning emerges in the UCFWG, 2) other collaborative processes, 3) the kinds of capacities built in the UCFWG, and 4) how these capacities support actionable research and long-term partnerships. Ultimately this study provides critical insight into how collaborative research builds capacity and resilience in the context of complex water resource challenges.

Scientists from the University of Montana's Flathead Lake Biological Station (FLBS) are working alongside Montana citizens through a program called Monitoring Montana Waters (MMW) to protect and sustain Montana's iconic waters. Montana's size and sheer number of waterbodies bring a significant challenge to collecting enough data to manage waters. MMW was created to increase the capacity for volunteer water quality monitoring in the state. MMW supports water quality monitoring efforts by providing scientific, technical, and financial support to citizen-led watershed 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, etc.). MMW offers assistance and consultation in designing monitoring plans, selecting analytes for analysis, and providing on-the-ground training in methodologies. MMW also provides funding to groups to cover the costs of sample analyses at the FLBS Freshwater Research Laboratory, and gear funding to assist with the cost of sampling gear. All data that is generated from funded groups must be uploaded to DEQ EQulS database, so it is publicly available for everyone to use. The program's 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.

Citizen-led Monitoring groups like Kootenai Watershed Allies (KWA) and Yaak Valley Forest Council (YVFC) are playing the crucial role of collecting water monitoring samples to help protect the water quality of the Kootenai River Watershed. The Kootenai River sub-basin is an international watershed that encompasses parts of British Columbia, Montana, and Idaho. It is one of the uppermost major tributaries of the Columbia River, the largest North American river that empties into the Pacific Ocean. Land use in Montana along the Kooconusa Reservoir and Kootenai River is predominantly forestry and agriculture with a history of mining in the area. The Kootenai River hosts some of the largest rainbow trout in the country and is also home to two rare native fish species: the white sturgeon and burbot. Unfortunately, Kootenai River habitat is at risk from a number of stressors, including upstream Selenium mining in British Columbia. Both groups have worked with MMW to design a river-specific monitoring program to help better understand the current conditions of the Kootenai River and its tributaries, to protect this precious resource for future generations. By sampling water bodies several times each year over an extended period, volunteers help develop comprehensive data sets that help reveal longer-term water quality trends. The MMW program provides everyday citizens with the training and resources needed for them to help protect their local rivers and sustain their unique fisheries, wildlife, and culture.

## Management of Boat Gas Constituents in Whitefish Lake: 20 Years Later

Cassie Roberts, Mike Koopal

Whitefish Lake Institute

BTEX (benzene, toluene, ethylbenzene, and xylene) are boat gas constituents that cause a variety of human health problems. They can be found in any water body with motorized boats. In 2005 Whitefish Lake Institute (WLI) conducted a study at three of the public swimming areas on Whitefish Lake. At one swimming area, City Beach, WLI found levels of BTEX indirectly related to the number of motorized watercrafts. It was theorized this was due to pulling the transom plug and draining bilge water onto the City Beach boat ramp and directly back into the lake. In 2005, to prevent further BTEX contamination, the City of Whitefish installed an interceptor trench in the boat ramp located next to the swimming area at City Beach. In the summers of 2024 and 2025 WLI replicated the original study to test if BTEX levels have increased with perceived increased boat traffic and to test the effectiveness of the interceptor trench. We collected water samples from four sites on Whitefish Lake on summer days with high boat traffic. Sample sites included a mid-lake reference site and three shoreline sites with high boat densities and swimming areas. During each sampling event, we recorded count and catalogued the type of boat. Additionally, using satellite imagery we conducted a count of the number of boats, docks, and slips on the shore of Whitefish Lake in 2005 compared to 2023 (the year with most recent satellite data). Study results indicate a large drop in BTEX levels at all four sites. The highest BTEX levels continued to be at the City Beach site. Satellite imagery showed a decrease in docks on Whitefish Lake from 2005 to 2023 but an increase in boats and boat slips. Overall, the study indicates that the interceptor trench along with other developments and regulations affecting boat motor efficiency have resulted in a decrease in BTEX levels in Whitefish Lake. This decrease persists despite an increase in boats on the lake.

## Water Protection in the Native world: A case study at Chief Plenty Coups State Park

Madisan Chavez, Margaret Eggers, Stephanie A. Ewing, John Doyle

Indigenous communities may suffer greater impacts from water contamination and scarcity than predominantly non-Native communities, for multiple reasons. A review of publications by Native water scientists and Indigenous communities working to address Tribal water issues illustrates common themes and challenges, and provides perspective on water issues and actions at Chief Plenty Coups Spring on the Crow (Apsaalooke) Reservation. For Tribes, water is not simply a physical “resource;” it is culturally significant to Indigenous people across the world. Their traditional connection to place and respect for the Earth strengthens ties. Hence, many indigenous communities link cultural and language revitalization with environmental restoration. At the same time, historical context and jurisdictional complexities are at play with water issues in Tribal communities, complicating restoration and environmental protection efforts. Tribes are in government-to-government relationships with federal, state and County governments, and also have their own Tribal political organizations, laws and courts. Land ownership may be a patchwork of Trust, fee and federal lands. In the face of these structural challenges, an environmental health literacy program can inform and motivate Tribal community members about local water issues. Growing awareness about water issues has resulted in a community of Indigenous water scientists and “water protectors” who are working to steward their Tribal waters. Many strive to incorporate both Indigenous ways of knowing and western science to protect tribal water resources. Coupled with the motivation of Indigenous identity and world view, western science approaches provide data that are powerful in guiding decisions and shaping policy and practices. In our work, the Crow Environmental Steering Committee (CEHSC) and collaborators from Montana State University (MSU) have been sampling Chief Plenty Coups Spring at Chief Plenty Coups State Park, along with upgradient wells and surface waters, since 2013. The spring waters, contaminated with *E. coli*, have also had high nitrate and chloride levels, suggesting septic system influence. Presentation and discussion of the data and their cultural context with the State Park, Montana Department of Environmental Quality and the Governor’s office raised awareness about the issue. CEHSC, MSU and State Park employees worked together to undertake basic maintenance and improve drainage of the septic system and associated sump pumps. This partnership, the commitment of the Crow Tribal members involved, and the acquisition and presentation of water quality data resulted in the State taking action to address the contamination of this culturally vital spring.

## Water Protection in the Native world: A case study at Chief Plenty Coups State Park

Madisan Chavez, Margaret Eggers, Stephanie A. Ewing, John Doyle

Indigenous communities may suffer greater impacts from water contamination and scarcity than predominantly non-Native communities, for multiple reasons. A review of publications by Native water scientists and Indigenous communities working to address Tribal water issues illustrates common themes and challenges, and provides perspective on water issues and actions at Chief Plenty Coups Spring on the Crow (Apsaalooke) Reservation. For Tribes, water is not simply a physical “resource;” it is culturally significant to Indigenous people across the world. Their traditional connection to place and respect for the Earth strengthens ties. Hence, many indigenous communities link cultural and language revitalization with environmental restoration. At the same time, historical context and jurisdictional complexities are at play with water issues in Tribal communities, complicating restoration and environmental protection efforts. Tribes are in government-to-government relationships with federal, state and County governments, and also have their own Tribal political organizations, laws and courts. Land ownership may be a patchwork of Trust, fee and federal lands. In the face of these structural challenges, an environmental health literacy program can inform and motivate Tribal community members about local water issues. Growing awareness about water issues has resulted in a community of Indigenous water scientists and “water protectors” who are working to steward their Tribal waters. Many strive to incorporate both Indigenous ways of knowing and western science to protect tribal water resources. Coupled with the motivation of Indigenous identity and world view, western science approaches provide data that are powerful in guiding decisions and shaping policy and practices. In our work, the Crow Environmental Steering Committee (CEHSC) and collaborators from Montana State University (MSU) have been sampling Chief Plenty Coups Spring at Chief Plenty Coups State Park, along with upgradient wells and surface waters, since 2013. The spring waters, contaminated with *E. coli*, have also had high nitrate and chloride levels, suggesting septic system influence. Presentation and discussion of the data and their cultural context with the State Park, Montana Department of Environmental Quality and the Governor’s office raised awareness about the issue. CEHSC, MSU and State Park employees worked together to undertake basic maintenance and improve drainage of the septic system and associated sump pumps. This partnership, the commitment of the Crow Tribal members involved, and the acquisition and presentation of water quality data resulted in the State taking action to address the contamination of this culturally vital spring.

For students to gain an understanding of ecosystems, they need to understand the individual biological, geochemical, and physical processes that determine the structure and function of ecosystems. Though this can be achieved solely through traditional in-class approaches, the concepts can fail to resonate due to a lack of experience of students in a wide variety of ecosystems. A time-tested complementary approach for giving students a deeper understanding of the subject matter can be accomplished through field trips, allowing students to see the ways that all the different components of ecosystems interact, and allowing a deeper appreciation of how these interactions ultimately influence the structure and function of ecosystems. Though nothing can quite replace a well curated field trip, virtual reality has the potential to allow students to visit a wider variety of ecosystems than is possible in a field trip by allowing students to travel virtually to ecosystems including headwater streams and large rivers, kelp forests, and deep-sea hydrothermal vents. Virtual reality can also allow for immersive learning to be accessible to students with limited mobility, or who may find even half-day field trips challenging due to work, family, sports, or military service obligations. To gain experience, we implemented virtual reality modules in an upper division ecosystem ecology class. In addition to accessibility and reach, immersive technologies like virtual reality can foster a sense of embodied presence and perspective taking, helping students more deeply connect with the complexity and scale of ecosystems. In this poster, we will highlight our implementation of virtual reality, including demonstrations. We will also cover challenges we have encountered, lessons learned, and future plans.

The Montana Pesticide Stewardship Partnership Program (MT PSPP), based at the Flathead Lake Biological Station, is a collaborative network working to reduce pesticide pollution in our waters, improve water quality, and promote engagement and education. This year, MT PSPP has implemented a surface water quality monitoring program to assess pesticide contamination across the Columbia River Basin portion of Montana. Site selection was guided by a spatial framework using ArcGIS and publicly available datasets, incorporating land use patterns, watershed vulnerability, and partner input to prioritize sampling in areas where pesticide use may pose risks to aquatic ecosystems.

Monitoring is an essential part of the MT PSPP program framework and represents a crucial step towards the goal of reducing pesticide pollution in Montana's waters. There is very little existing data on pesticide concentrations in Montana's rivers and streams. The development and implementation of a comprehensive monitoring plan will help inform everyone who lives, works, and recreates in the upper Columbia River Basin about how what we do on the land can impact our waters. Monitoring data will also help inform MT PSPP education and outreach efforts. Effective messaging can be tailored to different audience types based on the location of detections with the goals of broader public awareness, voluntary behavior change, and updated land management practices.

Monitoring sites fall into two categories: focal sites located at USGS and DNRC stream gauging stations, and baseline sites selected to reflect varying pesticide risk across agricultural, urban, forested, and discrete land uses. Procedures include surface water sampling, in situ measurements, and laboratory analysis for a suite of 103 pesticide compounds. Seasonal sampling captures variability in pesticide application and runoff, providing insight to contamination potential across land uses over time.

Over 400 water samples have been collected so far for pesticide analysis. Initial review of the data show detections of multiple pesticides (some include: aminopyralid, atrazine, bentazon, diuron, imazapic, imazapyr, MCPA, MCPP, prometon, and tebuthiuron). Data analysis is ongoing, and we look forward to sharing our results with all of our partners.

Our monitoring efforts will continue in upcoming sampling seasons through 2028. We are continuing to investigate sampling designs to best detect the presence of pesticides throughout the CRB region of Montana in future sampling years.

## Seasonal Groundwater Dynamics of Montana Aquifers

Dan Buckley

Long-term groundwater level data from the Montana Bureau of Mines and Geology's statewide monitoring network were analyzed to better understand and quantitatively describe different patterns of seasonal groundwater level dynamics seen in Montana aquifers. Standardized annual hydrographs were generated from the groundwater level data and were subsequently modeled using cubic B-splines. Model results were evaluated using functional data analysis, which involves applying an unsupervised clustering algorithm to the model coefficients in order to extract general trends that occur across models. Both K-means clustering and principal component analysis were applied to the model results. Three representative hydrographs were derived using the K-means method, and these hydrographs highlight patterns of (1) natural, snow-driven hydrology, (2) human-induced drawdown, and (3) human-modified recharge. The first and second patterns occur throughout Montana, but the third pattern generally only occurs in or around agricultural areas. In addition, two principal components were found which provide further context regarding the inflection of the hydrograph and the timing of hydrograph features, respectively. The first principal component is positive for the first and third patterns, where recharge is the dominant process, and negative for the second pattern due to the negative inflection caused by drawdown. The second principal component, on the other hand, is positive when the annual minimum and maximum water levels occur earlier in the year, which is the case for the first pattern, and negative or near-zero for later-occurring features observed in the second and third patterns. The second principal component trends from positive to negative in the direction of local groundwater flow. These results provide insight into the workings of Montana groundwater systems, and supplement and refine prior studies conducted at the national level.

## Title: Water Budget Analysis for a Rapidly Developing Headwaters Community

A water budget analysis was conducted for the West Fork Gallatin River watershed to enhance the Big Sky community's understanding of water availability in a changing climate and enable wise stewardship of water resources as population and visitation continues to grow. A water budget is a tool that quantifies where water comes from and where it goes within a watershed on an annual basis. This analysis was produced using a combination of climatic models, regional SNOTEL precipitation data, measured stream stage data, water use data, and assumptions based on norms from watersheds in similar climates. The analysis is considered an "open" water balance since inputs and outputs don't necessarily add up to 100% based on available data, highlighting gaps in data availability and annual and geographic variability. In this high elevation watershed, primary water inputs include precipitation in the form of snow and rain, with a snowmelt dominated spring runoff that shapes channel morphology and provides fresh surfaces for the growth of riparian vegetation. Water outputs include shallow groundwater infiltration that supports late-season baseflows, along with water that leaves the watershed through evaporation, sublimation and deep aquifer infiltration. This water budget characterizes seasonal and spatial trends in snow-water storage with applications for maintaining productive fisheries and enhance ecosystem resiliency in the face of lower and warmer late-season flows. Management recommendations include expanded monitoring networks and restoration actions that maximize precipitation capture and slow the flow of water through the system, along with development practices that mimic natural processes to infiltrate water and reuse actions to cycle water back into the hydrologic system.

## Enhanced Ground Water Monitoring in the Big Sky Meadow Village

Mike Richter, Alex Johanson

MBMG Ground Water Assessment Program

The Meadow Village Aquifer (MVA) in Big Sky, Montana is highly productive, unconfined, and supplies the Big Sky Water and Sewer District PWS wells in the Meadow Village. This aquifer is connected to surface water and is vulnerable to contamination. Nitrate values greater than 5 mg/l have been observed in periodic sampling results. The Montana Bureau of Mines and Geology (MBMG) Long-Term Ground Water Monitoring has monitored the MVA since 2008 with wells instrumented for hourly water level and temperature measurements, and periodically sampling in collaboration with the Gallatin Local Water Quality District. In 2023 and 2024, the seven long-term MVA monitoring wells were instrumented to report specific conductance (SC) in addition to water level and temperature. In 2025, two additional wells in the Upper Gallatin Corridor were also instrumented for SC. Specific Conductance is an indirect measure of the total dissolved solids (TDS). Preliminary results show SC varies across the monitored part of the aquifer by as much as 1,000  $\mu\text{S}/\text{cm}$  and individual wells fluctuated seasonally up to 400  $\mu\text{S}/\text{cm}$  at 25 °C. These enhancements to the continuous data collection will give insights into sources and timing of recharge and contamination to these important aquifers.

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## **American Water Resources Association – Montana Conference 2025**

**Authors:** Madison Foster, Johanna Blake, Travis Schmidt, Meryl Storb, Nathan Cook

**Title:** Where are the fish? Evolving metal-related risks and sources in the Clark Fork River

**Word limit:** 350 words (currently 318)

### **Abstract:**

A legacy of hard rock mining has historically impaired the ecological health of the upper Clark Fork Basin (Montana, USA). Since the Superfund designation in the 1980s, large stretches of the upper Clark Fork River and its tributaries have been restored, leading to improvements in water quality and fish populations. However, in the last decade, nearly all three-year-old or younger brown trout have been absent from the most upstream reach of the Clark Fork River, from below Warm Springs to Galen. To better understand metal-related risks to aquatic life, we evaluated metal(loid) (arsenic, cadmium, copper, lead, zinc) concentrations and loads. Assessments looked across four sites in the upper Clark Fork Basin with varying degrees of restoration, exposure to active and historical mine wastes, and fish population histories. Flow-normalized trends in metal concentrations and loads were estimated using the Weighted Regressions on Time, Discharge, and Season model. Annual average concentrations of most metal(loid)s have declined over nearly 30 years, with the largest declines at restored sites and smallest declines at unrestored sites. For example, from 1997 to 2024, total copper concentrations declined by 91% at Silver Bow at Opportunity (restored) yet only 16% at Clark Fork at Deer Lodge (unrestored). Despite declines in metal(loid) concentrations, all sites still commonly exceed chronic water quality criteria that are protective of aquatic life. Concentration-discharge analysis and differences in loads among sites suggest that restoration is effective at reducing the source of copper available for transport to the river. However, upstream improvements due to restoration are not translated to downstream unrestored sites because the restored sites contributed only 12% of the total copper load at the most downstream site (Clark Fork at Deer Lodge) between 2019 and 2024. These results suggest arsenic, cadmium, copper, lead, and zinc concentrations may not be related to the decline in fish populations, but are a persistent stressor to aquatic life, especially in reaches that have yet to be restored.

Key words: metals, mining, water quality, toxicity, restoration

## Estimating Intermediate-Scale Groundwater Net Exchange Using Synoptic Environmental Tracer Sampling

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Here, we explore techniques to estimate net groundwater exchange over scales of 10-100km using multiple environmental tracers and differential stream discharge. Estimating integrated stream loss to the subsurface over long reaches is challenging. Current measurement methods are limited in scale largely point-based, are limited to injected tracers, hydraulic gradient and/or temperature profile time series. These methods are difficult to upscale, especially in large streams where large volumes of applied tracers would be required. Synoptic sampling for environmental tracers has been used successfully in the past for detecting and quantifying groundwater discharge (gain) to streams over 1-100 km length scales across a variety of settings globally. Stream water loss in isolation does not affect the concentration of tracers in the stream, making tracer-based methods more sensitive to groundwater discharge. Thus, non-applied, tracer-based methods have traditionally only been used to quantify groundwater gain and not loss. However, stream loss is a fundamental term in the stream water mass balance which is coupled to the tracer mass balance, thus coupled tracer and discharge measurements can be used to measure gain, loss and net exchange. Here we model stream transport with the coupled transport and stream mass balance equations, which include groundwater loss, to explore the effect of stream loss on tracer concentration. We discuss the theory, quantify the sensitivity of tracer signals to stream loss and identify conditions where stream loss can be estimated by tracers. Finally, we apply this method to field data, to estimate integrated loss, gain and net exchange in the upper Clark Fork River along the Deer Lodge Valley. Improved methods to quantify integrated loss and net exchange over larger spatial scales would improve both stream and groundwater budgets, as well as knowledge of the interaction between stream and alluvial groundwater systems.

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The Montana Bureau of Mines and Geology (MBMG) Groundwater Investigation Program (GWIP) is evaluating the potential for managed aquifer recharge (MAR) to mitigate low, late-summer stream flows in the Big Hole River Valley near Wisdom, MT. The Big Hole Drought Management Plan identifies minimum conservation flows of 20 cfs as the late-summer target at the Wisdom USGS gage; between 2015 and 2024 late-season flows were below the 20 cfs target for a median of 17 days per year. In 2025 the flow dropped below 2 cfs. The objective of this study is to assess the potential of using MAR to store water when physically available in the spring, and releasing it during low flows. The two MAR methods under evaluation are surface infiltration and aquifer storage and recovery (ASR). Surface infiltration techniques typically include running water through leaky canals, percolation basins, or across fields to enhance infiltration and recharge shallow unconfined aquifers. ASR uses wells to inject and extract water in semiconfined to confined aquifers.

Areas for potential surface infiltration will be evaluated using a GIS-based multi-criteria decision analysis (MCDA). This will include evaluating the same criteria as used in the statewide analysis (Hanson and others, 2024), but with more refined local data, such as 1:100,000 scale geologic maps, LiDAR elevation data, and site-specific potentiometric mapping. Additionally, we will enhance the analysis by looking at site specific factors, such as the locations of irrigation canals and irrigated fields and by assessing the timing of return flows to the Big Hole River.

To evaluate ASR, we installed three 500-foot exploratory wells that showed deep (> 350 ft) confined sand aquifers. Short duration (~2 hr) pumping tests were conducted to estimate transmissivity and specific capacity. The wells were sampled for major ions, trace metals, and water isotopes. Handheld x-ray fluorescence (XRF) measurements of the drill cuttings were used to identify zones of geochemical interest, and lab-scale leaching tests were conducted on these zones. A production well and a shallow monitoring well will be installed at the most promising site for a future 72-hour constant rate aquifer test. Results will be used to develop a groundwater model to further assess ASR potential at this site.

To characterize the quality and quantity of potential recharge water, monthly samples are being collected at ten surface water sites; most of the sites are paired with DNRC gaging stations. Sixteen wells are being monitored monthly to evaluate seasonal groundwater-level fluctuations and to obtain groundwater quality data. The water-quality data along with geochemical analysis of aquifer materials will be used to evaluate chemical issues that may result from MAR.

# Implementing New Data and Methods to Keep Montana Well-Educated

Hendrick Moore, Adam Sigler, Nick Kiekover, Gabrielle Jawer,

A significant portion of Montana's population gets their water through private wells. Private wells are not regulated by the EPA; thus, it becomes the well owner's responsibility to ensure their water is safe for use. Over the last two decades, the MSU Extension Well-Educated program has sought to provide Montana's private well owners with reliable water quality testing and educational resources.

Over 10,000 participants have worked with the program in the last twenty years and 93% of survey respondents indicated that the program materials made it easy to understand their water quality. Additionally, the Well-Educated program has produced a wealth of groundwater quality data since its inception in 2005 and has sought to improve public access to a summary of those results.

In 2025, we made great strides summarizing Well Educated data for public use in addition to including data summaries from Montana Bureau of Mines and Geology, Groundwater Information Center (GWIC). On the Well Educated website, program data and GWIC data are summarized by county and watershed. Results are presented in the context of human health standards set by the EPA for public water supplies and also relative to more conservatively protective human health thresholds.

New data summaries also present results as cumulative human health risk, following methodology published by Eggers et al. in February of 2025. These data show that when conservatively health protective thresholds are applied, 75% of watersheds had cumulative risk values greater than 1.0 based on median concentrations of 19 inorganic contaminants. The Well-Educated team is also piloting new public engagement approaches using testing clinics and exploring analysis of samples on MSU campus.

## **Soil Moisture-Driven Irrigation Scheduling to Reduce Pesticide Leaching in Semi-Arid Agricultural Systems.**

Authors: Hezekiah Afolabi, Dr. Adam Sigler, Dr. Clain Jones, and Dr. Tim Seipel.

In Montana, farmers depend on pesticides to protect valuable crops like wheat, barley, and specialty vegetables from pests, diseases, and weeds that can severely impact yield and quality. However, once applied to plants or soil, pesticides are subject to various environmental fates, including leaching to groundwater. In semi-arid agricultural regions like Montana, irrigation across 1.0 million hectares accounts for 97% of consumptive water. The intersection of intensive pesticide application and water management creates critical opportunities for groundwater protection through precision irrigation scheduling. This research investigates how soil moisture-driven irrigation scheduling can minimize pesticide leaching while maintaining agricultural productivity.

We hypothesize that maintaining soil water content at, or below, field capacity through precision irrigation scheduling reduces drainage under gravity and associated pesticide transport to deeper soil layers and groundwater. Our study utilizes a monitoring network at the Montana State University Northwest Agricultural Research Center in Creston, featuring four instrumented sites with lysimeters at 30 cm (12 inches) and 60 cm (24 inches) depths and soil water sensors at 15, 30, 60, and 90 cm (6, 12, 24 and 36 inches) depths. HYDRUS-1D, a mechanistic model that solves Richard's equation to simulate water movement through unsaturated porous media. The model enables quantification of deep percolation rates under various irrigation scenarios through integration with field observations, providing mechanistic understanding of soil-water-pesticide interactions.

Two years of monitoring at Creston (2024-2025) suggests that pesticide transport remains largely confined to the upper 30 cm of the soil profile. In 2024, twelve different pesticides and metabolites were detected at 30- cm depth, including compounds from applications five years prior, while no pesticides were found in the 60- cm lysimeter samples. The 2025 results had similar patterns, with four pesticides or their metabolites detected at 30 cm, including pesticides applied four- year previously, while recently applied pesticides were not detected. Importantly, soil water content at 90- cm depth did not respond to irrigation events, indicating minimal deep-water penetration under current management practices. However, over-winter wetting does occur to 90 cm depth, indicating leaching risk outside the irrigation season.

This research demonstrates that strategic irrigation scheduling based on soil moisture monitoring has potential to effectively contain pesticides within the biologically active root zone where natural degradation and plant uptake processes occur. Our preliminary results support our hypothesis that maintaining soil water contents below field capacity during the irrigation season can control vertical water movement and pesticide transport, optimizing both water-use efficiency and environmental protection. These findings help address the critical need for sustainable agricultural practices in water-limited regions.

The Madison Stream Team (administered by the Madison Conservation District) performs biweekly stream monitoring of Jack Creek and other Madison River tributaries, but these discrete site-visits do not capture the nuanced dynamics of parameters which exhibit daily cycles. Dissolved oxygen (DO) concentration is one such parameter. This key indicator of water quality strongly varies between day and night because it is highly impacted by variation in temperature (affecting DO solubility) and ecosystem metabolism (photosynthesis and respiration). Capturing daily minimum DO concentrations is critical for ensuring the wellbeing of fish and macroinvertebrates, and the magnitude of the daily swings in DO concentration provides insights into the rates of stream metabolism, including gross primary productivity and aerobic ecosystem respiration.

To capture the daily behavior of DO concentration in Jack Creek, we deployed six miniDOT sensors (Precision Measurement Engineering) logging at 30-minute intervals between July 10th, 2025, and Oct 3rd, 2025. Sensors were deployed in two stream reaches (Lower Jack Creek and Upper Jack Creek), monitoring two different habitat types (pool and riffle) in each reach. The lower reach is located in the Madison River valley at an elevation of 1487 m above mean sea level (AMSL), where land use intensity and nitrogen concentrations are higher. The upper reach is located in the Madison Range at an elevation of 1931 m AMSL, just down gradient of the Moonlight Ski Area, with lower nitrogen concentrations. Data from two pools and one riffle were collected in Lower Jack Creek, and data from one pool and one riffle were collected from Upper Jack Creek. A sixth sensor was rotated between sites for quality assurance.

Preliminary results indicate that the pools at Lower Jack Creek experience a greater DO delta (median 2.58 mg/L) and lower daily minimum DO concentration (median 6.85 mg/L) than values for the other three sites (lower riffle and both upstream habitat types) where median DO delta was 1.28 mg/L and minimum daily DO was 7.34 mg/L. In addition, these lower pools observe a peak in DO shortly after noon and minimums around midnight, while all other sites demonstrate a peak in DO around 8-9 am MT and minimums around 4-5 pm MT. The DO cycles of downstream pools closely mirror photosynthetically active radiation (PAR), while other sites' cycles more closely align with an inverse temperature relationship, indicating control by DO solubility.

Our data provides initial insights about DO behavior along Jack Creek to facilitate exploration of controls on DO based on habitat type versus nutrient and associated metabolism dynamics. Further, these instrument deployment trials are an opportunity to engage volunteers and educate community members about the nuances of water quality monitoring and the invisible ways the stream chemistry can dramatically change over a given day.

Jeremy Wood, Gallatin River Task Force. Tracking long-term changes in nutrient levels in Big Sky

The Gallatin River Task Force (GRTF) has been collecting water quality data in the Upper Gallatin River and its tributaries since 2000 to track long term changes. Over this time, the Upper Gallatin River has been under pressure from conditions associated with climate change and an increase in residential and visitor populations. In 2018, the first large-scale nuisance algae bloom occurred on the Upper Gallatin River, from roughly Portal Creek to Yellowstone National Park, raising questions about what may be driving its growth. Drivers of algae growth include:

- 1.) Water flowing at 0.4-0.7 m/s
- 2.) Clear water that allows sunlight to reach the streambed
- 3.) Sunlight to allow for photosynthesis
- 4.) Higher nitrogen and/or phosphorus levels
- 5.) Water temperatures between 10 and 25 degrees Celsius
- 6.) pH levels greater than 7.0
- 7.) Water that is high in minerals such as calcium and magnesium (MT DEQ, 2019)

Comparison of nitrate and phosphorus levels over time was completed to see if significant changes have occurred and if these changes are influencing algae growth.

Brett Oliver

Montana Bureau of Mines and Geology

09/15/2025

Title: Combining NHDPlus HR and Lidar for Improved Streambed Elevation Estimates in Agricultural, Suburban, and Urban Areas

Residential development is increasing demand from the Billings alluvial aquifer system, and the change from flood-irrigated agricultural to residential land use is potentially reducing groundwater recharge. The Billings aquifer system spans a series of terraces that are generally in contact with the Yellowstone River and Canyon Creek and is transected by a dense network of irrigation supply canals and drainage ditches. The aquifer system includes coarse-grained sand and gravel deposits that have an average thickness of 15 feet and are underlain by low-permeability Colorado Group shale. The aquifer system in the study area is recharged by excess irrigation, canal leakage, groundwater inflow along the western and northern study area boundaries, and precipitation. Groundwater is discharged from the aquifers to wetland and riparian evapotranspiration, consumptive well use, and surface-water streams and drainage ditches. Appropriate quantification of groundwater flow into and out of the Billings alluvial aquifer system is critical to simulating this system to better understand the potential impacts of land-use changes to groundwater resources. Surface water features like canals and streams are particularly important to the water balance of this system as both recharge and discharge sources.

Quantifying canal and streambed leakage pose challenges to estimating groundwater flow into and out of the Billings aquifer system. Inaccurate locations and elevations of streams, canals, and ditches in the National Hydrography Dataset High Resolution data (NHDPlus HR) are particularly problematic, leading to unrealistic flows and groundwater levels in numerical groundwater models. High-resolution elevational data products like lidar are useful for overcoming inaccuracies in NHDPlus HR data; however, anthropogenic structures like bridges and culverts impede autonomous processing of continuous surface-water flow paths with channel network delineation algorithms. To overcome these challenges, we developed a method that integrates both the NHDPlus HR data and high-resolution elevational data to more accurately determine the elevations of streams, canals, and ditches in the Billings study area, which lead to improved simulation of groundwater-surface water interaction. We present this method as a case-study, applicable to other areas where NHDPlus HR and high-resolution elevational data are available.

## Hydrogeochemistry of Natural Acid Rock Drainage in the Tobacco Root Mountains, Montana

Josie Grigsby, Chris Gammons, Glenn Shaw

We are currently investigating the hydrogeochemistry of the East Fork of the South Boulder River (EFSBR) in the northern Tobacco Root Mountains, Madison County, Montana. The upper 5 km of the main stem of the EFSBR is acidic ( $\text{pH} < 5.5$ ) despite the fact that no mining has taken place in the area, a phenomenon referred to as Natural Acid Rock Drainage (NARD). Dissolved concentrations of several trace metals, including Al, Cd, Cu, and Zn, are highly elevated, and exceed chronic aquatic life standards by 2-3 orders of magnitude. Unsurprisingly, the EFSBR appears to be devoid of trout. High mountains (up to 10,500') bounding the valley harbor a number of small rock glaciers and other periglacial features that influence the hydrogeology and chemistry of the watershed. Seasonal melting of buried ice provides a steady flow of cold water in the hot summer months, during the same time period that neighboring drainages are drying up. Additionally, rock glacier meltwater has higher concentrations of dissolved constituents due to the grinding action of the ice that creates fresh mineral surface area, and thus an enhanced rate of chemical weathering. In the EFSBR, headwater springs are both cold ( $T < 4^\circ\text{C}$ ) due to buried ice, and acidic ( $\text{pH} < 5.5$ ) from the presence of pyrite in hydrothermally altered (but unmined) granite bedrock. Preliminary data shows that the rock glacier meltwater is enriched in  $^{18}\text{O}$  compared to other tributaries within the catchment. This is likely due to the freeze-thaw cycles occurring in the subsurface. Neutralization of the acidic water by alkaline tributaries results in the precipitation of aluminum hydroxysulfate (basaluminite), which covers the streambed with a vivid white mineral coating. Although the EFSBR has a smaller drainage area than the nearby West Fork (WFSBR), the streamflow of the EFSBR exceeds that of the WFSBR in late summer, due in part to the effects of rock glacier meltwater in the EFSBR. Solute loads are nearly twice as high in the EFSBR, with a much higher predominance of sulfate in the anion charge balance. Pristine catchments exhibiting NARD can serve as a reference for establishing baseline water quality conditions for restoration in areas impacted by mining or other anthropogenic disturbances, where historical data does not exist.

Understanding patterns in pesticide detection across a non-irrigated agricultural landscape

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Pesticide and fertilizer applications are commonly used in modern agriculture and increase yields and grain quality. Pesticide applications also provide essential weed control, especially in no-till systems. However, these applications can present a risk to human health when leached from soil into groundwater. After passage of the 1989 Montana Agricultural Chemical Groundwater Protection Act, long-term groundwater monitoring of pesticides and fertilizers has been conducted across the state by the Montana Department of Agriculture Groundwater Protection Program (MDA GWPP). In this study, we focus on a terrace landform managed for non-irrigated crop production within the Judith River Watershed (JRW) of central Montana. A monitoring well located on the terrace has been annually sampled for nitrate since 1994 and pesticides since 2000 by the MDA GWPP. This monitoring has demonstrated elevated and rising nitrate concentrations (now ~20-30 mg nitrate-N L<sup>-1</sup>, above the 10 mg nitrate-N L<sup>-1</sup> drinking water standard), and an evolving suite of pesticide detections with concentrations below drinking water standards. Previous work has demonstrated high nitrate leaching risk from thin soils to a shallow, perched aquifer, and subsequent decreases in nitrate with upland groundwater passage through riparian corridors that drain the terrace. However, pesticide movement and transformation are not as well characterized at these sites. With this work, we evaluate how pesticide sorption to soil and aquifer materials delays transport and facilitates degradation between terrace soil application and drainage from riparian corridors, resulting in lower concentrations and delayed detections in riparian groundwater and stream water. We assess pesticide movement and transformation in this environment using MDA GWPP monitoring data, additional groundwater sampling of the terrace aquifer and riparian corridors, and laboratory experiments testing sorption to iron oxides and organic matter. We focus on the pesticides sulfosulfuron and pyrasulfotole, two herbicides that have been detected in the study area. These herbicides have different solubility, degradation, and sorption characteristics along with different usage histories with statewide estimates of sulfosulfuron usage since 1999 and pyrasulfotole usage since 2008. Patterns in pesticide detections indicate 11- to 16-year lag times between EPA registration and peak detection in groundwater, and 7- to 9-year lag times between peak application rates and peak concentrations. Experimental sorption coefficients indicate sorption to iron oxides is stronger and more likely under neutral to alkaline pH conditions, but sorption to soil organic matter enhances retention and is also expected to contribute to degradation. Using sorption coefficients inferred from laboratory experiments, simulated reactive pesticide transport under unsaturated and saturated flow conditions suggests transit times of months to years depending on the spatial distribution of application relative to

groundwater flow direction and the sampling location. Our integrated assessment demonstrates how pesticide detections in agricultural landscapes reflect the combined effects of application proximity to sampling locations, application history, and transport that is slowed by sorption to diverse media.

## AWRA Abstract

Title: Evaluating Soil Water Sensor Performance Across Soil Types

Authors: Kyla Schrauben, Adam Sigler, Meghan Robinson, Bridget Warrenfeltz, Anish Sapkota, Safal Adhikari

Sensor-based volumetric water content (VWC) measurements in soil can exhibit significant variability across different technologies, manufacturers, and models. Additionally, various factors, including soil texture, can impact readings. However, evidence-based comparative analysis on the performance of soil moisture sensors in Montana soils is lacking. Therefore, knowledge about sensor performance across soil textures is essential for leveraging these tools to optimize irrigation water use efficiency. In this study, we evaluated the performance of METER TEROS 12, HOBO Decagon 10HS, and ACCLIMA TDR-315H sensors in lab and field settings in three different soil textures (clay loam, silt loam, and sandy loam). As time allows, we also plan to evaluate the performance of some sensors commonly used by farmer collaborators, including CropX, Soil Tech, and Aqua Spy. METER TEROS 12, HOBO Decagon 10HS, CropX, Soil Tech, and Aqua Spy sensors use capacitance, while ACCLIMA sensors use time domain reflectometry (TDR). In the lab setting, the sphere of influence was initially measured for each sensor to inform lab testing configurations, with the largest being 10 cm for METER TEROS 12. This sphere of influence informed configurations for sensors in lab experiments to prevent external factors from affecting the data. Then, the VWC readings in air, water, dry soil, and saturated soil were measured in replicate across the three soil textures for each sensor. The VWC for saturated soil was also measured gravimetrically. In the field, METER TEROS 12 and ACCLIMA TDR-315H were installed in three different experimental fields where the lab soils were collected to collect field data for the same textures assessed in the lab. During the 2025 field season, pairs of sensors (1 METER and 1 ACCLIMA) were installed 20 cm below the soil surface, replicated three times at each field site. VWC results will be compared across sensor technology and model for the different soil textures and conditions and assessed relative to gravimetric VWC measured in the lab. By understanding the different VWC sensors, how they work, and the data they produce, users can make informed decisions on sensor selection based on their field environment. With this information, users can ensure proper sensor placement to obtain accurate and reliable data and can use the data to improve irrigation management and gain a better understanding of soil conditions.

## Comparative vulnerability of riverine benthic and aquifer stoneflies in large alluvial river floodplains

Floodplains of gravel-bed rivers occur throughout the globe and are hotspots of biodiversity, maintained in part by their connectivity in longitudinal, lateral, and vertical dimensions. At the surface, processes of cut-and-fill alluviation result in a shifting mosaic of aquatic and terrestrial habitats for species from microbes to grizzly bears. Below the surface, alluvial aquifers are vast and interconnected, supporting a unique community of both obligate and opportunistic fauna. Work on hyporheic zones and processes has traditionally focused on streams where the scale of surface and groundwater exchange is measured at the scale of cm-m. However, in systems like the Nyack floodplain in Montana, these processes occur at the scale of m-km, where aquifer discharge interacts with surface waters.

Over 50 years ago nymphs of the Plecoptera species, *Paraperla frontalis* (Plecoptera: Chloroperlidae), were shown to exist in a shallow floodplain aquifer of the Tobacco River, a gravel-bed river in western Montana and later they were documented throughout the main stems of the Flathead River system. Nymphs are almost never found in surface waters, until they emerge on the river shorelines. As teneral adults, they mate and subsequently deposit fertilized eggs into the river. This novel life cycle is termed "amphibitic." Over the years we and others have found *P. wilsoni* (Plecoptera: Chloroperlidae), *Kathroperla perdita* (Plecoptera: Kathroperlidae), and 5 species of *Isocapnia* (Plecoptera: Capniidae), occupying amphibitic niches in the alluvial aquifers of rivers in Washington, Idaho, Colorado, Alaska and British Columbia.

Living in alluvial aquifers, these stoneflies exhibit unique adaptations, including remarkable tolerance to hypoxia and anoxia. These adaptations allow them to exist as abundant consumers in aquifer food webs subsidized by ancient methane. However, living in alluvial aquifers, aquifer stoneflies are exposed to much more stable groundwater temperatures compared to benthic species in the river, and they may be more sensitive to warming temperatures. We predicted that benthic stoneflies would be less sensitive to warming temperatures because they are exposed to more variable river temperatures. We measured critical thermal maximum ( $CT_{MAX}$ ) and conducted intermittent respirometry experiments on nymphs of five benthic and three aquifer stonefly species to test their sensitivity to warming temperatures.  $CT_{MAX}$  values of benthic taxa were ~ 5 °C higher than those of aquifer taxa and varied among genera. In contrast, the thermal sensitivities of metabolic rates were surprisingly indistinguishable between benthic and aquifer taxa. During respirometry experiments benthic and aquifer taxa stopped moving (an indicator of stress) at similarly high temperatures and survived at similar rates. On average, however, benthic taxa had higher metabolic breadth than aquifer taxa (5.4 vs. 2.7), suggesting greater ability to sustain adequate metabolic rates in warmer temperatures. Together, differences in  $CT_{MAX}$  and metabolic breadth suggest that benthic stoneflies may tolerate warming temperatures better than aquifer species.

**Title:** Metal concentrations in streams vary with time since fire

**Authors:** Jacob McArtor, Rachel Malison, Benjamin P. Colman

**Abstract:**

Wildfires are natural disturbances, but they are increasing in frequency and severity in the western United States due to climate and land-use change. These events profoundly alter freshwater ecosystems by mobilizing nutrients, sediments, organic matter, and metals into streams and rivers. Though fire-driven changes in nutrients, sediments, and organic inputs have been widely studied, the mobilization of metals remains less understood. Metals released from burned vegetation and soils can elevate streamwater concentrations well above baseline levels, have the potential to persist for years through continued leaching, and can potentially have adverse effects on aquatic organisms that are sensitive to elevated metals concentrations. To better understand how metals may influence the structure and function of aquatic ecosystems, it is first necessary to characterize how metal concentrations change after wildfire, and how that signal persists over time. In this study, we sampled water from headwater streams at sites that varied in their time since fire with four replicate sites in each of five age categories: 0 – 1, 1 – 2, 2 – 5, 5 – 10, and 10 – 25 years since fire. We restricted our sites to control for edaphic and climatic variables, and then chose sites to minimize variability. The fires in the watersheds sampled were all of medium to high severity and burned an average of >90% of the watershed upstream of the sampling point. We analyzed filtered and unfiltered water samples for 57 elements using inductively coupled plasma mass spectrometry and found that there was a clear influence of time since fire on metal concentrations in streamwater, with some elements having concentrations sufficiently high to potentially be of concern for sensitive benthic macroinvertebrates, especially at younger sites. This work will be paired in the future with measurements of metals in benthic organic matter, periphyton, and macroinvertebrates, as well as macroinvertebrate community composition to examine the degree to which they may be shaping ecosystem structure within this timescale to help inform watershed management and post-fire recovery planning in Montana and across the western United States.

Title: Seasonal soil cracking and dynamic nitrate concentrations control deep percolation and leaching in an irrigated system

Authors: Meghan Robinson, Dr. W. Adam Sigler, Dr. Clain Jones, Dr. Kent McVay, Dr. Robert A. Payn

Abstract:

Effective soil water and nitrogen management are crucial for supporting profitable agricultural crop yields while minimizing environmental consequences from nitrate leaching. In irrigated systems, extended periods with high soil water content create prolonged opportunities for deep percolation that promote nitrate leaching. Through work with cooperating producers, we aim to understand the mechanisms controlling the spatial and temporal variability in deep percolation and nitrate leaching risk in irrigated soils. Research was conducted in a center pivot irrigated field cultivated with small grains near Fairfield, Montana. Nine monitoring sites were instrumented with soil water sensors at four depths (15, 30, 60, and 90 cm) and suction lysimeters at two depths (30 and 60 cm). Field data were collected during three growing seasons (2023 through 2025). We estimated deep percolation with Hydrus 1D using the dual permeability module to account for preferential flow. Leached nitrate was estimated by multiplying volumetric deep percolation rate predictions from Hydrus by nitrate concentrations measured with lysimeters. Modeling efforts suggested 2.6 to 5.2 cm of cumulative deep percolation in 2023, and 4.9 to 7.7 cm during the 2024 growing season. In 2023, we estimated that 0.5 to 2.8 kg ha<sup>-1</sup> of nitrate-N leached, a relatively low quantity reflecting that the highest observed nitrate concentrations coincided with a period of limited deep percolation following tillage and fertilizer application. In 2024, we estimated a much higher cumulative 4.6 to 18.0 kg ha<sup>-1</sup> of leached nitrate-N, which we attribute to the application of a slow-release fertilizer that sustained higher nitrate concentrations through periods of higher deep percolation. Modeling work for the 2025 season is forthcoming. Across years, the highest deep percolation risk occurred after the development of desiccation cracks at the soil surface, and nitrate leaching potential varied based on fertilizer and irrigation applications. These findings imply that the incorporation of dynamic soil structural parameters is important for accurate simulation of temporal variability in the risk of deep percolation and nitrate leaching in cultivated soils. The variable deep percolation responses before and after desiccation crack formation also has implications for irrigation management, emphasizing the need to understand seasonal patterns in soil and nitrate behaviors to improve water and nitrogen use efficiency in irrigated agricultural systems.

**Title:** Identification of Buried Channels via Electrical Methods in NE Montana

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**Abstract:**

The topography of Northeast Montana is controlled by its history of Pleistocene glaciation, resulting in a largely low relief surface suitable for agriculture. Despite this, there is a relict landscape below the surface. The ancestral Missouri river (and tributaries) as well as periglacial runoff carved a network of river channels that have since been filled with till and glaciofluvial sediments. These features are known as buried channels and can serve as productive aquifers. They have been extensively mapped in the neighboring Dakotas and Canadian Prairie Provinces but are less well defined in Montana.

In partnership with the Montana Bureau of Mines and Geology (MBMG), The University of Montana Western's Applied Environmental Geophysics class has conducted two field campaigns to investigate the use of geophysical techniques to identify and image these buried channels. We based our surveys near the town of Medicine Lake, where previous work identified the presence of buried channels. Over two years we conducted about a dozen Electrical Resistivity Tomography (ERT) surveys and one Transient Electromagnetic (TEM) survey largely centered near pre-existing monitoring wells. ERT and TEM are sensitive to the electrical properties of the subsurface, which are in turn controlled by porosity, saturation, and fluid/host rock resistivity. Previous surveys were hampered by a limited depth of investigation; in our second campaign we doubled our depth of investigation by

increasing our surface line length to over 500 meters which gave us images of up to 100 meters deep.

Our surveys reveal that the low relief surface belies a complex subsurface setting, consistent with a chaotic sub- and periglacial depositional environment. Because electrical methods depend on contrasts in resistivities, distinction between till and the local Fort Union Sandstone (which is both the bedrock and the source of the till) can be challenging. However, in many instances, we can distinguish between till, bedrock, and likely intra-till channels. At the scale of our ground-based survey it is difficult to identify large-scale features (whole buried channels) but we can identify smaller features such as intra-till channels and the till-bedrock interface.

**Word count: 338**

## **Preliminary Predictive Simulation of Land Use Change Impacts on Groundwater Recharge West of Billings, Montana**

**Kurt Zeiler**

The West End area of Billings, Montana, has been undergoing residential development that is expected to continue into the future. Much of the land being developed has been irrigated cropland with irrigation water sourced from the Yellowstone River. These lands are primarily flood irrigated, which likely provides significant groundwater recharge to the underlying sand and gravel aquifer system. The alluvial sand and gravel aquifer is generally thin with a reported average saturated thickness of approximately 15 feet and is underlain by low permeability Colorado Group shale bedrock. This relatively thin aquifer system is both the primary water source for the residences and likely sensitive to reductions in recharge.

Residential development is expected to reduce groundwater recharge in this area due to cessation of the flood irrigation of crops as well as increases in impervious surface. To develop quantitative predictive estimates of future recharge under changing land use conditions, we have implemented the USGS Soil-Water Balance (SWB) model. The SWB model incorporates meteorological, soil, overland flow, and land use inputs to estimate potential groundwater recharge using a modified Thornthwaite-Mather water-balance approach. Preliminary predictive SWB simulations have been performed in which past meteorological inputs are used as a proxy for future conditions. Simulated land use in the West End area is sequentially converted from existing conditions to residential development, including cessation of irrigation and increases in impervious surface. The locations of hypothetical future residential development are based on converting developable lands within quarter-quarter section areas that are pseudo-randomly assigned a future year of land use change under different assumptions of rates of residential development ranging from 120 to 220 new homes per year. This preliminary methodology for predicting future changes in recharge resulting from expected continuing land use changes will be further refined based on feedback from stakeholders and results will be incorporated in predictive groundwater flow simulations with a MODFLOW 6 model currently under development and calibration.

## River Ranch Restoration on the Yellowstone River (15min)

The Dover Island / River Ranch property was identified in 2017 as a priority restoration site using criteria from the Natural Resource Damage Program's (NRDP) Damage Assessment and Restoration Plan, developed in response to the July 1st, 2011 Yellowstone River oil spill. The spill occurred upstream of Laurel, Montana, when an ExxonMobil pipeline breached during high flows, releasing approximately 63,000 gallons of oil into the river.

Today, in cooperation with the new landowner—the Yellowstone River Parks Association (YRPA)—design and permitting work is underway at Dover Island. The project will remove approximately 1,600 linear feet of riprap and breach a section of levee to reconnect a side channel to the mainstem river. These actions will meet NRDP's restoration goals and improve river health and ecological function in this reach of the Yellowstone River.

The project also addresses the cumulative anthropogenic impacts identified in the 2015 *Yellowstone River Cumulative Effects Analysis*, prepared by the U.S. Army Corps of Engineers and the Yellowstone River Conservation District Council. That report identified impacts such as altered hydrology, armored banks, blocked side channels, disconnected floodplains, converted riparian vegetation, reduced wetlands, increased invasive species, and declining water quality. A restoration project at Dover Island / River Ranch property will either directly or indirectly address many of these impacts within the project area. Pre- and post-project monitoring will help evaluate the resource benefits resulting from this work and inform future restoration initiatives.

## The Clear Lake Aquifer in Sheridan County, Montana

The Clear Lake Aquifer, located in Sheridan County, Montana, is an essential groundwater resource that supports agricultural, domestic, and ecological needs in the region. Formed thousands of years ago by the ancestral Missouri River and glacial sedimentary processes, the aquifer plays a critical role in the local community. In 1974, landowner Marlowe Onstad was convinced of a significant water source and drilled one of the first production wells completed in the aquifer. Hydrologists documented the aquifer in the mid-20th century during statewide groundwater mapping efforts. Over the last 5 decades, it has been crucial for sustaining crop irrigation and livestock production, especially during drought periods. Currently, the aquifer is mapped from Westby, Montana to Homestead, Montana.

Historical monitoring records show both stable recharge rates and response to changing climate patterns. In response to these challenges, the Sheridan County Conservation District has established a monitoring program to track water quality, depth, and usage trends. Currently, 79 wells and five lakes are monitored hourly using pressure transducers, with data collected monthly. Additionally, 66 wells are manually measured on a monthly basis, while another 65 wells are manually measured semiannually.

To ensure the sustainability of the Clear Lake Aquifer, every new production well must go through a comprehensive application and review process. This includes an Aquifer test, water sampling, and an evaluation by our Technical Advisory Committee, featuring experts from the Local City/County Planner, U.S. Fish & Wildlife Service, Water Resources for the Assiniboine & Sioux Fort Peck Tribes, U.S Geological Survey, USDA Natural Resource Conservation Service, and the Montana Department of Natural Resources.

This aquifer's geological origins, patterns of human utilization, and the evolution of conservation strategies provide context for discussing current management practices aimed at preserving this critical water resource for future generations.

## *Extreme Winter Precipitation Drives Recharge of Mountain Groundwater*

*Matthew J. Swarr, Donald F. Argus, Hilary R. Martens, Zachary H. Hoylman, Zachary M. Young, Adrian A. Borsa, Nicholas Lau, W. Payton Gardner*

Mountain groundwater systems have been increasingly recognized as a dynamic and critical source of water storage and release to adjacent low-elevation communities. Persistent declines in groundwater storage have been observed across the western US over the past two decades, driven by warming air temperatures and variable snowpack accumulation. Initial forecasts indicate that climate change could exacerbate groundwater declines, threatening the sustainability of ecosystems, and impacting resources relied upon by our society. Furthermore, precipitation is forecast to become more variable as climate change intensifies, however, it is unclear how that will affect groundwater recharge. Using high-precision Global Navigation Satellite Systems (GNSS) surface displacements that reflect the solid Earth's deformation response to loading and unloading as well independent estimates of water stored within hydrologic reservoirs, we isolate changes in mountain groundwater storage in mountainous regions of the western US with high spatial and temporal resolution over the past two decades. We find that diminishing groundwater storage is the dominant component of long-term water storage loss within mountainous regions of the western US, such as the Sierra Nevada of California, composing up to 95% of the water lost. However, extremely wet winters, such as that of 2023, can recharge groundwater storage by more than twice the average annual flux over relatively short periods, driving the state of groundwater storage from historical lows to above or near-normal conditions over relatively short periods. Further, we find gains in groundwater storage associated with these events are relatively durable, persisting over several proceeding years despite modest winters following an extremely wet year, indicating that brief but extreme precipitation events can provide refuge for adjacent lowland regions dependent upon mountain groundwater for several years post-event. In a future with increasingly variable precipitation, the strong influence of these extreme events may act to maintain mountain groundwater, sustaining ecosystem health and buffering adjacent areas against drought conditions during dry periods.

## *Geodetic Constraints on Mountain Bedrock Aquifer Flow and Diffusivity*

*Matthew J. Swarr, Donald F. Argus, Zachary H. Hoylman, Brett J. Oliver, W. Payton Gardner*

Groundwater flowing through the fractured bedrock composing most mountain ranges has been increasingly recognized as a vital source of freshwater for both low-elevation communities and mountain ecosystems, maintaining streamflow and constituting a large portion of recharge to lowland aquifers used to support human activities. Despite the growing awareness of groundwater's role in mountain hydrology and the potential impacts of climate change on mountain groundwater, it remains a challenge to study the dynamics and properties of these systems, largely due to the low density of observational wells and challenges in characterizing the mountain block over large areas and depths. Here, we report on a new approach to characterize the flow and hydraulic properties of mountain groundwater systems at the mountain range scale. We utilize high-precision Global Navigation Satellite Systems (GNSS) observations of vertical crustal displacement produced by the redistribution of freshwater on or near the Earth's surface to estimate changes in groundwater storage within the Sierra Nevada and Cascades Range of the western United States over the past two decades. Utilizing identified periods of groundwater discharge, we characterize the effective hydraulic conductivity, specific yield, saturated thickness, and flow path length of these groundwater systems using fluid diffusion models in combination with our GNSS-inferred groundwater storage estimates. Through probabilistic inference, we demonstrate that geodetic observations provide new information on these parameters, yielding relatively high values of effective bedrock conductivity ( $\sim 1 \times 10^{-6}$ - $1 \times 10^{-4}$  m/s) compared to expected values based upon each region's bedrock lithology, for example, suggesting that areas with highly fractured bedrock as well as saprolite may exert a strong control on groundwater discharge at the mountain range scale. Furthermore, our results indicate that groundwater flow paths can span lengths on the order of 100s-1000s of meters, supporting the notion that groundwater can flow over extended areas within the mountain block, providing recharge at both a local and regional scales. Comparison of parameter estimates derived from groundwater well observations and streamflow recession confirm that GNSS-inferred estimates of groundwater storage capture the behavior of mountain groundwater systems at the mountain range scale. As consideration of mountain groundwater contributions to adjacent lowland aquifer systems becomes increasingly important in coming years, improved understanding of the properties and dynamics of these systems will assist in the management of freshwater resources and response to future extremes.

## Montana AWRA Abstract

**Presentation title:** Snow simulations predict future changes in frequency of rain-on-snow events and snowmelt in the upper Gallatin watershed

**Authors:** Sarah Newcomb, Meryl Storb, Theo Barnhart, Aaron Heldmyer

**Abstract:** As global and regional temperatures rise, mountain headwaters across the upper Gallatin watershed are projected to receive a greater portion of precipitation falling as rain, lower snow accumulation, and earlier snowmelt. While the hydrologic effect of this snow-to-rain transition depends on the timing and intensity of rain events, more rain can lead to an increased occurrence of rain-on-snow (RoS) events. Although RoS flood events are often associated with warm, maritime snowpacks, events such as the 2022 Yellowstone floods demonstrate that RoS events can also produce extreme hydrologic responses in the cold, continental snowpacks of the Greater Yellowstone Ecosystem. As warming changes storm characteristics, it is important to understand how changes in precipitation, temperature, and seasonal snow cover interact to determine hydrologic response to RoS events. To investigate these changes regionally, we used high-resolution SnowModel simulations of the Gallatin River watershed upstream of the USGS gage near Gallatin Gateway (U.S. Geological Survey streamgage 06043500). Simulations were run for 2001-2013 using two scenarios: (1) historical meteorology as control and (2) pseudo global warming (PGW) where control air temperature and precipitation were perturbed to represent mean end-of-century conditions under a high emissions scenario. Model outputs showed that, while the entire watershed experienced rainier, less snowy years in the PGW scenario, the timing and effect of this change varied with elevation. At the lowest elevations (< 7,200 ft), warmer PGW winters resulted in more mid-winter melt events and more winter precipitation falling as rain. On the other hand, elevations above 8,200 ft experienced only minor reductions in winter snowfall fraction, despite over 4°C of warming. As PGW spring months became rainier, these upper elevations that retained spring snow experienced more frequent RoS events. Snowpacks between 8,200-10,200 ft were the most responsive to springtime rain events and, on average, generated more snowmelt during RoS events in the PGW scenario. Together, these results indicate that with warming, the headwaters of the Gallatin River watershed may experience more frequent snowmelt-producing RoS events. This elevation-dependent snowmelt has important implications for flood forecasting, tourism, and water-supply predictions in the Gallatin River watershed and Greater Yellowstone Ecosystem.

## **Characterizing Risk from Emerging Contaminants to Montana's Public Water Supplies**

Montana has over 2,200 Public Water Supplies (PWS) providing drinking water to over two thirds of the state population. These PWS are monitored for over 90 contaminants as required by the United States Environmental Protection Agency's (EPA) Safe Drinking Water Act. The EPA has identified over 200 additional emerging contaminants (EC) that potentially pose health risks, but do not have federal monitoring regulations. Existing data for water quality and their risks are often sparse for many of these ECs, making risk characterization and mitigation difficult for PWS managers. In this study, we assess the health risks for Montanans from public drinking water exposure to 191 chemicals and 12 microbes selected by the Montana Department of Environmental Quality as contaminants of concern from the EPA's Contaminant Candidate lists (CCL 1-5). These contaminants include metals, pesticides, pharmaceuticals, industrial chemicals, PFAS, pathogens, and cyanotoxins associated with harmful algal blooms (HABs).

Our first objective was to amass all Montana water quality data on the selected ECs that are available in public databases, to assess the quality and quantity of data for each contaminant and to perform a statewide risk assessment for PWS. Current data sources include: the Montana Bureau of Mines and Geology's Groundwater Information Center (GWIC); the EPA's Water Quality Exchange (WQX), including data from the US Geological Survey (USGS) National Water Information System (NWIS); the Montana Department of Agriculture's (MDA) groundwater testing database; the Safe Drinking Water Information System (SDWIS) database containing PWS samples; and EPA's Unregulated Contaminant Monitoring Rules' (UCMR1-5) PWS sample data.

We applied two methods for assessing the health risks of ECs, depending on the availability of data. For contaminants with sufficient water quality data, concentrations were assessed relative to EPA health reference levels (HRLs) to produce hazard quotients (HQs) reported as state or HUC 8 watershed-level percentile values. For contaminants which lacked reliable concentration data, we assessed risk based on presence vs. absence to determine if and how commonly each contaminant occurs in the state. Concentration and HQ data for each contaminant are also mapped by individual sample points and by 90<sup>th</sup> percentiles of concentrations within HUC8 watersheds to explore spatial patterns and identify regions where PWS may require additional monitoring.

Sample data has been found for 161 of the 191 ECs, with 108 ECs having at least one detection in the state. Some of the contaminants with the highest HQ values are metals such as lithium, vanadium, manganese, and cobalt. Some ECs found at high levels relative to their HRLs include 2,4-dinitrotoluene, dieldrin, microcystin-LR, and germanium, but these contaminants have fewer detected concentration values (< 100). This preliminary analysis of contaminants is accompanied by an ongoing assessment of data quality to ensure that results used by DEQ to inform monitoring decisions, accurately represent the presence of ECs in the state. Future work includes incorporation of microbial contaminants into the existing workflow, as well as further efforts to maximize data retention while maintaining a high data quality standard.

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Implications of function choice in modeling hyporheic exchange

Hayley Oakland, Samuel Fritz, Anna French, Lindsey Albertson, Geoffrey C. Poole

Dynamic water exchange between stream channels and hyporheic zones plays a crucial role in ecosystem processing and function. Key components of this influence can be derived via conservative breakthrough curve modeling, using foundational mathematical relationships between the water age distribution of hyporheic discharge, the rate of hyporheic exchange, and the hyporheic storage volume. We assess how alternative model assumptions affect estimates of hyporheic properties with real and simulated breakthrough curves. We employ a Bayesian curve fitting framework with a flexible, user-defined functional form for hyporheic water age distributions. Incorporating the hyporheic water age distribution perspective resulted in more accurately modeled tracer dynamics, while avoiding simplifying assumptions inherent to common models (e.g., well-mixed hyporheic zones, infinite maximum water residence times). Our approach similarly reveals that alternative models can yield vastly different outcomes for metrics of channel and hyporheic hydrology, with major implications for modeling biogeochemical processes.

## Surface water - Groundwater interaction at Public Water Systems

By Scott Patterson, Montana Department of Environmental Quality

The health concerns for using surface water or groundwater as a drinking water source are different and the corresponding regulations that are required for each source water are distinct. Because surface water is in contact with the atmosphere and receives sunlight, it is assumed to be harboring microbes, some of which can be harmful for people to consume. The Safe Drinking Water Act requires filtration and disinfection treatment of surface water sources and corresponding monitoring to ensure the treatment process is functioning. Whereas groundwater sources are assumed to be void of microbes because of the natural processes of filtration, biodegradation, and the long time frames it takes to recharge aquifers. The regulations require public water systems to monitor groundwater sources to ensure their source has not been contaminated. Montana's Department of Environmental Quality, who regulates public water systems in Montana, evaluates all groundwater sources to identify potential surface water contamination of groundwater sources. Water sources that are under the influence of surface water are regulated as a surface water source. An overview of the ground water under direct influence of surface water (GWUDISW) evaluation process will be presented. Examples of public water systems with surface water influenced sources and the actions they took to meet the regulations will also be shared.

## **Title: Groundwater Recharge on Irrigated Fields**

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### **Abstract**

Montana has nearly 2 million acres of irrigated land, making irrigation the largest consumptive use of water in the state. Irrigation efficiency, the fraction of diverted water that is consumed by the crop, is typically maximized to sustain crop yield in water limited systems. However, in some instances the most efficient irrigation practices lead to reduced groundwater recharge and irrigation return flows since applied irrigation water that is consumed by the crop leaves the field as evapotranspiration (ET). Unconsumed irrigation water can contribute to soil water storage or be partitioned to runoff or deep percolation. Since surface water accounts for ninety-nine percent (99%) of irrigation in Montana, irrigation is one mechanism for capturing seasonal high flows in streams and storing that water in soil or groundwater for an extended period of benefit. We are investigating the interaction of irrigation with soil moisture storage and groundwater recharge by monitoring irrigation application and the movement of water through the vadose zone. Our study site consists of three pivot irrigated fields (approximately 1 km<sup>2</sup> total) in the Gold Creek drainage, a significant tributary in the Clark Fork watershed, with soil types ranging from clay loam to sandy loam. Each field has two monitoring locations measuring soil water tension, soil volumetric water content (VWC), and deep percolation (groundwater recharge). We are also monitoring irrigation application, precipitation, and actual evapotranspiration (ET). Hydrus-1D will be calibrated with these data and used to model various irrigation scenarios and assess how irrigation timing and intensity interact with soil characteristics and weather to impact partitioning of water to loss pathways. Model results will contribute to improved understanding of irrigation scheduling for maximizing crop water use versus groundwater recharge. Discrepancies between water flux results from models calibrated with different observational data streams (soil water tension, VWC, deep percolation, and actual ET) will be assessed for insights on water balance uncertainty, model reliability, and limits to model application.

## **Managed Aquifer Recharge in the Gallatin Valley- Partnering with Middle Creek Ditch Company to Identify Project Opportunities Along the Ditch Network**

Alzada Roche<sup>1</sup>, Jeff Dunn<sup>1</sup>, Kevin Haggerty<sup>2</sup>, Patrick Byorth<sup>3</sup>, Lila Rickenbaugh<sup>3</sup>, Harley Harris<sup>3</sup>

<sup>1</sup> WGM Group; <sup>2</sup> Middle Creek Ditch Company; <sup>3</sup> Gallatin Water Trust

The irrigation ditch network in the Gallatin Valley plays a critical role in recharging alluvial aquifers during the irrigation season. Water storage achieved through Managed Aquifer Recharge (MAR) has gained attention as a drought mitigation strategy in Montana, but implementation has been limited by regulatory challenges and a lack of site-specific opportunities. At the same time, development pressures threaten the long-term viability of ditches and the passive recharge that they provide. The Middle Creek Ditch Company maintains over 30 miles of ditches and laterals that flow from the Gallatin mountains through the heart of the rapidly developing City of Bozeman. The Gallatin Water Trust, supported by an RDGP grant, has partnered with the Middle Creek Ditch Company to explore opportunities for MAR along the Middle Creek Ditch network. This effort includes mapping and documenting ditches, monitoring flows at key points, and developing recharge concepts that both sustain groundwater resources and secure the relevance of ditch infrastructure in the face of land use change. By fostering creative partnerships between ditch companies and conservation organizations, projects like this demonstrate pathways for advancing MAR in Montana while protecting vital water conveyance systems and the water rights holders that use them.

## **Water Quality Impacts to Fort Belknap Indian Reservation Groundwater Resources from Landusky Mine in Little Rocky Mountains, North-Central Montana, 20 Years after Mine Closure**

The Landusky Mine operated in the Little Rocky Mountains of North-Central Montana from 1979-1998 utilizing cyanide heap-leach pads. Extensive water quality impacts are documented from mine activities. This project reports activities to identify a potable water source for tribal powwow grounds, in an adjacent mountain valley, on the Fort Belknap Indian Reservation. The research program includes surface water quality and flow monitoring, and the installation of two groundwater well clusters in the powwow grounds. The ongoing study began in 2021 and demonstrates significant changes in water quality from data presented in a 1993 USGS reports on the area. At King Spring, a former drinking water source for the community, a TDS from June 1990 was 313 mg/L and Calcium-Bicarbonate water type. Data from 3 recent samples show variable TDS near 1000 mg/L and Calcium-Sulfate water type. Stream water quality in South Bighorn Creek flowing onto the reservation from the known area of mine impacted water, adjacent to King Spring, shows a similar Calcium-Sulfate water type with variable TDS up to 2830 mg/L with Fluoride up to 8.4 mg/L. Stable stream temperatures around 8°C indicate these waters are from groundwater. Variability in water quality is attributed to dilution of waters from snowmelt during spring/early summer when TDS is generally lower than late summer/fall dry conditions, and reflecting different annual conditions. Piper/Stiff diagrams show these two waters have different water quality types, and the water isotope data shows different recharge sources. All of these waters infiltrate into the subsurface upgradient from the tribal powwow grounds. The downgradient monitoring well clusters include shallow wells screened at the bedrock/alluvium interface, and deeper wells into the Paleozoic bedrock unit. Data from June 2025 indicate that the shallow wells have Calcium-Sulfate water with TDS around 1000 mg/L, similar to King Spring. The deep wells show different water types, with the upgradient well being Sodium-Sulfate with TDS at 1280 mg/L, and the downgradient well Calcium-Bicarbonate with TDS at 288 mg/L, similar to a sample from 1990. The mine hydrology conceptual model infers two shear zones provide primary groundwater flow conduits through the area. The current data indicate slower, more diffuse contaminated regional groundwater flow from the mining area onto tribal lands. These impacts may prohibit developing a potable water source in this area.

Models can be difficult, ornery, and puzzling. When it comes to modeling water quantity, the MT Department of Natural Resources and Conservation (DNRC) has had on-and-off relationships with hydrologic modeling, but nothing seemed to stick. Recently, the Water Sciences Bureau at DNRC has entered a new relationship with modeling as we look to estimate a comprehensive water balance for the entire state. We just completed an important study in the Upper Yellowstone Basin where we developed the first test of an integrated hydrologic modeling framework that will be adapted to meet our statewide goals. At the regional level, the study provides important water resource information for water users and managers. The Yellowstone River is a major source of water that supports communities, agriculture, and recreation in southern Montana. As an un-regulated, free flowing river it retains a natural variability in flow as witnessed over the last decade with serious drought in 2016 to catastrophic flooding in 2022. The integrated modeling framework was central to the Upper Yellowstone Basin Study as it provides a tool for analyzing climatic inputs and associated water management options to deal with particularly difficult years. It simultaneously accomplished DNRC's goal of providing a roadmap for the future of water supply modeling and water administration. This foray into the headwaters of an iconic Montana river truly transformed our modeling relationship. Maybe you've been in a long-term relationship with a model too, maybe you don't know where to go next on your modeling journey, or maybe you're just entering the modeling scene? If so, join us on a retreat to the Upper Yellowstone River where we formulated, and will share with you, our key steps to repairing, rekindling, or realizing your "optimal" modeling relationship.

## Water Use and Consumption in Montana

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Water use in Montana reflects the state's diverse geography, agricultural economy, and rural-urban distribution. According to the U.S. Geological Survey, Montana withdraws approximately 9,796 million gallons per day (Mgal/d) across eight primary categories: irrigation, public supply, domestic, livestock, industrial, mining, thermoelectric power, and aquaculture. Irrigation overwhelmingly dominates water withdrawals, accounting for roughly 96.5% of total use—about 9,452 Mgal/d—primarily sourced from surface water. This is driven by Montana's extensive agricultural lands, with over 2.5 million irrigated acres. Despite high withdrawal volumes, 75% of this water returns to the hydrologic system via runoff or infiltration.

Public supply (153 Mgal/day serving 728,000 people) and self-supplied domestic water (24 Mgal/day serving 305,000 people) represent a smaller but vital portion of water use, with groundwater serving as a key source, especially in rural areas. Livestock water use (42 Mgal/day) is significant in Montana's ranching regions, while industrial (10 Mgal/day) and mining (22 Mgal/day) withdrawals are localized but can be highly consumptive, particularly in areas with active resource extraction. Thermoelectric power generation (76 Mgal/day) and aquaculture (17 Mgal/day) contribute minimally to overall withdrawals but are notable for their specific regional impacts.

Water consumption—defined as water that is not returned to its source—varies significantly across use categories in Montana. Irrigation is the largest contributor, accounting for approximately 2,370 million gallons per day (Mgal/day), or 92% of total consumptive use. The remaining seven categories combined represent just 8% of consumptive use, with self-supplied domestic water contributing roughly 1%. Although evaporation is not classified as a water use, it is estimated for major reservoirs and regulated lakes to provide context alongside withdrawal data. Net reservoir evaporation is substantial, totaling about 1 million acre-feet annually, which equates to an average of 891 Mgal/day. This daily evaporation rate exceeds the combined average daily withdrawals for public supply, self-supplied domestic, industrial, thermoelectric power generation, livestock, aquaculture, and mining—highlighting its significant impact on Montana's overall water budget.

Montana's water management is shaped by legal frameworks, adjudicated water rights, and basin-specific restrictions due to over-appropriation. Understanding category-specific water use is essential for sustainable planning, especially amid climate variability and competing demands. This abstract provides a snapshot of Montana's water use landscape, highlighting the need for continued monitoring, efficiency improvements, and policy adaptation to ensure long-term resource resilience.