



# PROCEEDINGS

for

## **Water Quality & Quantity in a Changing Climate**

**American Water Resources Association Montana Section 2016 Conference**

**October 13 - October 14, 2016**

**Fairmont Hot Springs – Anaconda, Montana**

### **Contents**

Thanks to Planners and Sponsors

Full Meeting Agenda

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Concurrent Session and Poster Abstracts\*

Session 1. Surface Water

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Session 3. Isotopes, Evapotranspiration, Forestry

Session 4. Water Management, Groundwater/Surface Water Interaction

Session 5. Modeling

Session 6. Microbiology I

Session 7, Site Characterization

Session 8. Microbiology II & Water Quality

Poster Session

Meeting Attendees

**\*These abstracts were not edited and appear as submitted by the author, except for some changes in font and format.**

## THANKS TO ALL WHO MAKE THIS EVENT POSSIBLE!

- **The AWRA Officers**

Todd Myse, President – Montana Bureau of Mines and Geology

Aaron Fiaschetti, Vice President – Montana DNRC

Emilie Erich Hoffman, Treasurer – Montana Dept of Agriculture

Nancy Hystad, Executive Secretary – Montana Water Center

- **Montana Water Center, Meeting Coordination**

Wyatt Cross, Nancy Hystad

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



*Todd Myse*



*Aaron Fiaschetti*



*Emilie Erich Hoffman*



*Nancy Hystad*

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## WEDNESDAY, OCTOBER 12, 2016

### REGISTRATION

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10:00 am – 7:00 pm REGISTRATION

8:00 am – 12:00 pm **USGS Led StreamStats Training**  
(Separate registration\*)

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1:00 pm – 5:00 pm **FIELD TRIP** - *Leave Fairmont Hot Springs promptly at 1:00 PM*

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6:00 pm – 7:00 pm **HYDROPHILE 3MILE - 5K RUN/WALK**

*Dinner - on your own*

## THURSDAY, OCTOBER 13, 2016

### REGISTRATION

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7:00 am Breakfast included with Registration this year and served in Cut-Throat/Grizzly Room

7:30 am REGISTRATION - Gather for coffee and Conversation with Colleagues

### OPENING DAY PLENARY SESSION

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8:00 am Welcome with Introductions, Logistics, & Announcements - Todd Myse (MT AWRA President)

8:15 am Wyatt Cross – Montana Water Center Director

8:20 am Special Speaker – Martha Narvaez, National AWRA President

8:35 am KEYNOTE SPEAKER 1. Dr. Shemin Ge - 2016 Birdsall-Dreiss Distinguished Lecturer -  
*Groundwater Dynamics in Headwater Regions under a Changing Climate*

9:35 am BREAK

10:00 am KEYNOTE SPEAKER 2. Dr. Kelsey Jencso and Dr. Nick Silverman - U of Montana and Montana  
Climate Office  
*Building Montana Water Resource Resiliency Through Information Gathering and Communication at  
Multiple Space and Time Scales*

## THURSDAY, OCTOBER 13, 2016 (continued)

- 11:00 am Special Speaker - Helen Thigpen, Senior Staff Attorney - Legislative Update
- 11:30 am Break for Lunch in the Cut-Throat/Grizzly Room - provided to all registered conference attendees

### ORAL PRESENTATIONS

Red text indicates student presenters.

#### SESSION 1 (Concurrent) *SURFACE WATER*

Moderator: Mike Roberts

- 1:00 pm Charles Parrett. *Using LOESS to See if Streamflow is Changing in a Hotter Montana*
- 1:20 **Michael Chambers. Several methods to assess groundwater-surface water interactions along Lolo Creek in Lolo, Montana**
- 1:40 Beau Downing. *Multi-faceted Restoration to Address Multiple Limiting Factors Affecting Fisheries Populations in Harvey Creek - Upper Clark Fork River Basin, Montana*
- 2:00 Daniel March. *Callahan Creek Flood Risk Reduction and Channel Restoration*
- 2:20 Alex Leone. *Impacts of Low Summer Streamflow on Water Resources in the Jefferson Valley: Historical Responses and Future Challenge*
- 2:40 Adam Johnson *A Preliminary Evaluation of the Value of Water Resources Originating in Montana Wilderness Areas*
- 3:00 **BREAK - POSTER SETUP**

#### SESSION 2 (Concurrent) *WATER QUALITY & QUANTITY IN A CHANGING CLIMATE*

Moderator: Andrew Wilcox

- 1:00 pm Christine Brick. *Assessment of Watershed Vulnerability to Climate Change on the Lolo National Forest: Bull trout, Water Supply and Forest Infrastructure*
- 1:20 John Doyle. *Exploring effects of climate change on Tribal water and health*
- 1:40 Phil Farnes. *Is Expanding Population a Bigger Threat Than Climate Change?*
- 2:00 **Gabriel Bromley. Regional changes in summer climate in the North American northern Great Plains: Is Montana experiencing the cooling trend observed in the Dakotas and Prairie Provinces?**
- 2:20 Kyle Flynn. *Evaluating climate change impacts on water quality using mechanistic receiving-water models*
- 2:40 Rebekah Levine. *A watershed prioritization framework for directing conservation efforts in the face of climate change, Upper Missouri Headwaters, Montana*
- 3:00 **BREAK - POSTER SETUP**

## THURSDAY, OCTOBER 13, 2016 (continued)

### SESSION 3 (Concurrent)

#### *ISOTOPES, EVAPOTRANSPIRATION, FORESTRY*

Moderator: Tom Michalek

- 3:20 pm *Mallory Morgan Ecosystem water-use efficiency in a flood-irrigated malt barley field in south-central Montana*
- 3:40 Paul Stoy. *The role of agricultural management on the flux of water, carbon and heat to and from Montana agroecosystems and implications for precipitation processes*
- 4:00 Stephen Parker. *Shallow lake-bed sediments: connections between geochemistry and microbiology. A case study from Georgetown Lake, MT.*
- 4:20 *Zachary Hoylman. Landscape Heterogeneity Modulates Forest Sensitivity to Climate*
- 4:40
- 5:00 POSTER SESSION

### SESSION 4 (Concurrent)

#### *WATER MANAGEMENT, GROUNDWATER/SURFACE-WATER INTERACTION*

Moderator: Kathy Chase

- 3:20 pm Ginette Abdo. *Over 150 years of Irrigation – Implications for Montana’s Water Resources*
- 3:40 Brian Sugden. *15-Year Implementation and Effectiveness of the Weyerhaeuser Native Fish Habitat Conservation Plan in Montana*
- 4:00 Aaron Fiaschetti. *Lawyers, Grizzly Bears, and Water. A Hydrologists Study of the Teton River from the Bottom of the Food Chain*
- 4:20 Mike Roberts. *Water Management from the Trenches*
- 4:40 Andrew Bobst *Using Water Temperatures to Understand Groundwater/Surface-Water Interactions in Southwest Montana*
- 5:00 POSTER SESSION

### POSTER SESSION IN THE ROCKY MOUNTAIN FOYER

5:00 – 7:00 pm AWRA 2016 POSTER PRESENTATIONS

1. Blais *Evaluating the Influence of Irrigation on Groundwater in Northern Big Horn County*
2. Bowman *Watershed Restoration Planning in the Flathead Valley*
3. Brissette *Science to inform restoration: Effects of channel reconstruction on hydraulic exchange and baseflow generation*
4. Brown *Characterization of groundwater near oil and gas development in eastern Montana*
5. Carstarphen *Montana Bureau of Mines and Geology’s Groundwater Investigations Program The Lolo Creek Watershed Groundwater Investigation*
6. Carstarphen *Montana Bureau of Mines and Geology (MBMG) Ground Water Assessment Program Fluoride Concentrations in Montana’s Groundwater*
7. Chandler *Groundwater flow modeling of the Clear Lake Aquifer south of Medicine Lake, Montana*

## THURSDAY, OCTOBER 13, 2016 (continued)

8. Chase *Improving our Knowledge of Hydrology and Climate in the Upper Missouri and Upper Columbia Basins by Studying Paleofloods, Tree Rings, and Archeology*
9. Fouty *Investigation changes in entrainment by debris flow with changes in scale.*
10. Galhouse *Beaver use and impacts on stream and riparian habitats of the Robb-Ledford and Gravelly-Blacktail Wildlife Management Areas*
11. Harrington *When the levee breaks: A Superfund site in the middle Clark Fork River*
12. Jackson *Promoting lipid accumulation in *Chlorella vulgaris* UTEX395 using nitrogen limitation and bicarbonate amendment under different nitrogen regimes*
13. Kuzara *Irrigation efficiencies impact on domestic groundwater supplies*
14. Lawonn *Gallatin Stream Teams - The Environmental Stewards of the Gallatin Valley, Montana.*
15. Livesay *Quantifying the spatio-temporal dynamics of groundwater recharge in a headwater basin*
16. Mangold *Remediating Mine Waste Impacted Streams: A Flexible Solution Using Natural Channel Design*
17. Michalek *Understanding Gallatin Valley Groundwater: The Key to Sustainability?*
18. Mumford *Fitting Together the Puzzle Pieces: Building Drought Resiliency in Broadwater County*
19. Reiten *Physiography of Northeastern Montana with Emphasis on Drainage Development and Aquifers*
20. Rivero *Water Quality and Stream Flow Rates Within the Helena Area.*
21. Schmidt *Natural Amelioration and the Increase of Arsenic in Flooded Underground Mines*
22. Snyder *Developing a defensible local meteoric water line: some pitfalls to avoid*
23. Storb *Understanding human influence on a stream network ecosystem through analysis of diel and seasonal patterns of metabolic regimes in stream water.*
24. Swierc *Isotope Hydrology of Helena Area Aquifers*
25. Thomas *Post-Restoration Assessment of Poindexter Slough in the Beaverhead River Drainage Near Dillon, Montana*
26. Woods *Ownership of Islands in the Yellowstone River*
27. Zoanni *Traditional Ecological Knowledge and Tribal Water Governance at Fort Peck Indian Reservation, MT*

### BANQUET

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- |         |                                                                                                       |
|---------|-------------------------------------------------------------------------------------------------------|
| 7:00 pm | BANQUET                                                                                               |
| 7:30    | SPECIAL SPEAKER<br>Tom Osborne<br><i>Hydrologic Reconnaissance in the High Atlas Range of Morocco</i> |
| 8:30    | PHOTO CONTEST                                                                                         |
| 9:00    | CLOSING COMMENTS                                                                                      |

7:00 am Breakfast included with Registration this year and served in Cut-Throat/Grizzly Room. Gather for Coffee and Conversation with Colleagues

**SESSION 5 (Concurrent)**  
**MODELING**

Moderator: Brian Sugden

- 8:00 am *Katie Fogg. When and How Dynamic Hyporheic Temperature Mosaics Influence Channel Temperature Regimes*
- 8:20 *Ali Gebril. Changing irrigation practices in the Jefferson River Valley; potential impacts on the river and tributary streams near Waterloo, Montana.*
- 8:40 *Mary Sutherland. NOT another MODFLOW talk: Using models to understand the Gallatin Valley Aquifer and analyze changing water use*
- 9:00 *Kirk Waren. A Groundwater Flow Model for a part of the Central Bitterroot Valley, Ravalli County, Montana*
- 9:20 BREAK

**SESSION 6 (Concurrent)**  
**MICROBIOLOGY I**

Moderator: Melissa Schaar

- 8:00 am *Maurice Valett. Cladophora Blooms and Ecosystem Development: Implications for Restoration of the Upper Clark Fork River, MT*
- 8:20 *Alysia Cox. Defining Microbial Habitats in Mining Impacted Watersheds*
- 8:40 *Katherine Davis. Identifying the source, pathways, and rates of enhanced microbial coalbed methane production in the Powder River Basin*
- 9:00
- 9:20 BREAK

**SESSION 7 (Concurrent)**  
**SITE CHARACTERIZATION**

Moderator: Ashley Rivero

- 10:00 am *James Rose. The Flathead Valley Deep Aquifer: Part 1—The three-dimensional digital geologic model*
- 10:20 *John Wheaton. The Flathead Valley Deep Aquifer: Part 2 – Some Hydrogeologic Aspects of the Flathead Valley Deep Aquifer*
- 10:40 *James Madison Mountain Block Recharge in Western Montana*
- 11:00 am *John LaFave. Baseline Water-Quality Investigation, Emigrant Creek Watershed, Southcentral Montana*

**SESSION 8 (Concurrent)**  
**MICROBIOLOGY II & WATER QUALITY**

Moderator: Jennifer Harrington

- 10:00 am *Raja Nagisetty. Modeling Dissolved Oxygen in Effluent and Macrophyte Rich Upper Silver Bow Creek*
- 10:20 *Vicki Watson. How will climate change affect attached algal levels in Montana rivers?*
- 10:40 *Kelsey Brasseur. The Gallatin Microplastics Initiative: watershed-scale data collection by adventure scientists*
- 11:00 *Melissa Schaar. Natural Arsenic Levels Flowing from Yellowstone National Park: Measured by Science and Managed by Policy and Regulation.*

**FRIDAY, OCTOBER 14, 2016 (continued)**

11:20 am Willis Weight. *The Mystery of the Butte Sinkhole*

11:20 am Christine Miller. *Western Gallatin Valley Arsenic Distribution Project*

11:40 am BREAK

11:40 am BREAK

**CLOSING PLENARY**

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11:50 am CLOSING PLENARY

Announcements, New Officers, Student Awards, Next Year's Location

12:00 pm ADJOURN

**MT GROUNDWATER CHARACTERIZATION COMMITTEE MEETING**

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1:00 pm Ground Water Assessment Program Steering Committee Meeting-location to be accounced

## KEYNOTE SPEAKER

### Shemin Ge, Ph.D.

Shemin Ge is Professor of hydrogeology in the Department of Geological Sciences at the University of Colorado-Boulder. She received her Ph.D. from The Johns Hopkins University in 1990, subsequently worked at S.S. Papadopoulos and Associates, and then joined the University of Colorado in 1993. At the confluence of subsurface fluid flow physics and rock mechanics, Ge's early research examined the effects of tectonic deformation on paleo-fluid flow dynamics in sedimentary basins. She has since moved on to explore interactions between groundwater and earthquakes. She and her students and colleagues study earthquake-induced groundwater flow as natural experiments to reveal the hydrologic properties of geologic systems. They also explore the mechanisms of seismicity induced by reservoir operation and wastewater injection. Another thread of Ge's research relates to groundwater resources and surface-groundwater interactions under a changing climate with a focus on headwater regions. She has also ventured into fracture flow and fault zone hydrology, as well as subsurface thermal energy transport and storage. A list of her publications can be found at <http://www.colorado.edu/GeolSci/faculty/ge.htm>. Ge has served the hydrogeologic and broader geoscience communities in various capacities. She was Chair of the Hydrogeology Program Planning Group for the Ocean Drilling Program from 1999 to 2002. She was Editor for Hydrogeology Journal and Associate Editor for Geofluids and Journal of Ground Water. She recently served a two-year term as Program Director for the Hydrologic Sciences Program at the US National Science Foundation.



### Abstract: **Groundwater Dynamics in Headwater Regions under a Changing Climate.**

Groundwater systems receive significant recharge in high-altitude headwater regions. Seasonal and longer term variations in surface temperature and precipitation are expected under a changing climate, which could substantially impact groundwater recharge and subsequently groundwater storage and discharge to surface waters downstream. These headwater regions are hydrologically sensitive to surface temperature changes due to the presence of frozen grounds that freeze and thaw seasonally and degrading permafrost. The freeze and thaw processes lead to changes in subsurface hydrologic properties and dynamically impede or invigorate groundwater flow. A key question is how seasonal and long-term surface temperature variations impact recharge to groundwater and its interaction with surface water. This presentation addresses this question as it relates to groundwater flow in headwater regions. Coupled heat transfer and groundwater flow processes are modeled for two headwater catchments, one in the Colorado Rocky Mountains and the other on the Tibet Plateau. These studies illustrate that shallow groundwater flow in summer and early fall is most energetic as thawed ground promotes snowmelt infiltration, invigorating the exchange between groundwater and surface water. Under increasing temperature scenarios, groundwater discharge to surface may experience a several-fold increase in magnitude over the decadal scale. While projected warming leads to increased groundwater discharge to surface waters, in the long run, insufficient recharge upstream will make it challenge to sustain the discharge.

## KEYNOTE SPEAKERS

### Nick Silverman, Ph.D.

Nick Silverman, is a Research Scientist with the Montana Climate Office at the University of Montana. His research focuses on identifying hydroclimatic trends in mountainous landscapes. Nick received his undergraduate degree in Physics and Engineering from Washington and Lee University in 2001. He completed a Masters in Engineering from the University of Washington in 2004. After graduating, Nick worked as a Water Resources Engineer in Seattle, WA specializing in stream and



wetland restoration. In 2010 he went back to school at the University of Montana to get a PhD in Regional Hydrology. He is currently leading the climate analysis for the Institute on Ecosystems' (IoE) state Climate Assessment and is working as a consultant on the Montana Research and Economic Development Initiative (MREDI) through the MSU Agriculture Department. Nick is the owner of Adaptive Hydrology, LLC which specializes in connecting land managers with state-of-the-art climate and hydrologic technology.

### **Kelsey Jencso, Ph.D.**

Kelsey Jencso is an Assistant Professor of Watershed Hydrology in the College of Forestry and Conservation at the University of Montana. His related basic research focuses on forested mountain terrain and the factors that influence the redistribution of water, nutrients and sediment across hillslopes and entire watersheds. His current funded research focuses on the role of landscape topography for regulating forest productivity through differences in microclimate and plant available water. In his capacity as the Montana State Climatologist Dr. Jencso also places strong emphasis on bridging the gap between basic research in hydro-climatology and the extension of information to the public in a user specific context. Currently Dr. Jencso is leading an effort to develop a network of soil moisture and meteorological stations and decision support tools across agricultural and rangelands in Montana, is participating in a collaborative effort to develop a statewide climate assessment, and the development of satellite based remote sensing tools for quantifying evapotranspiration and water deficit for agriculture and water resource management.



### **Abstract: Building Montana water resource resiliency through information gathering and communication at multiple space and time scales**

Climate is characterized at the regional and decadal scales; nevertheless, the impacts from a changing climate affect decisions by Montanans seasonally and at the scale of individual watersheds, municipalities, and fields. Mountainous topography and a mixture of climatic regimes complicate our ability to develop accurate and local climate predictions. In spite of these challenges, we must be prepared to optimize our water resource management decisions from the state-level all the way down to small watersheds and farm fields. To make these decisions, climatic information and data should be relevant, timely, accurate and readily accessible. In collaboration with state agencies, watershed groups, and private landowners, the Montana Climate Office is working to provide climate and water data that can be used by all Montana stakeholders. Through the Institute on Ecosystems, a statewide climate assessment is currently underway to examine projected changes and their impacts on water, forestry, and agriculture. In addition the MCO is facilitating the development of a meteorological and soil moisture network; with plans of over 100 stations by 2018. Finally, with researchers at NASA, the University of Montana, and MT DNRC, remote sensing techniques are being developed and validated to get a more complete picture of water availability at high resolution and repeatable time scales across MT. These coordinated and complementary efforts provide first steps towards building our understanding of water availability across our headwater state and for taking advantage of changes in the future.

## **SPECIAL SPEAKER**

### **Martha Narvaez**

Martha Corrozi Narvaez is a Policy Scientist at the University of Delaware's Water Resources Center, a unit of the Institute for Public Administration. Martha is responsible for providing regional watershed technical, policy, and research support to state and local governments; University staff and faculty; and nonprofit organizations in Delaware and the Delaware Valley. These responsibilities include research in water resources issues and policy, development and coordination of public education and outreach initiatives, advisement

on State and local water resource issues, assistance with graduate courses at the University of Delaware, and advisement of graduate and undergraduate students. Prior to becoming a University of Delaware staff member, Martha was employed by the Chesapeake Research Consortium at the USEPA's Chesapeake Bay Program Office in Annapolis, Maryland; the Public Works Department in the City of Wilmington, Del.; the Conservancy of Southwest Florida in Naples, Fla.; and Environmental Consulting Services Inc. (ECSI) in Middletown, Del. Martha received her Bachelor of Science (BS) in Biology from Lehigh University and her Master of Public Administration (MPA) degree from the University of Delaware where she specialized in watershed management.



Martha has been a member of AWRA for over 15 years, both as a student and professional, and served on the Board of Directors from 2008-2013. Martha was the charter president of DEAWRA and is currently a DEAWRA board member. Martha has served on numerous local and national AWRA conference committees, including Co-chair for both the 2010 Annual Conference and the 2007 Mid-Atlantic Sections Conference. Martha received AWRA's A. Ivan Johnson Award for Young Professionals in 2007. Martha currently serves as AWRA President (2016).

## SPECIAL SPEAKER

### Helen Thigpen

Helen Thigpen is a senior staff attorney with the Legislative Services Division where she focuses on environmental and natural resources issues and water policy. Ms. Thigpen is legal counsel for the Environmental Quality Council and the Water Policy Interim Committee and staffs the House Judiciary Committee during legislative sessions. Prior to joining the Legislative Services Division, Ms. Thigpen served as a law clerk at the Montana Supreme Court. She is a graduate of the University of Montana School of Law and originally hails from Billings.



## BANQUET SPEAKER

### Tom Osborne

Vice President | Professional Hydrologist

Tom is a Registered Professional Hydrologist with 40 years of experience working on water quality, mining hydrology, water supplies, contaminant cleanup, energy and agricultural water issues. Tom conducts hydrological, water quality, and environmental investigations; performs strategic regulatory consulting and permitting; and provides expert services in support of litigation. He has authored and co-authored over 40 professional publications and presentations, including 16 related to coal hydrology or coal energy impact assessment. He is active philanthropically and personally with water development projects in Africa.

B.S., Forestry, Natural Resource Management, University of Wisconsin at Stevens Point; M.S., Water Resources Management, University of Wisconsin



**Abstract: Hydrologic Reconnaissance in the High Atlas Range of Morocco**

Many Montanans are adventurers and some take it to extremes. One of these is Cloe Medina Erickson, who, after earning an M.A. in architecture from MSU, gravitated to Arabic architecture and culture. She founded the Atlas

Cultural Foundation and has lived with her family in a remote region of Morocco for 13 years. At her invitation I conducted a preliminary investigation of the water resources in the Zawya Ahansal region of Morocco in May 2016.

This is a remote and mountainous high desert region beyond the end of the road network located between 1,700 and 4,700 meters elevation in Morocco's Central High Atlas Mountains. This region drains to the 555 km-long River Oum Er-Rbia (the mother of springtime in Berber). Accumulating snow in the high country feeds perennial springs and streams. Equivalent terrain in the US would be southern Utah.

The primary purpose of my visit was to conduct a preliminary assessment of the principal water supply sources of the region, which consist of springs and streams fed by springs. Potential water quality threats include domestic wastewater, animal waste, in-stream laundries, natural mineralization, and mining of sulfide ore bodies. Getting to the springs and selected stream locations meant anything from a moderate hike (1 – 5 km) to an overnight backpack (25 km) through canyons and over passes.

The discharge of watershed baseflow consisted of a) small springs, 2 - 10 liters per minute (l/m) at high elevations emanating from local perched aquifers in the layered sedimentary rocks, and b) large springs, 5,000 – 100,000+ l/m discharging from limestone mountain-front fault systems into the principal river valleys. Two measured springs, described below, probably represent regional discharge features. It was the first flow measurements of these springs in the memory of local authorities.

The main Taghia Spring has an indescribably dramatic setting at the base of limestone cliffs that rise 700 meters. Water discharges from a series of near-vertical fractures about 30 meters above the base of the canyon. Immediately above the springs the valley reduces to a tortuous slot canyon. The stream created by the main Taghia springs was about 4 meters wide. Velocity was measured with the age-old method of a surface float—in this case a Moroccan orange. The spring discharge was 0.113 m<sup>3</sup>/sec (4.00 ft<sup>3</sup>/sec). Field SC was 343 µS at 12.5 C.

The discharge of the main Ahansal River Spring near Aguddim was determined by difference in the Ahansal River flow plus an irrigation diversion, which gave a total discharge of 1.857 m<sup>3</sup>/sec (65.6 ft<sup>3</sup>/sec). The estimated accuracy of measurement was probably in the range of +/- 10–15%. While local people knew that the river dramatically increases in size due to the spring discharge, most were surprised to learn that the flow increased 11 times. I believe that the main Ahansal River Spring is a regional groundwater discharge feature that transcends the local watershed boundaries. It is hoped that this reconnaissance will lead to a long term monitoring program.

**Using LOESS to See if Streamflow is Changing in a Hotter Montana**

*Charles Parrett, Professional Hydrologist, Retired from USGS, 5235 Creekside Lane, Helena, MT 59601, chuckparrett@yahoo.com, (916) 813-1663*

Montana, with its large size, northern location, and widely varying topography, has a highly variable climate. Temperatures are cold in winter and warm in summer, but have generally been increasing since records began near the beginning of the twentieth century. The rate of increase also generally has gotten larger since the 1970s. Various climate studies have indicated that rising temperatures may lead to increased flooding and droughts, as flows become more variable.

To examine whether high flow (annual peak discharge) and a measure of low flow (annual mean August discharge) have substantially changed in Montana, I looked at long-term discharge records at 34 USGS gaging stations. Twenty-seven of these stations had suitable annual peak-discharge records, and 24 had suitable annual mean August discharge records.

To evaluate changes in streamflow at each site, I constructed scatterplots of the log of the discharge metric (either annual peak discharge or annual August mean discharge) for each year of record. The scatterplots showed a considerable amount of inter-annual variability, and I used a LOESS smoothing routine to dampen the large annual fluctuations in discharge and produce a fitted smooth curve that could better be used to visually detect trends or changes in discharge over the period of record. The degree of LOESS smoothing is controlled by a gap parameter that varies from 0 (little damping) to 1 (more damping and more linear). I used a gap parameter of 0.5 for all analyses; which resulted in smooth curves that better seemed to fit the cyclical variations in streamflow that are often seen in long record lengths. I also used LOESS smoothing to evaluate whether the variance of annual peak discharge changed over the period of record. While a scatterplot of annual peak discharge might not indicate a long-term change, the variance might be changed as a result of a period having peaks that are both larger than normal and smaller than normal. This has important implications for flood-frequency analyses, because flood-frequency can change if either the mean or the variance of discharge changes. To visually evaluate changes in variance, I made separate LOESS curve fits to the positive and negative residuals from the original LOESS curves through the logs of annual peak discharges. An increasing spread between the LOESS curves through the residuals indicates an increase in variance, whereas a decreasing spread indicates a decrease in variance.

Overall, the LOESS curves indicated little change in either annual peak discharge or mean August discharge throughout Montana. Of the 27 sites analyzed for change in annual peak discharge, 2 sites showed a clear increasing trend, while 2 showed a clear decreasing trend. Five other sites showed a slight increasing trend, and 4 showed a decreasing trend. Of the 24 sites analyzed for change in mean August discharge, 5 sites showed a decreasing trend and 5 showed an increasing trend. Finally, of the 27 sites analyzed for change in variance of annual peak discharge, 6 showed an increasing trend and 3 showed a decreasing trend.

**Several methods to assess groundwater-surface water interactions along Lolo Creek in Lolo, Montana**

*Michael Chambers, Montana Tech of the University of Montana, 1325 W Quartz St Apt 103, MT 59701 United States, MChambers@mtech.edu*

Lolo Creek is located 11 miles to the southwest of Missoula, Montana and is the northernmost tributary of the Bitterroot River. The upper and middle sections of Lolo Creek flow through a relatively narrow valley in the Bitterroot Mountains. In its lower reach, Lolo Creek exits the mountain valley and flows across the wide, low angle Lolo Creek alluvial fan before reaching its confluence with the Bitterroot River. It is an ecologically important perennial stream and has been identified as a critical bull trout habitat. Over the past three

decades, there have been several years where certain reaches along the lower section of Lolo Creek have become dewatered during late summer. The focus of this study, initiated in April, 2016, is to identify gaining and losing reaches along lower Lolo Creek and compare methods for quantifying groundwater flux at the sediment-water interface. There are several widely used methods that hydrogeologists use to characterize groundwater-surface water interactions. The methods used in this study include comparing groundwater and surface-water elevations near the stream; synoptic flow measurements, 1-dimensional temperature profiles, collecting and evaluating radon-222, and stable isotope data. Four locations were chosen along a 4-mile stretch of Lolo Creek for monitoring streamflow and stage in conjunction with near stream wells. The wells were instrumented for continuous recording of groundwater levels with three temperature sensors at different depths for 1-D temperature gradients. Characterizing and quantifying groundwater-surface water exchange is critical for water resource management and stream ecology.

### **Multi-faceted Restoration to Address Multiple Limiting Factors Affecting Fisheries Populations in Harvey Creek - Upper Clark Fork River Basin, Montana**

*Beau Downing, Montana Natural Resource Damage Program, 1720 9th Ave, Helena, MT 59601 USA, beaudoing@mt.gov, (406) 444-0291, Additional Author: Casey Hackathorn, Trout Unlimited, chackathorn@tu.org*

Restoration on Harvey Creek is a pilot study in maintaining viable agricultural operations while meeting restoration goals using multiple complementary restoration actions. The goals of restoration on Harvey Creek include improved riparian and fisheries habitat, improve fish migration and reduce entrainment in irrigation ditches, improve instream flow conditions and protect native fish populations all while maintaining or improving the productivity of an active cattle ranch. Restoration of this scale and intricacy is not without its challenges, but underscores the potential for holistic restoration in other watersheds, while acknowledging the increased complexity associated with multiple landowners and/or competing priorities and interests. The Montana Natural Resource Damage Program (NRDP), in partnership with Trout Unlimited (TU), the Harvey Creek Ranch (HCR), and Granite County, is implementing a variety of passive and active restoration projects on the lower 3 miles of Harvey Creek. Harvey Creek, a tributary to the Upper Clark Fork River ~ 30 miles southeast of Missoula, supports both genetically pure cutthroat trout and the threatened bull trout. Harvey Creek affords a unique opportunity to pursue a holistic, multi-faceted restoration approach that includes riparian habitat protection, fish passage and entrainment reduction, bio-engineered bank stabilization, instream flow enhancement, and a migratory fish barrier to protect native fishes in the drainage. Advantageous landownership patterns upstream of the conversation minded HCR allows for a systematic approach to addressing limiting factors to fisheries habitat and fish populations. Restoration efforts completed to date on the HCR include 2 miles of riparian fencing, installation of an upstream passable irrigation diversion and installation of a 4 cfs vertical plate fish screen at the upstream most point of diversion on Harvey Creek, installation of irrigation efficiency to 1) reduce water use from Harvey Creek and 2) consolidate two other diversions to the screened diversion (thus eliminating passage and entrainment issues). A 100' eroding streambank adjacent to a bull corral was treated using a bioengineered approach to restore riparian vegetation and protect HCR infrastructure. The NRDP, with Granite County, also replaced a failing culvert and timber crib structure that acted as a fish migration barrier with a new concrete box culvert and an 8' tall vertical fish barrier made of an inverted 3 sided concrete box culvert. Future projects on the HCR include further consolidation of remaining irrigation points of diversion to the screened diversion, and the conversion of the remaining water rights to in-stream flow. A comprehensive monitoring plan has been developed and implemented to monitor both the riparian plant community response to permanent cattle enclosure and the fisheries population response to restoration efforts. This presentation focuses on the use of multiple restoration strategies to achieve restoration goals, while maintaining or improving agricultural operations on an active cattle ranch, and how this approach may be applied in other watersheds.

### **Callahan Creek Flood Risk Reduction and Channel Restoration**

*Daniel March, HDR Engineering, 682 South Ferguson Avenue, Suite 1, Bozeman, MT 59718, daniel.march@hdrinc.com, (406) 577-5015, Additional Authors: Mike Fraser, Fraser Management & Consulting*

Flooding of Callahan Creek in December 2015 resulted in damage to infrastructure and increased flood

risk to the residents of Lincoln County. During repair of a washed out County road and removal of sediments to reduce flood risk, Lincoln County violated Section 404 of the Clean Water Act. This presentation will discuss negotiations with regulators, restoration of damaged infrastructure (roads and levees), restoration of channel impacts, removal of a natural on-site sediment source, and development of a flood risk reduction plan for potential future work. Topics for stream restoration will include: examination of the geomorphic setting; evaluation of channel plan, dimension and profile; design/construction of a floodplain bench to buttress an eroding high terrace; Corps of Engineers nationwide verses individual 404 permits; and working within designated critical bull trout habitat.

## **A Preliminary Evaluation of the Value of Water Resources Originating in Montana Wilderness Areas**

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Clean water in reliable quantities is essential for ecosystem processes and allows human populations to thrive. The value of high-quality water will likely increase as threats to resources expand and human demands increase. In Montana, public lands often contain relatively pristine watersheds. Wilderness and similarly-managed lands are critically important because they often provide disproportionately large volumes of clean water that serve a variety of purposes and uses. Preliminary information from recent studies indicates that the quality of surface waters draining wilderness lands is higher than in non-wilderness regions. Water quantity evaluations suggest that precipitation, snowmelt, runoff, and water supply volumes in these regions are high relative to their surface areas.

With few exceptions, Montana wilderness areas are associated with headwater drainages whose runoff provides flow toward downstream populated regions. Geospatial analysis of publicly-available data provides a preliminary qualitative valuation of water draining wilderness and similar regions. Maps illustrate the physical proximity of high-quality surface water resources to the population centers of Kalispell, Great Falls, Butte, Helena, Livingston, Bozeman, Missoula, and Ronan. A GIS analysis evaluated proxies for water use/valuation within the host watersheds for these communities as follows. More than 700 public water supplies are associated with the 'wilderness-alluvial system', which is defined as the combination of 1) stream-aquifer systems draining wilderness lands and 2) intermediary river reaches between wilderness catchments and the eight urban areas. More than 40,000 groundwater wells are located in the wilderness-alluvial system for these eight watersheds, as are more than 20,000 surface water rights and 30,000 groundwater rights. This information should be used for general discussion purposes only, and does not consider basin-specific characteristics such as groundwater flow directions or groundwater-surface water interactions.

Recent federal research has provided a framework for understanding the contributions and benefits of water from wilderness areas for a variety of uses on a national scale. More recent studies have begun to refine our understanding of these resources in the areas of water supply and quantity, water quality, ecosystem services, and climate change impacts. Expected outcomes of climate change include alterations in water quality and volumes, the timing of stream flows, reductions in glacial ice masses, and declining snow volumes. These impacts may be more significant in wilderness areas, and will have a marked effect on public supplies and water for other human needs.

Additional crucial research and data are needed to document and evaluate the values and benefits of wilderness water resources and their importance to ecological vitality, to economies, and to future generations. Research studies should investigate the volume of runoff draining wilderness areas in Montana, their contributions to water supplies, and the values and benefits derived from the excellent quality of the resource. With this information in hand, we will be better able to: quantify the value of one of the most precious natural resources in the state; predict and respond to water supply threats; understand how ecological functioning in wilderness may be effected by changes in the water regime; and plan for and adapt to climate change.

## **Impacts of Low Summer Streamflow on Water Resources in the Jefferson Valley: Historical Responses and Future Challenges**

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In an attempt to understand the complex interrelationships between climate, water infrastructure regimes, and water governance this thesis examines relationships between drought and water use in the Jefferson River Basin in southwest Montana. The Jefferson River is one of the three great headwater streams of the Missouri River and is itself comprised of the Beaverhead, Big Hole and Ruby Rivers, encompassing a substantial drainage basin of 9,532 sq. miles. The Jefferson's unique hydrological position inherently situates the basin 'at the end of the line' of water users and flows at its confluence have plummeted to 200 cubic feet per second (cfs) during extreme drought periods, leaving little water in the river to appease appropriators along the river's remaining 80 miles. The Jefferson River (and all of its important tributaries) is highly utilized for agriculture, resulting in chronic dewatering during peak irrigation demand (typically July through mid-September). Persistent water scarcities over the last 15 years have tested the Basin's ability to sustain historic levels of agricultural production and maintain a commercial sports fishery. This thesis provides a resilience assessment of water resources in Jefferson Basin. RA's attempt to conceptualize dynamic interactions between linked social and ecological systems (SES's). Analysis of complex human use systems (SES's) is inherently interdisciplinary and necessitates a mixed methods approach. The RA completed for this thesis integrated physical analyses of the water use system (utilizing GIS, hydrology, climate and demographic data) with a qualitative survey of water stakeholders with the goal of understanding the processes that drive the Jefferson SES and identifying weaknesses that reduce resilience. Over the last 30 years the Jefferson Basin has benefited from a unique subset of water users and natural resource managers that have successfully worked to improve conditions in the face of extreme environmental challenges. This RA found that although it is highly likely that the Jefferson will be challenged by extreme conditions in the future (related to a changing climate), it is also evident that there is potential for the basin to transition into alternate and more resilient regimes.

## **SESSION 2 Water Quality & Quantity in a Changing Climate**

### **Assessment of Watershed Vulnerability to Climate Change on the Lolo National Forest: Bull trout, Water Supply and Forest Infrastructure**

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Climate change is complicating the ability of the nation's forests to 'sustain the health and productivity' (USFS mission) of forestlands and secure 'favorable conditions of water flows' (1897 Organic Act) in the nation's headwaters. With over 2 million acres of varied landscape providing diverse vegetation, wildlife habitat, water resources, and recreational opportunities, the Lolo National Forest (LNF) seeks to proactively understand potential impacts from climate change to better manage its resources and maintain maximum ecosystem resiliency. The effects of these changes to forest resources are not well understood at the watershed level, thus the LNF partnered with the Clark Fork Coalition and our consultant to develop this watershed vulnerability assessment.

Our goal in this study was to evaluate the overall vulnerability of 6th level hydrologic unit code watersheds (HUC 12) to changing climate by combining metrics of exposure (changes in modeled climate-based variables) and sensitivity (inherent properties of the watershed). We targeted three specific forest resources for this analysis: bull trout, water supply, and forest infrastructure (recreation sites, trails, roads). It's important to recognize that our results are relative to other HUC 12 watersheds in the LNF and for the most part not defined by absolute thresholds. Overall, we found bull trout populations relatively more vulnerable to projected changes in flow than in temperature, with greatest exposure in the western study area extending south along the Idaho-Montana border. With respect to temperature effects on bull trout, greatest exposure occurs at lower elevation, generally not in areas that bull trout currently inhabit. For water supply, expected patterns of lower summer flow and shift of flow timing to earlier in the year are predicted to have the greatest im-

pact in northwestern portions of the LNF and along the MT-ID border, as well as in headwater streams of the Blackfoot. Less exposure generally occurred in lower elevation valley streams and in Rock Creek. For forest infrastructure, we assumed that greater potential for winter flooding events would contribute to exposure, while location in floodplains or high geologic hazard areas would increase sensitivity and therefore vulnerability. Our analysis targeted some specific areas for further investigation, but there were no geographic patterns of infrastructure vulnerability across the forest.

While we emphasize the uncertainty inherent in this analysis, and while it is important for LNF managers to interpret this information in the context of their on-the-ground knowledge, we hope this effort will help forest managers understand stressors to bull trout, water supply, and infrastructure such that they can prioritize scarce financial resources for risk reduction, restoration, identification of additional data needs, development of monitoring programs, and outreach opportunities. The full report can be found at: <http://www.fs.usda.gov/main/lolo/workingtogether>

### **Exploring effects of climate change on Tribal water and health**

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American Indians have unique vulnerabilities to the impacts of climate change because of the links among ecosystems, cultural practices, and public health, but also as a result of limited resources available to address infrastructure needs. On the Crow Reservation in south-central Montana, a Northern Plains American Indian Reservation, there are community concerns about the consequences of climate change impacts for community health and local ecosystems. Observations made by Tribal Elders about decreasing annual snowfall and milder winter temperatures over the 20th century initiated an investigation of local climate and hydrologic data by the Tribal College. The resulting analysis of meteorological data confirmed the decline in annual snowfall and an increase in frost free days. In addition, the data show a shift in precipitation from winter to early spring. The number of days exceeding 90°F (32°C) has doubled in the past century. Streamflow data show a long-term trend of declining discharge. Elders noted that the changes are affecting fish distribution within local streams and plant species which provide subsistence foods. Concerns about warmer summer temperatures also include heat exposure during outdoor ceremonies that involve days of fasting without food or water. Additional community concerns about the effects of climate change include increasing flood frequency and fire severity, as well as declining water quality. The authors call for local research to understand and document current effects and project future impacts as a basis for planning adaptive strategies.

### **IS EXPANDING POPULATION A BIGGER THREAT THAN CLIMATE CHANGE?**

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Increasing population may be a much greater threat than increasing levels of greenhouse gases. The Administration has proposed reducing CO<sub>2</sub> by 28% over the next 10 years. With our population doubling about every 50-60 years, the 28% decrease will be nullified in about 18-22 years because of increased population. Also, increased population demands increased energy for housing, transportation, as well as land to produce food, for roads, schools, office buildings, stores, etc. Now is the time to determine if people on earth are going to control their reproduction or die of starvation or fighting for food. It looks like we are preparing to spend lots of money under the pretense of lowering CO<sub>2</sub> but will just be passing the problem down to future generations since it is not 'Politically Correct' to discuss population control. In case you do not think population is increasing, start with your Grandma and Grandpa. They probably had one house and one car. Now, determine how many houses and cars are being used by their descendents.

Water is one of the limiting resources. Historically, runoff from most streams in Montana has varied from about 50% average to 160% average. However, much of the development has been based on near average water supply. California is experiencing shortages again. Don't be surprised to see a resurgence of the NAWAPA

plan which was generated during some of the drier years in the 1950's. It would take water from as far north as Alaska and from tributaries it crosses and transports it by canal through British Columbia, down the west side of the Continental Divide to California. Another canal would take water from Alberta and from tributaries it crosses, through Montana to Arizona for production of crops.

We need to remember that 1934 was still one of the warmest years on record for Montana (NOAA's Climate at a Glance). By starting with 1970's data, trends are much different than those starting in 1895. If CO<sub>2</sub> causes warmer temperatures, what was the CO<sub>2</sub> in 1934? Did CO<sub>2</sub> cause the droughts in the 1930's? If CO<sub>2</sub> is the culprit, how come it correlates poorly with climatic variables over longer time periods? However, CO<sub>2</sub> does have a very high correlation with population. What is the ideal level of CO<sub>2</sub>? If Montana wants warmer temperatures to grow certain crops but Florida wants cooler temperatures for their retirees, who has priority? If the population continues to double every 50 or so years, how long is it before the food needed to support the population exceeds our ability to produce enough food?

In order to reduce the US 2006 energy consumption by 10% by 2030, some of the information I have read suggests it will take about 145 nuclear plants, 33,000 solar thermal plants or 131,000 wind turbines to replace coal fired generators. Increased demands of 1.5% per year would require an additional 20% generating capacity to keep up with increases between now and 2030.

### **Regional changes in summer climate in the North American northern Great Plains: Is Montana experiencing the cooling trend observed in the Dakotas and Prairie Provinces?**

*Gabriel Bromley, Montana State University, gbromley@wisc.edu, Additional Authors: Paul Stoy, Montana State University*  
The average annual temperature in Montana has increased by over 1 °C from the 1950s until the present, similar to global warming trends. Precipitation in MT has neither increased nor decreased over the same time frame and instead exhibits multi-year cyclical trends. The end result is an increase in aridity across MT as greater atmospheric demand for water has not been met with an increasing supply of water on average. Embedded within these annual statewide patterns are important seasonal and regional changes that warrant further study. For example, maximum summer temperatures have decreased by ca. 2 °C, relative humidity has increased by some 7%, and summer precipitation has increased by an average of 10 mm/decade since the 1970s across parts of the Canadian Prairie Provinces. The Dakotas have also experienced a cooling trend during summer months that contrasts global warming patterns over the same time frame. This cooling effect is thought to be due to the role of summer fallow reduction on atmospheric boundary layer processes. Namely, more planted acres have resulted in an increase near-surface temperature and moisture, and an increase in evaporation versus sensible heat flux, which combined have increased the likelihood of convective precipitation and cloud formation. It is unclear if these trends in summer climate have also impacted MT, which has likewise seen a decline in summer fallow in favor of crops, but to a lesser degree and with different timing than neighboring North Dakota and Saskatchewan. Here, we mine climate station observations and climate reanalysis products to quantify the area and seasonality of the North American northern Great Plains cooling trend. We focus our analysis on climate trends in Montana on ascertaining if land management changes are consistent with climate changes as has been found in regions to our north and east. Results demonstrate that there is reason to believe that parts of MT have experienced a cooling, or at least not a warming, trend during summer, but detailed climate models are necessary to determine if these changes are due to land management changes. The statistics of convective precipitation have likewise changed but must be interpreted in the context of the multi-annual precipitation signal. Identifying the dynamics of the North American northern Great Plains "warming hole" is an important first step for quantifying the role of land management in the climate system across the region.

**Evaluating climate change impacts on water quality using mechanistic receiving-water models-**  
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The Western United States will likely experience earlier snowmelt, increased spring flow, and decreased

summer flow in the future on account of global climate change. Large river basins like the Missouri, Clark Fork, and Yellowstone River are projected to experience changes in magnitude, timing, and duration of water yield under different warming and precipitation scenarios. While lower summer flows will impact Montana's aquatic resources by increasing water temperature and causing thermal stress, such changes are just the tip of the iceberg when it comes to water quality. Trickle-down effects are more widespread and include changes in trophic state or whole system shifts in water quality. In this regard, the full impact of climate change on water quality will likely not be understood until a sufficient suite of studies have been conducted to evaluate site-specific responses.

Existing mechanistic water-quality models provide a framework to assimilate knowledge and information about expected behavior of water resource systems. Such models can readily be linked with downscaled climate projections to compute expected changes in water quality. While alterations in streamflow and air temperature or atmospheric conditions influence the energy balance, advective or dispersive mass transport (residence times), biological and chemical kinetics, oxygen solubility, pollutant concentrations, and many other factors, the interrelationship of these variables requires further exploration. This talk provides a basic overview of the deterministic linkages in existing receiving-water models that make water-quality effects of climate change predictable. We then examine the application of these principles to one river in Montana (Yellowstone River) where downscaled CMIP3 and CMIP5 climate and hydrology projections are evaluated using an existing mechanistic water-quality model.

### **A watershed prioritization framework for directing conservation efforts in the face of climate change, Upper Missouri Headwaters, Montana**

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In the North American Rocky Mountains, reliable late summer water in perennial streams is necessary to sustain in-stream habitat, support healthy riparian vegetation, and maintain diverse and productive wetland habitats. Flow data shows, however, that the major trend is a decline in late summer flows across the western United States driven by climatic change that has shifted the ratio of precipitation toward less snow and earlier snowmelt. The shifts in snow distribution and melt patterns changes the timing of groundwater discharge to streams, impacting late season flows. In a region that is already water limited, conservation of stream and riparian habitats has been an important focus for decades, yet the selection of projects is often based on species conservation or improvement of degraded habitat and does not consider whether a stream can buffer the effects of climate change. To aid in conservation planning, we are developing a classification scheme that includes relative watershed resilience to climate change. Our classification is based on the total area of a given watershed that serves as snow refugia during the melt season. The elevation, total incoming solar radiation and slope are all variables that we hypothesize are 1st order drivers, and immutable properties of river basins, that control whether an area of a basin serves as a snow refuge. We are testing our predictions across thirty 12 digit Hydrologic Unit Code (HUC) watersheds in the Upper Missouri Headwaters (UMH) area of southwest Montana. Watershed areas range from 3900 - 16,290 hectares and all contain at least 900 hectares above 2400 meters. For each watershed we summed the total area that met our snow refuge requirements: > 2400 m elevation, slopes between 15 and 30 degrees and areas with low accumulated solar radiation during the melt season. Low solar radiation levels were defined using natural breaks in June accumulated solar radiation data and were adjusted based on snow patches from June satellite and aerial imagery data over multiple years. Flow data was collected in late summer in 2014-2016. In addition, flow data was collected in 2012, 2014-2016 for 3 sets of paired watersheds to constrain for weather patterns and geological effects on hydrology. Analysis of late-season flow data, shows that the total area of snow refugia within a basin is a better predictor of discharge magnitude than basin area, or even high elevation basin area, alone. Data from our paired watersheds shows that watersheds with northerly orientations, and thus greater area of snow refugia, have late season normalized flow rates that are 1.3 - 2.6 times those of their southerly oriented pair. Our classification tool provides a framework for understanding watershed climate resiliency quickly, across large areas of the landscape, from

which more careful analysis can develop. Looking at watersheds in terms of climate resiliency has provided a jumping off point for conservation projects in the UMH that seek to enhance late-season flows by changing land management practices to increase alluvial aquifer storage. The increase in storage will improve critical late-season flows for wildlife and habitat.

### SESSION 3 Isotopes, Evapotranspiration, Forestry

#### **Ecosystem water-use efficiency in a flood-irrigated malt barley field in south-central Montana**

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There are over 2 million acres of irrigated land in Montana, of which 64% is diverted from surface streams. Strategically utilizing water sources can be beneficial for conserving water and irrigation efforts while simultaneously maximizing economic gain and agricultural yield. However, few studies to date have quantified the water use efficiency of irrigated crops in Montana. Here, we use the eddy covariance technique to simultaneously measure evapotranspiration of water and the net ecosystem exchange of carbon dioxide, from which carbon uptake through photosynthesis can be estimated, across the growing season in a flood-irrigated malt barley field in Huntley, MT. We find that the 'crop coefficient,' or the ratio between actual surface conductance to water and that of an idealized crop, reaches only 0.6 when using the Priestley-Taylor equation to estimate reference ET. These findings are less than expected for a barley crop, and could be in part due to heating of the cold Yellowstone River water used to irrigate the crop. Total evapotranspiration was approximately 17 inches from mid-May until mid-August. Net ecosystem carbon exchange frequently exceeded  $-30 \text{ mol m}^{-2} \text{ s}^{-1}$  during the peak of the growing season (using the micrometeorological convention where negative values represent ecosystem carbon uptake) and the seasonal pattern of carbon uptake reflected crop growth stages. As a result, ecosystem water use efficiency decreased as a function of growth stage, frequently taking values of  $0.2 \text{ mol J}^{-1}$  during May and June and values approaching zero already beginning in July. These results highlight the importance of crop growth stage for interpreting carbon flux and water flux and thereby water use efficiency. Results also point to the importance of quantifying energy flux into the cold irrigation water in this unique cropping system, which reduces the amount of energy available for evapotranspiration. Future studies should compare flood, drip, and pivot-irrigated barley and wheat agroecosystems in Montana to understand how management efforts impact water use, carbon gain, and crop yield.

#### **The role of agricultural management on the flux of water, carbon and heat to and from Montana agroecosystems and implications for precipitation processes**

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The area of summerfallow has decreased by tens of millions of acres since the 1970s in the northern North American Great Plains as producers have recognized that avoiding fallow usually confers economic benefits. This shift toward cropping coincided with a  $6 \text{ W m}^{-2}$  decrease in summertime radiative forcing and associated increase in precipitation that is consistent with the effects of fallow reduction on cloud formation processes. A large region of central North America is cooler now in the summertime than it was four decades ago, a trend that counters observed global warming. Research on this 'warming hole' to date has focused largely on the Canadian Prairie Provinces; the role of regional-scale changes in agricultural management on boundary layer climate has yet to be ascertained in the U.S. Northern Great Plains, including Montana. To address this knowledge gap, we used the eddy covariance method to measure fluxes of carbon dioxide, latent heat, and sensible heat in Montana dryland winter and spring wheat, irrigated winter wheat and barley, and summer fallow and used

these observations to drive models of atmospheric boundary layer and lifted condensation level height. Evapotranspiration in the dryland wheat crops was over 100 mm greater than the  $275 \pm 39$  mm observed in the fallow field during the study period. Surprisingly, cumulative sensible heat flux during the growing season was of similar magnitude in the dryland wheat and irrigated barley despite negative sensible heat flux after irrigation events in summer because of the early harvest of the barley crop. Modeled maximum daily atmospheric boundary layer height was up to 900 m higher as a result of fallow versus dryland spring wheat, but the modeled atmospheric boundary layer and lifted condensation levels crossed more frequently in the fallow scenario, a necessary but not sufficient condition for convective precipitation. Results indicate that the timing of agricultural management practices can be as important to surface-atmosphere exchange processes as the crop itself and that the role of agricultural management in altering near-surface temperature and moisture - and thereby the lifted condensation level - is critical for understanding regional precipitation processes.

### **Shallow lake-bed sediments: connections between geochemistry and microbiology. A case study from Georgetown Lake, MT.**

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Our research group has been studying the biogeochemistry and microbiology of the water column and more recently the sediment processes in Georgetown Lake for about 8 years.

These previous studies have documented seasonal anoxic conditions near the lake bottom, with stratification that takes place during periods of ice cover. These conditions contribute to accumulations of reduced species such as methane, hydrogen sulfide and ammonia in the bottom 1.5-3 m. These studies have also recorded the increase in dissolved methane in this anoxic zone during the winter with dramatic decreases in concentration when ice leaves the lake; presumably leading to significant release of methane to the atmosphere.

More recent work includes a multi-disciplinary study in order to better understand the lake water-sediment interactions including quantification and sequencing of microbial 16S rRNA genes in a sediment core in conjunction with stable isotope analysis of carbon, nitrogen and sulfur. A pore water sampler was also used to gain insight into the composition of dissolved solutes within the sediment matrix. Sediment cores showed a general decrease in total carbon with depth which included a decrease in the fraction of organic carbon combined with an increase in the fraction of inorganic carbon. One sediment core showed a maximum concentration of dissolved organic carbon, dissolved inorganic carbon and dissolved methane in pore water at the 4 cm depth which corresponded with a sharp increase in the abundance of 16S rRNA templates as a proxy for the microbial population size as well as the peak abundance of a sequence affiliated with a putative methanotroph.

Using sediment core carbon concentrations, predictions were made regarding the breakdown and return of stored carbon per year from this temperate climate lake with as much as 1.3 Gg C/yr being released in the form of carbon dioxide and methane.

### **Landscape Heterogeneity Modulates Forest Sensitivity to Climate**

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At the scale of large forested watersheds, water and energy limitations have been shown to strongly influence net ecosystem productivity. However, previous work has provided little insight into how hillslope topography may modulate spatial patterns of plant available water and microclimate that lead to differences in forest growth. We analyzed 331 tree cores from three coniferous tree species across topographically driven climatic conditions and various hillslope positions in the Lubrecht Experimental Forest, Montana, USA. We com-

pared the annual basal area increment (BAI) to measures of the annual climatic water deficit and topographic indices derived from Light Detection and Ranging (LiDAR) digital elevation models. Our results indicate strong relationships between measures of BAI and the topographic wetness index, with differing slopes dependent on tree species. Generally, trees located in wetter landscape positions (hollows) exhibited greater annual basal growth relative to trees located in drier landscape positions (sideslopes). At the watershed scale, we evaluated the relationships between landscape position, LiDAR derived estimates of basal area and seasonal patterns of the Landsat derived Normalized Difference Vegetation Index (NDVI; 1984-2012). These analyses indicated enhanced growth in landscape positions with decreased climatic water deficits (local convergence and northerly aspects). These observations suggest that the topography of semi-arid watersheds is a necessary consideration for quantifying conifer productivity and resiliency, due to its potential to mediate local microclimate, shallow soil moisture and subsurface water redistribution.

## **SESSION 4      Water Management, Groundwater/Surface-Water Interaction**

### **Over 150 years of Irrigation \_ Implications for Montana's Water Resources**

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Irrigation, with its beginnings in the Bitterroot Valley, has been ongoing in Montana since the 1840's. Two of the first five nationwide U.S. Bureau of Reclamation funded projects to support, '...the construction and maintenance of irrigation works for the reclamation of arid and semi-arid lands' were Montana's Milk River and Huntley Irrigation projects (Newlands Reclamation Act, 1902). The effects of more than 150 years of irrigation, including augmented groundwater recharge from canal leakage and excess applied irrigation water, are illustrated by reports produced by the Ground Water Investigation Program (GWIP) at the Montana Bureau of Mines and Geology (MBMG) and hydrographs available from the MBMG's long-term groundwater monitoring network.

Estimates of irrigation-induced recharge are pivotal to understanding water use, developing water budgets, and understanding groundwater and surface water dynamics. In the Dillon area, about 20 percent of annual flow in the Beaverhead River is attributed to late season irrigation returns. New proposals to take land out of irrigation in favor of other uses would modify that balance, and if not considered carefully, could have far-reaching consequences. In other GWIP studies, modeled simulations predict decreased groundwater levels and surface water flow as irrigators attempt to 'save' water by converting to more efficient irrigation practices. Water managers should consider the implications of irrigation-practice-related recharge and how more efficient practices such as lining canals, land use changes that remove land from irrigation, and conversion to more efficient irrigation methods might decrease seasonal water availability.

Conversely, knowledge about how recharge works and a more complete understanding how aquifers store and release water are building blocks that have the potential to increase groundwater and surface water availability when used to develop artificial recharge concepts.

### **15-Year Implementation and Effectiveness of the Weyerhaeuser Native Fish Habitat Conservation Plan in Montana**

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The Native Fish Habitat Conservation Plan (NFHCP) was approved by the US Fish and Wildlife Service (the Service) under the federal Endangered Species Act in 2000. This 30-year agreement conserves and enhances bull trout (*Salvelinus confluentus*), westslope cutthroat trout (*Oncorhynchus clarki lewisi*), and Columbia River redband rainbow trout (*Oncorhynchus mykiss gairdnerii*) habitat on 780,000 acres of Weyerhaeuser (for-

merly Plum Creek) timberland in western Montana. Biological goals of the plan are to maintain or improve '4 Cs' essential to trout conservation: Cold water, Clean water, Complex and Connected habitats. The NFHCP has 55 individual commitments to reduce sedimentation from logging haul roads, upgrade fish barrier culverts, provide effective buffers along streams during harvest operations, implement grazing management practices, place protective riparian deed restrictions on lands that are sold, riparian restoration, and research and monitoring the effectiveness of the NFHCP. Every five years, the Service conducts a major review of the NFHCP with Plum Creek, and determines if the plan is meeting its goals. If not, the plan can be modified through a framework outlined in the NFHCP. This framework includes a number of adaptive management 'triggers', which if observed, require evaluation of biological relevance, causal factors, and as warranted, revision of the plan. Earlier this year, a fifteen-year review of the NFHCP was conducted with the Service. This presentation describes the outcome of the review, including accomplishments of the plan for road and watershed restoration, results of adaptive management research studies, and effectiveness of the plan at meeting biological goals.

### **Water, Lawyers, and Grizzly Bears: A hydrologists study of the Teton River from the bottom of the food chain.**

*Aaron Fiaschetti, Hydrologist Montana DNRC, 1424 9th Ave, Helena MT, ariaschetti@mt.gov, 406-396-2944*

The Teton Watershed is located along the iconic Rocky Mountain Front northwest of Great Falls, Montana. Water supplies are limited in the Teton and irrigation has developed to 76,000 acres, using the majority of the water supply. This has led to a rich history of water right conflicts and persistent no-flow conditions on local waterbodies. Water users have adapted to limited supplies though the; development of off-stream reservoirs, bypassing a losing reach of the river, and improvements in irrigation efficiency. All of which alter the hydrology.

### **Water Management from the Trenches**

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Science and policy both play a key role in the management of water in Montana, but in reality how does that equate to actual water management and water conservation on the ground. Watershed groups, water planners, water commissioners, and hydrologists are often tasked with using data and policy to manage scarce water resources to meet the demands of existing uses in the state. While in some cases, a framework to implement water management and conservation strategies may be in place, results are not always realized without cooperation with the water users themselves. This talk will focus on approaches taken in some watersheds that work directly with individual water users and result in documented improvements to water use practices and increases in instream flows. It will provide examples of interactions and problem-solving with individual water users that have provided short-term and long-term benefits, as well as some approaches that did not work out so well and were chalked up to character building and lessons learned.

### **Using water temperatures to understand groundwater/surface-water interactions in Southwest Montana**

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Conjunctive management of groundwater and surface-water resources requires a firm understanding of how water moves between surface water bodies and aquifers. The direction of and the amount of flow is determined by the hydraulic gradient, and the rate at which water enters or leaves the subsurface. Streams may have gaining, losing, flow-through, and parallel-flow reaches; the reach type may change rapidly across short distances. Flow measurements, water elevations, and geochemical signals can be useful tools to determine the direction of flow, but each has drawbacks. Flow measurements have several challenges including: an inherent uncertainty of 5 percent or more; logistical difficulty of measuring all inflows and diversions; and that each measurement integrates flow for the entire reach. Stream and groundwater elevations clearly depict hydraulic gradients at specific sites; however, it is difficult to translate these gradients into overall system behavior, and hydraulic conductivity values are needed to estimate the amount of water moving to or from the stream. Geochemistry (e.g. electrical conductivity, major ions, radon, etc.) can provide information on groundwater/surface-water

interaction; however, resolution depends on the groundwater and surface water having distinct geochemical signatures, and is limited by the number of samples collected.

Water temperatures can be combined with other methods to provide a relatively inexpensive, reliable, means of helping to identify gaining and losing stream reaches. Water temperatures in combination with water-level elevations collected at sites in the Boulder Valley and Upper Jefferson River Groundwater Investigation Program (GWIP) areas greatly added to understanding surface/groundwater flow at these sites, as well as some aspects of seasonal changes in the flow directions. Comparison of diel and seasonal variations in stream temperatures with groundwater temperatures and hydraulic gradient measurements confirmed that temperatures were useful in defining sites where streams were gaining or losing, and improved confidence in these designations. In the Upper Jefferson River GWIP area stream temperature measurements were compared over time at sequential surface-water stations to evaluate seasonal stream temperature differences. Reaches where there was cooling in the summer, warming in spring and fall, and the changes were greatest during low flow were identified as strongly gaining. Thermal imaging at Alkali Creek and Long Creek will be conducted in August 2016, and are expected to show small scale variations in gains and losses, which will be combined with in-stream temperature monitoring and flow monitoring to better understand the effects of beaver complexes on gains and losses. Temperature information combined with other measurements provides a more robust understanding of the hydrogeologic system, and this understanding aids in developing informed water management decisions.

## SESSION 5      Modeling

### **When and How Dynamic Hyporheic Temperature Mosaics Influence Channel Temperature Regimes**

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Because hyporheic residence times follow a power-law distribution and residence time determines hyporheic temperature, the temperature pattern of hyporheic water returning to the channel is spatially variable and changes over time. Therefore, hyporheic exchange may alter diel and annual channel temperature cycles in complex ways. We developed a simple 2D stream temperature model that simulates heat exchange among the atmosphere, channel, and hyporheic zone. The model partitions the hyporheic zone by residence time, tracks the temperature of water returning to the channel from each partition, and thus simulates the resulting influence on stream channel temperature. We performed a sensitivity analysis by varying the magnitude of hyporheic exchange in a model stream reach. Model results reveal a non-linear, multi-metric, whole regime response in channel temperature due to hyporheic exchange. We are able to identify these patterns in field data where substantial hyporheic influence is expected.

### **Changing irrigation practices in the Jefferson River Valley; potential impacts on the river and tributary streams near Waterloo, Montana**

*Ali Gebril, Montana Bureau of Mines and Geology, agebril@mtech.edu*

Willow Springs and Parson's Slough near Waterloo are groundwater-fed streams that provide late summer flows of 40 to 60 cubic feet per second (CFS) of relatively cool (~12°C) water to the Jefferson River. There are concerns that changes in irrigation management practices, such as lining canals or changing from flood to pivot irrigation, may decrease the volume or change the timing of groundwater flow that reaches Willow Springs, Parson's Slough, and the Jefferson River.

Both streams provide important spawning habitat for brown and rainbow trout. Also, direct groundwa-

ter inflow to the river is critical during low flow conditions to maintain pool connectivity, and to lower river temperatures. Near Waterloo, significant groundwater flow that directly reaches the river originates as leakage from the Parrot and Creeklyn irrigation canals, and subsurface drainage from flood irrigated fields.

A numerical groundwater flow model was developed using MODFLOW 2000 to evaluate impacts from changing irrigation practices on Willow Springs, Parson Slough, and the Jefferson River. The model design was based on a conceptual model derived from analysis of groundwater and surface-water monitoring data; aquifer tests; well logs; and GIS analysis of soil, climate, vegetation, land-use, and water-rights data. A steady-state version proved model performance under long-term average field conditions and demonstrated model sensitivity to input parameters. The transient version simulated time-dependent stresses such as seasonal irrigation activities and changes in precipitation. The transient model was also used to run several predictive scenarios, extending simulation times to year 2025. Specific simulations included reduced canal seepage resulting from lining canals and reduced groundwater recharge resulting from flood to pivot irrigation conversion. Extreme case scenarios (all canals lined and/or all flood irrigation areas converted to pivot systems) estimated reduced flows to the Jefferson River from Parson's Slough and Willow Springs to be 6 to 7 CFS during August, in addition there would be a 6 to 11 CFS decrease in direct groundwater flow to the Jefferson River from flood irrigated fields (combined reduction up to 17 CFS).

### **NOT another MODFLOW talk: Using models to understand the Gallatin Valley Aquifer and analyze changing water use**

*Mary Sutherland, MBMG, 1300 W Park Ave, Butte, Montana 59701, simoriahtyler@hotmail.com, (406) 496-4410*

In the groundwater world, the term 'model' elicits thoughts of MODFLOW. The definition of a model is "any representation of a real system" and as such, we are all modelers. Groundwater scientists use many types of models to interpret data, develop an understanding of the hydrogeologic system, and to demonstrate the system to technical and non-technical audiences. From a general conceptual model to a refined transient MODFLOW model, everyone models. The Groundwater Investigation Program (GWIP) uses a variety of models to answer an assortment of water resource questions. For example, GWIP investigators working in the Gallatin Valley have used an array of models to address questions about water development and changing land use:

- A conceptual model to understand the basic flow and connectivity of surface and ground water.
- A "Surfer" model to communicate technical understanding of a complex system to multiple non-technical audiences.
- A GIS model to calculate the daily evaporation from land surfaces using LANDSAT infrared data to determine how subdivision density affects water consumption.
- An Excel spreadsheet model to quantify drawdown expected from pumping to determine how aquifer characteristics affect distance-drawdown.
- Numerical MODFLOW models to evaluate stream depletion for a potential public water supply system and predict the potential impact of future development.

These analyses were used to address water resource questions posed to GWIP, and all of these analyses qualify as models. Each model addressed a specific question that the others could not answer as effectively or efficiently, yet most groundwater scientists consider only MODFLOW when thinking of models. Groundwater scientists frequently utilize a wide variety of models, often without realizing that they are, in fact, modeling.

### **A Groundwater Flow Model for a part of the Central Bitterroot Valley, Ravalli County, Montana**

*Kirk Waren, Montana Bureau of Mines and Geology, Montana Bureau of Mines and Geology, 1300 W Park St, Butte, MT 59701, kwaren@mtech.edu, (406) 496-4866*

The Montana Bureau of Mines and Geology (MBMG) has developed a three-dimensional numerical groundwater flow model for a two- to three-mile wide section of the Bitterroot Valley between Corvallis and Stevensville, Montana. The model combines hydrogeologic parameters with accurate placement of surface water features and flows to provide a tool to evaluate how major changes in irrigation operations would impact groundwater levels and surface water flow. An extreme example, in which cessation of all irrigation activ-

ity is modeled, suggested that seasonal outflow in the Mitchell Slough near Stevensville would decrease about an order of magnitude, from about 90 to 9 cfs. Groundwater levels in irrigated areas that are a mile or more away from the river are presently elevated 5 to 10 feet above the river because of seasonal irrigation recharge. In the no-irrigation model run, groundwater levels declined to about the altitude of the Bitterroot River. The model can be used to evaluate system responses to various types of hydrologic stresses. When the project report is completed, several versions of the groundwater model will be available from the MBMG publications website.

## SESSION 6 Microbiology I

### **CLADOPHORA BLOOMS AND ECOSYSTEM DEVELOPMENT: IMPLICATIONS FOR RESTORATION OF THE UPPER CLARK FORK RIVER, MT**

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Restoration of the Upper Clark Fork River, MT represents a landscape-scale effort to address remediation and recovery over 190 km of river. State agencies, including the MT Department of Environmental Quality (DEQ), Natural Resource Damage Program (NRDP), and Fish, Wildlife, and Parks (FWP), have been working closely with the stream ecology lab at the University of Montana to coordinate assessment of a 55 km reach where depauperate fisheries are subject to thermal and nutrient loadings. Abundant phosphorous (SRP, 20-45 ppb) and scarce inorganic N (DIN, 4-8 ppb) suggest N limitation during summer. During base flow conditions, excessive blooms of the green algae, *Cladophora*, frequently reach 600 mg/m<sup>2</sup>, simplify river bottom habitats, translate to low oxygen concentrations in near-bottom water (0.2 mg/L maximum), and generate suspended particulate organic matter concentrations (100 - 500 mg/L) that approach those of the Amazon River. Over the course of the bloom, *Cladophora* mats entrain partially decomposed organic matter that may influence metal abundance and form with implications for macroinvertebrate community composition. In the context of human influences on river complexity, *Cladophora* may act as an endogenous driver of ecosystem structure and function, and bloom phenology may control ecosystem form and function with implications for river food webs and game fisheries.

### **Defining Microbial Habitats in Mining Impacted Watersheds**

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Microbes are an essential part of any ecosystem. Microbial diversity, abundance, and activity integrated with water quality serve as indicators of environmental health. We collected planktonic and sediment microbial communities at 13 locations along the Upper Clark Fork and headwaters concurrent with a suite of full geochemical analyses in order to determine a baseline for microbial health in the Clark Fork watershed. Our geochemical analyses include in situ measurement of temperature, pH, conductivity, and dissolved oxygen by meters, field spectrophotometric analyses of redox active species, and simultaneous sample collection and preservation for laboratory analysis of oxygen and deuterium isotopes in water, major cations and anions, trace elements, and dissolved inorganic and organic carbon. DNA extraction of sediment samples has proven successful and PCR amplification using universal, eukaryotic, bacterial, archaeal small subunit ribosomal RNA genes has yielded products for sequencing. Integration of microbial diversity with water quality parameters will help establish the health status of the mining impacted Clark Fork Watershed.

### **Identifying the source, pathways, and rates of enhanced microbial coalbed methane production in the Powder River Basin**

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From 2000 to 2012, combustion of coal accounted for 46% of the global primary energy supply. When used for electricity generation, coal combustion produces 2x the CO<sub>2</sub>, 4x the NO<sub>x</sub>, and >100x the SO<sub>2</sub> and Hg compounds per kWh than burning natural gas. In the Powder River Basin where most of the coal is too deep to be mined by conventional means, indigenous microorganisms produce biogenic coalbed methane (CBM). Natural CBM production rates are slower than those of commercial gas collection, resulting in short well lifespan and many abandoned wells. Developing economically feasible in situ strategies for increasing the rate of coal to methane bioconversion will provide a cleaner and renewable alternative to conventional coal, extend the life of already existing CBM production wells, and reduce the need for additional well drilling.

Previous studies have demonstrated enhanced biogenic CBM production in the laboratory by stimulation with nutrient addition. To improve the understanding of the mechanisms of CBM stimulation, different biostimulants (microalgae, cyanobacteria and yeast) were added to coal from the Powder River Basin (Montana) and non-coal containing treatments at two concentrations (0.1 g/L and 0.5 g/l). In 111 days, the unstimulated, coal-only condition produced 676 µg CH<sub>4</sub>/g coal at a maximum rate of 16.3 µg CH<sub>4</sub>/g coal/day. All biostimulated treatments demonstrated CBM enhancement relative to the unstimulated treatments in excess of the expected methane production from the stimulant itself. The lower biostimulant concentration resulted in a 2.5X increase in total methane production and 3X the maximum rate. The higher biostimulant concentration resulted in a 3.5X increase in total methane and 4X the maximum rate. All non-coal conditions produced less methane overall and had lower maximum production rates when compared to coal conditions. However, methane production in non-coal conditions were greater for yeast extracts compared to the algal or cyanobacterial biostimulants. This presentation will provide details of our efforts to delineate the exact pathways of CBM enhancement by combining isotopic labelling and microbial community analysis approaches with traditional productivity enhancement experiments.

## SESSION 7 Site Characterization

### **The Flathead Valley Deep Aquifer: Part I\_The three-dimensional digital geologic model**

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A deep, confined, sand and gravel aquifer supplies high-capacity municipal and irrigation wells in addition to thousands of domestic wells throughout the Flathead Valley. A growing demand for groundwater has raised concerns about the long-term sustainability of the deep aquifer and whether pumping from it will impact surface water resources. As a result the Montana Bureau of Mines and Geology-Ground Water Investigations Program (GWIP) initiated a hydrologic study of the deep aquifer. A need was identified during the study for more information about the subsurface geology.

To address these information gaps, and other concerns, GWIP needed to: 1) define the topography of the top of the deep sand and gravel, 2) map the trough features in the top of the deep aquifer, 3) investigate the continuity of the confining silt and clay layer that overlies the deep aquifer, 4) determine if the deep aquifer and the confining unit extend beneath Flathead Lake and (5) if these units are present, does the confining unit separate the aquifer from the lake. Troughs have been identified in the surface of the deep aquifer that are filled with lacustrine silt and clay. These troughs could impact groundwater movement in the deep aquifer.

GWIP developed a three-dimensional, digital, subsurface geologic model using data from previous geologic studies and driller's logs. The geologic model contains six hydrostratigraphic layers, beginning at the valley bottom: Layer 1-The Belt bedrock that surrounds the valley; Layer 2-Tertiary sediments infilling the bottom of the valley; Layer 3- the deep sand and gravel aquifer; Layer 4- the upper deep sand and gravel; Layer 5- the confining unit; and Layer 6- the shallow sand and gravel. To construct the model, lithologic intervals from well logs were assigned to one of the six layers based on estimated hydrologic properties. Gravity survey measurements and seismic data were used to define the depth to bedrock and bathymetry was used to estimate sediment thickness above the bedrock and beneath Flathead Lake. To construct the model, digital well coordinates and contact elevations were used to form TIN surfaces representing the top of each hydrostratigraphic unit.

The model digitally recreated the surface topography of the deep sand and gravel, including the traces of eroded troughs. Previously unidentified troughs and other depressions were also identified. The modeled confining unit revealed the variability in the thickness of the unit, and showed areas where gaps in the confining layer may exist. Using modeled results, the subsurface geology was defined at the north shore of Flathead Lake and the deep sand and gravel and confining unit were projected beneath the lake using seismic and bathymetric data, to show a possible stratigraphic scenario.

The 3-D geologic model is a valuable tool to graphically depict subsurface geology and provides the ability to construct cross sections through any part of the model. As a planning tool, it can be used for locating water supply wells and aid in interpreting the hydrogeology at specific locations in the valley.

### **The Flathead Valley Deep Aquifer: Part 2 \_ Some Hydrogeologic Aspects of the Flathead Valley Deep Aquifer**

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The Flathead Valley deep confined aquifer supplies high-capacity municipal and irrigation wells in addition to thousands of domestic wells. Continued groundwater demand has raised concerns about the long-term sustainability of the deep aquifer and whether pumping from it will impact surface water resources. Three research objectives were established in order to address these concerns: 1) Explain long-term and seasonal water-level trends in the deep aquifer; 2) Investigate and report the geologic configuration and hydrogeologic characteristics of the confining unit; and 3) Identify possible sources and mechanisms of recharge and discharge in the deep aquifer. This presentation is focused on the hydrogeologic objectives.

Groundwater flow through the entire deep aquifer is estimated to be about 200,000 acre-feet per year. Annual pumping from all wells is estimated to be about 25,000 acre-feet. Groundwater in the deep aquifer flows south in the direction of Flathead Lake, although actual discharge to the lake has not been identified or confirmed. Water levels in both the lake and deep aquifer follow minimally similar trends and changes in discharge from the lake have not been successfully correlated with deep aquifer pumping. Pumping creates broad, seasonal groundwater level declines that recover in most areas each year. Multi-year groundwater level declines in the deep aquifer have been documented in very few locations and are not occurring aquifer-wide.

Recommendations that resulted from this research include maintaining long-term groundwater monitoring and establishing (or clarifying) roles of a local water management organization. In addition, properly plugging and abandoning wells that are no longer in use will reduce loss of water and paths of contamination to the deep aquifer. The deep aquifer is a phenomenal resource, that can both be used and conserved.

### **Mountain Block Recharge in Western Montana**

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The hydrogeology of intermontane basins in western Montana has been characterized mostly by the Montana Bureau of Mines and Geology, the U.S Geological Survey, and researchers in the Montana University System. The characterizations often include definition of the geologic framework that controls movement of groundwater, evaluation of the chemical quality of groundwater and differentiation of groundwater recharge/discharge. Mountain-front recharge is a component of intermontane basin recharge that originates in an adjacent mountain block and is recognized as an important recharge component not only in Montana, but throughout the world. That recharge enters the basins from mountain blocks is reasonably well understood, but how are the mountain blocks recharged? In Montana, mountain blocks receive most of their annual precipitation during November through March when evaporation is very low; the precipitation accumulates as ice or snow until the snow pack slowly melts during a four- to six-week period each spring. Snow depths greater than 30 inches provide enough insulation to thaw previously frozen ground or prevent it from freezing. In the spring, the daily snow melt typically does not exceed the infiltration rate of the soil, and the melt will sink into the ground; there is little evidence of overland flow underneath snow packs. No plant consumption or evaporation occurs during snowmelt, so all of the melt water infiltrates the soil. Once in the ground, the water enters local, intermediate, or regional groundwater flow systems within joints, faults, and fractures. These openings transmit water through the mountain block to streams and into the adjacent basins. It is the increase in groundwater discharge from the local systems to streams that makes up what has been traditionally described as the direct runoff portion of a stream hydrograph (Freeze and Cherry, 1979; page 223). Groundwater discharge from regional, intermediate, and to a lesser extent, local flow systems sustains streamflow in many of Montana's streams throughout the rest of the year. In contrast to melt-water recharge, plant use and evaporation reduces the amount of late spring and summer precipitation that may potentially recharge the mountain block.

### **Baseline Water-Quality Investigation, Emigrant Creek Watershed, Southcentral Montana**

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In June of 2015 Lucky Minerals Inc. submitted an exploration plan to assess the presence of base and precious metals in the Emigrant Creek watershed, approximately 7 miles SE of Emigrant, Montana. The plan called for exploratory drilling on US Forest Service lands and on private patented claims. In October 2015, prior to the proposed drilling, the Montana Bureau of Mines and Geology characterized baseline water-quality in the Emigrant Creek and East Fork of Emigrant Creek drainages. Water samples were collected from 17 groundwater and surface water sites, and analyzed for major ions; trace metals; stable-water isotopes of oxygen and hydrogen; and tritium.

Although all the sampled water had <300 mg/L total dissolved solids (TDS), the dissolved constituent concentrations and the pH varied. The TDS for the groundwater and surface water samples ranged from 59 to 271 mg/L. Acidic (field pH < 3.0), metal-rich, SO<sub>4</sub>-type water was observed in the sample from the Allison Tunnel adit discharge and in samples from two nearby springs. Moderately acidic (pH 5.8 - 6.1) Ca-Mg-SO<sub>4</sub>-HCO<sub>3</sub>-type water was observed in two samples from the East Fork of Emigrant Creek and in samples from two springs in the East Fork drainage near the St. Julian mine. Surface-water samples from Emigrant Creek and spring, and groundwater samples from the Emigrant Creek drainage, had neutral pHs (7.2 \_ 7.8) and were of a Ca-Mg-HCO<sub>3</sub>-SO<sub>4</sub>-type.

The proposed exploratory drilling is about 6 miles east of Chico Hot springs and about 2,500 feet higher in elevation. High elevation catchments can be important sources of groundwater recharge to adjacent lowland areas. However, there is no clear hydrogeologic or geochemical evidence to suggest that water from the Emigrant Creek watershed is connected to the geothermal system that feeds Chico Hot springs.

### **The Mystery of the Butte Sinkhole**

*Willis Weight, Carroll College, 3781 Yuhas Ave, Helena, MT 59602 USA, weightws@gmail.com*

In July 2012 a sinkhole appeared in the backyard of a resident at 3210 Phillips Street in Butte Montana. The sudden appearance of the sinkhole terrified the resident and a request was made to determine its cause and the likelihood of the resident's home being in danger. Field investigations were conducted along with a rainfall analysis to determine probable cause. Rainfall events with significant intensities have produced runoff occurrences that have contributed to the problem over time. For example, approximately 100 storms producing in excess of 0.25 inches of rain occurred between 2008 and 2013 alone. It was ascertained that there was a connection with other historical water problems in the area. Broader and local dynamics over time had changed the nature of the surface and groundwater interactions and the surface and subsurface impacts. This presentation documents the connection of water problems from 20 and 40 years earlier and changing ecological conditions to bring about the resulting sinkhole.

The ability for the resident to obtain justice for damages was mostly evaded and the problem remains. The hope for improved conditions in the future is unlikely unless broader responsibility for water problems in the area is accepted.

## **SESSION 8      Microbiology II & Water Quality**

### **Modeling Dissolved Oxygen in Effluent and Macrophyte Rich Upper Silver Bow Creek**

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Silver Bow Creek (SBC, Blacktail Creek to Warm Springs Creek) is a small urbanized stream in western Montana (MT) identified as impaired for nitrate, total nitrogen, and total phosphorus on the 2016 303(d) draft list. Nutrient enrichment of upper SBC is believed to occur primarily from a single municipal point source (Butte WWTP) resulting in excessive primary production and macrophyte growth that impacts aquatic life and primary contact recreation. Macrophytes photosynthesize during the day in excess of reaeration driving dissolved oxygen (DO) well above saturation. At night they consume oxygen through respiration. Such conditions cause large diel DO swings that with additional DO depletion from ammonia oxidation creates nightly hypoxic conditions that likely impair aquatic life uses in SBC.

QUAK2K, a surface water-quality model, was used to evaluate the effects of effluent nutrient management scenarios on spatial and temporal variation of DO in SBC. Data collection in support of model development included: (a) continuous DO, conductivity, temperature, and pH measurement using YSI Exo Sondes, (b) sampling of nutrients, suspended solids, alkalinity, and sediment oxygen demand at four locations, and (c) acquisition of meteorological data. Data was collected before (2016 summer) and after (2017 summer) a significant Butte WWTP upgrade intended to reduce the effluent loads into SBC. Since QUAL2K does not currently support macrophytes, they were incorporated into the model as oxygen equivalents using closely spaced point sources with diurnal variation. Field experiments were conducted to measure the macrophytes photosynthesis and respiration rates and these rates were combined with the spatial distribution of macrophytes to appropriately reflect their influence on the oxygen mass balance. This presentation will discuss the new methodology to incorporate macrophytes in QUAL2K, future work to include macrophytes as a model state-variable, and the modeled DO response to different effluent loads.

### **How will climate change affect attached algal levels in Montana rivers?**

*Vicki Watson, University of Montana, Environmental Studies, University of Montana, Missoula, MT 59812 USA, vicki.watson@umontana.edu, (406) 243-5153*

Some of Montana's hard water streams have heavy growths of filamentous algae in some years, interfering with recreation and lowering nighttime oxygen levels below state standards.

The heaviest growths occur in years preceded by a few years with little ice scour and little scour by spring high flows. And the oxygen depleting effects of the dying algae are most pronounced in lower flow years with higher stream temperatures.

Predictions concerning climate change suggest that the conditions leading to the highest levels of algae and the greatest exacerbations of algae effects on water quality are likely to become more common and severe. Evidence will be presented from long term monitoring on the Clark Fork River for the connections between attached algae levels and flow patterns expected to be affected by climate change.

### **The Gallatin Microplastics Initiative: Watershed-scale data collection by adventure scientists**

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Microplastics are a growing environmental issue, posing potential threats to human and ecosystem health when they enter our waterways. Since early 2013, Adventure Scientist's ocean adventurers have collected surface water samples from every ocean across the globe to research microplastic pollution. The vast majority of the samples our volunteers collected were contaminated with plastic debris.

For this reason, we expanded our volunteer effort to focus on fresh water sample collections worldwide in 2015, and launched the Gallatin Microplastics Initiative as a targeted effort to understand plastic pollution and create change in the headwaters of the largest watershed in the lower 48 states.

In an Adventure Scientists pilot survey of five sites along the Gallatin River, microplastic particles were found in every sample, some in startlingly high numbers. With this knowledge, the full Gallatin Microplastics Initiative was launched in 2015/16 to study the abundance and types of microplastics found in Gallatin waterways.

Year one of the initiative brought great successes in high-quality data collection, volunteer management and community engagement. Adventure Scientists is now moving into the second year of the Gallatin Microplastics program, and will again employ 60+ highly trained adventure volunteers to collect water samples every three months from 70 sites across the watershed. As we continue to build this large baseline data set, we're also creating an in-depth picture of microplastic pollution, and hope to begin discovering its potential sources. This information will help us further understand the extent of the problem and how to move toward solutions.

### **Natural Arsenic Levels Flowing from Yellowstone National Park: Measured by Science and Managed by Policy and Regulation**

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Nationally and internationally, Yellowstone National Park is emblematic of all that is wild and natural. Ironically, the park's waters are a major source of a drinking water pollutant, arsenic, for many Montana communities. The geothermal waters from Yellowstone National Park are the main source of natural arsenic loads to the Yellowstone, Madison, and Missouri Rivers, resulting in concentrations that exceed the Montana human health standard of 10 ug/L. For example, water quality samples taken from the Madison River near the West Entrance to Yellowstone National Park average 300 ug/L, more than 30 times Montana's human health standard. The entire extent of the Madison River, which eventually forms the Missouri River, exceeds the human health standard for its entire extent. In the Missouri River, it isn't until below Fort Peck Reservoir that arsenic concentration consistently falls below the human health standard. Similarly, in the Yellowstone River, the arsenic concentration finally averages below the 10 ug/L standard near Forsythe, Montana. Under summer and fall baseflow conditions, the arsenic load remains relatively constant throughout these river reaches and dilution from tributaries is the main process for concentration reduction as the rivers flow through the state. Arsenic behaves conservatively in aquatic systems in Montana with minimal geochemical processes affecting the original Yellowstone National Park arsenic loads.

Within the United States, high natural concentration of arsenic in surface water is unique to Montana due to the magnitude of the geothermal activity and the resulting volumes of water flowing northward from the park. While this ecological condition is natural by any reasonable definition, the social management of the issue is complicated by the nature of arsenic. Arsenic is a carcinogen and public health drinking water supplies are the main concern. Ingested inorganic arsenic has been linked to increased incidence of cancer in lung, bladder, skin, kidney, and liver.

The Montana Department of Environmental Quality is conducting an investigation to characterize the actual level of natural arsenic in the Madison, Missouri, and Yellowstone Rivers. The activities and objectives of the investigation are (1) to review existing surface and groundwater data, (2) carry out basin-wide arsenic sampling, (3) undertake arsenic mass load modeling, (4) refine or develop water quality standards reflective of the natural arsenic load, and (5) work on public outreach. The model outputs will be used to demonstrate to the U.S. Environmental Protection Agency that the natural arsenic condition is elevated above the federally developed criterion of 10 µg/L, and is the first step towards Montana's development of an 'arsenic rule' followed by a longer process of policy development and water quality standards rule making.

### **Western Gallatin Valley Arsenic Distribution Project**

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The Gallatin Local Water Quality District (GLWQD) conducted a groundwater sampling project to further assess the distribution of elevated arsenic levels in the Gallatin Valley of southwest Montana. Arsenic is a known carcinogen and is related to a large variety of human health problems. The current U.S. Environmental Protection Agency (EPA) maximum contaminant level (MCL) for arsenic is 10 µg/L. Elevated arsenic (above the MCL) in drinking water is a problem in various locations throughout the globe, including some areas in Montana. Within the Gallatin Valley, existing data indicate the locations where elevated arsenic is present correspond to the Tertiary sediments on the western side of the valley, bounded on the west side by the Madison River Valley, and roughly bounded on the east side by the Gallatin River. The study focused sampling efforts on wells in or near this geologic area. Groundwater samples were collected from 23 wells to determine the arsenic concentration, nitrate concentration, and the species of arsenic. Sixty-one percent of the samples collected had arsenic exceeding the MCL. The vast majority of samples that were submitted for arsenic speciation had arsenic in the form of arsenate [As(V)], and undetectable arsenite [As(III)]. One sample collected from the edge of the study area along the Madison River Bluffs was an outlier in terms of the very high arsenic level (an order of magnitude greater than all other samples), as well as the arsenic species, and field parameter measurements. Residential wells were primarily used for the study so that the project results were directly relevant to those drinking the groundwater in the area. A fact sheet and an educational workshop were completed as additional project outreach communications to encourage other residents in the area to test their drinking water and to increase awareness of this drinking water contaminant in the Gallatin Valley.



**Evaluating the Influence of Irrigation on Groundwater in Northern Big Horn County**

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Previous work on the Bighorn Valley north of Hardin, Montana (Meredith and others, 2009) indicated that the primary source of recharge to the alluvial aquifer was from irrigation canal leakage, not the practice of flood irrigation. However, these findings contradict conditions documented in other irrigated alluvial valleys studied by the Montana Bureau of Mines and Geology. To investigate whether the Bighorn Valley is truly an anomaly or if findings from the earlier work were an artifact of an incomplete hydrogeologic picture, the Montana Bureau of Mines and Geology in partnership with the Big Horn Conservation District is creating a groundwater flow model in MODFLOW-2005 to tease apart the interrelated influences on groundwater quantity. The model is bounded by the Two Leggins Canal on the west, the Bighorn River on the east, and constant flux boundaries on the north and south. The areal extent is approximately 15 miles long by 4 miles wide. Published information from 83 boreholes (GWIC, 2016) including water-table elevations, total depths, and lithologies helped to define the stratigraphy, hydraulic conductivity, specific storage, specific yield, and porosities. Recharge was defined from annual average precipitation, irrigation diversions, and loss measurements along the irrigation canals and the Bighorn River.

A 2-layer 3D grid of 200 by 800 foot cells defined an alluvial upper layer as well as a shale bottom layer. The land surface elevation was determined by creating scatter points from the borehole data and interpolating the scatter points to the 3D grid. The bottom elevations of layer 1 (which also are the top elevations of layer 2) were created with the same process. An arbitrary elevation of 2,700 feet above mean sea level was chosen to represent the bottom of layer 2.

MODFLOW simulations characterized the movement of groundwater within the model and input parameters including aquifer characteristics and recharge rates were calibrated until the model replicated average annual water-level altitudes measured during the last three years in 11 observation wells. Transient simulations are ongoing to estimate relationships between recharge from ditch leakage and deep percolation from flood irrigation.

**Watershed Restoration Planning in the Flathead Valley**

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In response to the recent completion of the Flathead-Stillwater TMDL document (2014), the Flathead Conservation District (FCD) has taken the lead in creating a watershed restoration plan (WRP) to mitigate nonpoint source (NPS) pollution in the Valley's water resources at a watershed scale. A WRP aims to create collaborations between organizations and landowners in a watershed to not only better the quality of water resources in the area, but to promote education and best management practices as a norm to the community; and to plan and implement projects to mitigate NPS pollution loading into impaired streams through those collaborations. WRP documents typically focus on streams that have been listed as impaired by the MT Department of Environmental Quality by an NPS pollutant (e.g., sediment, nutrients, temperature, ). The Flathead Valley WRP will focus on the 8 streams found in the Valley to be impaired, as well as several other 'Streams of Concern' that have been identified as a concern to either FCD or other local stakeholders. Because of the large scope of this plan, it is vital that the FCD collaborates with other organizations and agencies to ensure that this WRP becomes something that can be beneficial to everyone trying to conduct NPS pollution mitigation on the water resources in Flathead Valley. FCD and the Soil and Water Conservation Districts of Montana has taken on

a Big Sky Watershed Corps Member (Sarah Bowman) to draft the majority of the plan and to help coordinate efforts among the numerous organizations and agencies within the Valley.

Every watershed is unique, and, as such, each WRP is also different, both in format and project priorities and goals. FCD has decided to direct the WRP's short-term implementation priorities on supporting current and ongoing projects that are already working to mitigate NPS pollution. Each organization within the Valley has different objectives, and often they already have landowner engagement, so this WRP will highlight those organizations and their projects to help them get more projects on the ground and/or completed. Supporting current projects in the Valley will be the primary goal of the WRP, while the secondary goal is to increase the FCD's capacity to reach out to the community and educate citizens about NPS pollution and to gain new landowner interest in potential project work. Collaborations with other organizations will also occur to further the outreach to landowners in the Flathead Valley. These education and outreach activities will facilitate landowner and community interest in NPS pollution mitigation that will ultimately lead to reduced pollutant loadings into the Flathead Valley's water resources.

### **Science to inform restoration: Effects of channel reconstruction on hydraulic exchange and base-flow generation**

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Channel restoration is increasingly being considered as a tool to enhance late-season flows by increasing the storage and exchange capacities of streams and their adjacent alluvial aquifers. Previous research has shown that added geomorphic complexity and increased bed elevations can enhance hydraulic exchange and alluvial aquifer storage. However, few studies have linked these effects to changes in baseflow generation. We are using a combination of hydrometrics, dilution gauging, tracer analyses and geomorphic assessment to quantify the impact of restoration on hydraulic exchange and the alluvial aquifer discharge that contributes to streamflow. Our study compares restored and degraded reaches on Ninemile Creek, Huson, Montana throughout the hydrograph recession of 2016. Our initial results provide insights into the impacts of channel reconstruction on exchange, storage and baseflow generation processes. This is a critical first step towards understanding the efficacy of restoration in degraded watersheds and identifying how restoration may improve late season flows in the context of a changing climate and increased demands for water resources.

### **Characterization of groundwater near oil and gas development in eastern Montana**

*Allison Brown, Montana Bureau of Mines and Geology, 101 Grand Avenue, Billings, MT 59101, abrown@mtech.edu,* (The Montana Bureau of Mines and Geology (MBMG) characterized groundwater quality near oil and gas activity in Eastern Montana to: provide a water-quality baseline prior to additional oil and gas development, provide additional data for current and future aquifer characterization, and provide comparative data—should a participating well be resampled. The MBMG collected 100 groundwater samples from sites in Fallon, Dawson, Richland, Roosevelt, and Sheridan Counties during the 2015 field season; 40-60 additional samples will be collected during 2016. In addition to field parameters and inorganic analyses, the samples were analyzed for radiochemistry as well as dissolved organic carbon, gas and diesel range organics, volatile petroleum hydrocarbons, and headspace gases (methane, ethane, and ethene). Because of eastern Montana's long history of oil and gas development, most samples were collected near current energy development and did not represent "true" pre-development conditions. However, given the likelihood that energy development will continue, analytical results from these samples will provide a baseline.

Surprisingly, 71 of 100 samples contained measureable amounts of methane. The source of the methane is unclear as it was detected in wells as shallow as 28 feet and as deep as 1,720 feet. When detected, gas range organics (GRO), total purgeable hydrocarbons (TPH), diesel range organics (DRO) and total extractable hydrocarbons (TEH) were generally found in water from unconsolidated aquifers; 18 samples from the unconsol-

dated units had a detection of an organic constituent; 5 detections came from the Fort Union Formation; and 2 detections came from the Fox Hills-Hell Creek Formation. Geographically, nearly all of the GRO, TPH, DRO, and TEH detections came from Richland, Roosevelt, and Sheridan Counties in the northern part of the study area. One TEH detection came from the south in Fallen County. Potential sources for the organic compounds are being investigated in 2016.

In Sheridan County, some samples that contained detectable TPH or TEH came from wells on or near lands managed by the Medicine Lake Wildlife Refuge and completed in near-surface unconsolidated formations that lie above the Clear Lake Aquifer. The Clear Lake Aquifer provides abundant irrigation and domestic supply water. Although no human drinking water standards for organics were exceeded, the presence of these compounds could potentially be a management issue for the Refuge.

### **Montana Bureau of Mines and Geology's Groundwater Investigations Program The Lolo Creek Watershed Groundwater Investigation**

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The Montana Bureau of Mines and Geology (MBMG) Groundwater Investigations Program (GWIP) initiated a study in the Lolo Creek Watershed in April 2016 in response to a GWIP nomination by the Lolo Creek Watershed Group. The nomination documented concern about intermittent late-summer dewatering (since the mid-1980s) of Lolo Creek between its confluence with the Bitterroot River and Highway 93. Historically, Lolo Creek has been considered a perennial stream that supports important bull trout habitat, but the dewatered reach has raised concerns about fish habitat and other riparian issues with water managers and local residents. The project will identify groundwater/surface-water dynamics in the dewatered reach and quantify contributing factors to the dewatering such as: changes in precipitation which provides recharge to the stream/alluvial system; geomorphological changes that may separate the water table from the stream channel; surface water diversions and crop consumption; and general lowering of the water table because of land-use changes and/or groundwater withdrawals. Data collection will include video documentation; LiDAR altitude mapping; monitoring well installations (for lithology information, water levels, and water quality); groundwater and surface water measurements and sampling; and climate information. Monitoring programs are coordinated with the Department of Natural Resources and Conservation, the Montana Climate Center, the University of Montana, and Montana Tech graduate work. Additional cooperators include the Clark Fork Coalition, the Lolo Creek Watershed Group, the Missoula County Water Quality District, and the Lolo Water and Sewer District.

### **Montana Bureau of Mines and Geology (MBMG) Ground Water Assessment Program Fluoride Concentrations in Montana's Groundwater**

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Fluoride concentrations in Montana's major aquifers were characterized using data from 3,475 wells and 112 springs. The data, obtained from the Montana Ground Water Information Center (GWIC; (<http://mbmg-gwic.mtech.edu>), include sample results from every county and all the major aquifers; most samples were from basin-fill and alluvial aquifers (54 percent), followed by sedimentary-bedrock aquifers in eastern Montana (23 percent), and fractured-rock aquifers (13 percent)—mostly in the west. Overall, fluoride concentrations ranged from < 0.05 to 19.93 milligrams per liter (mg/L), with a median concentration of 0.33 mg/L. Fluoride concentrations were compared to the USEPA Secondary Maximum Contaminant Level (SMCL of 2.0 mg/L) and Maximum Contaminant Level (MCL of 4.0 mg/L). The fluoride concentration in 89 percent of the samples was less than the SMCL; fluoride concentrations in 4 percent of the samples exceeded the MCL. Concentrations exceeding the SMCL (2.0 mg/L) and MCL (4.0 mg/L) occurred most frequently in samples from sandstone aquifer

fers in eastern Montana; more than 30 percent of the Fox Hills-Hell Creek aquifer, and more than 40 percent of the Judith River aquifer samples exceeded the SMCL. The MCL was exceeded most frequently in samples from the Fox Hills-Hell Creek aquifer (12 percent), the Judith River aquifer (10 percent), and the Kootenai aquifer (8 percent). In general, samples from the western basin-fill and fractured-rock aquifers had low fluoride concentrations, with median concentrations of 0.21 - 0.26 mg/L, respectively.

### **Groundwater flow modeling of the Clear Lake Aquifer south of Medicine Lake, Montana**

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The hilly farmland between Medicine Lake and Froid, Montana, hides the buried sand and gravel deposits of the ancestral Missouri River and glacial meltwater streams that form the Clear Lake Aquifer. Data gathered by extensive drilling and water-level monitoring by the Montana Bureau of Mines and Geology (MBMG) in conjunction with the Sheridan County Conservation District (SCCD) has led to successful groundwater development for irrigation. The SCCD holds a groundwater reservation for future irrigation development and has been actively supporting responsible development. Although the reservation earmarks an additional 5,479 acre-feet of water to be developed, the SCCD must demonstrate that current and new development does not negatively impact other water resources. This issue was presented to the Ground Water Investigations Program in 2014 and selected by the Program Board for study. One project goal was to develop a groundwater flow model that would guide decisions on future groundwater development. Model construction included extensive stratigraphic modeling, evaluation of water use at existing irrigation pivot systems, and analyses of water-level responses to the current water use. Predictive simulations will be used to evaluate the aquifer response to see if current users have pumped their entire allocation. Additionally, predictive simulations will guide decisions in response to new groundwater development. This presentation focuses on the model development, the results of predictive simulations, and on how the model can be used as a management tool

### **Improving our Knowledge of Hydrology and Climate in the Upper Missouri and Upper Columbia Basins by Studying Paleofloods, Tree Rings, and Archeology**

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Future climate projections are available for many locations in the Upper Missouri and Upper Columbia River Basins in Montana, Idaho, and Wyoming. Scientists, engineers, and managers are working to understand how to incorporate these future climate projections into water supply forecasts, flood-frequency analyses, and structure designs. Understanding historic and prehistoric climate and hydrology can help place these future climate projections into context. A more complete understanding of Montana's climate and hydrology will be highly beneficial for water-supply planning, reservoir operation, and infrastructure design.

Researchers are investigating past climate, streamflow, and human adaptation in the Upper Missouri and Upper Columbia River Basins. USGS scientists have analyzed tree ring data from more than 400 sites across Montana, Wyoming, and Idaho to reconstruct streamflow over the past 400+ years. Carroll College (Helena, MT) researchers are gathering archaeological and paleoenvironmental data in order to investigate the relationships between paleoclimate change and human adaptation in the Big Belt Mountains of central Montana. We plan to augment these datasets with collection and analyses of paleoflood data. Understanding the frequency and magnitude of historic and prehistoric large floods can complement our understanding of Montana climate, streamflow and human behavior. Paleoflood information also can help paint a fuller picture of hydrology and climate in Montana, by placing predictions of future trends and climate projections into context of our observed and pre-observed past.

### **Investigation changes in entrainment by debris flow with changes in scale.**

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Debris-flows are phenomena that happen around the world. They occur in regions with steep slopes and are commonly observed after abundant rainfall. Compared with flooding events where sediment is pulled from water flow above the bed, debris flows are the combined movements of boulders, rocks, and mud. In steep upland regions, debris flows are one of the main mass movement processes, and they also pose significant hazards for people and infrastructure. While predictions of debris flows for hazard mitigation are improving, there is a relatively limited understanding of the process by which debris flows entrain material from the land and grow in size and hazard. In our research we are investigating this process using two different scale flumes to systematically identify physical mechanisms of entrainment rates by debris-flows. Using a high speed camera we photograph the debris flow and bed at a sufficiently high rate to enable us to locate and track particles throughout the run. We use a home-grown Matlab program to find entrainment height, entrainment rate, shear stress, and stress associated with fluctuating velocities (often called a granular temperature). Comparing the time-dependent entrainment data with the time-dependent stress data from both flumes we are able to determine the dominant physics of the entrainment processes and how they vary with scale. By understanding these details we will be able to improve the modeling process for hazards and geomorphological evolution associated with debris-flow events.

### **Beaver use and impacts on stream and riparian habitats of the Robb-Ledford and Gravelly-Blacktail Wildlife Management Areas**

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The Robb-Ledford and Gravelly-Blacktail Wildlife Management Areas (WMAs) of southwest Montana host relatively pristine locations to investigate beaver activity. Beaver are widely acknowledged as ecosystem engineers, primarily because of their hydrologic impacts and herbivory around dam sites. Because of the ability of beaver to improve hydrological connections within stream corridors, local organizations across the state of Montana are showing increasing interest in facilitating beaver use, or strategies modeled after beaver activity, to improve degraded stream habitats. By collecting data on beaver use across a diversity of streams, we hope to improve understanding of beaver effects that will be useful for making informed decisions about sites where beaver-related mitigation strategies can have the greatest impact. Stream scale and geomorphic attributes affect how beaver activity influences stream processes and the long-term impacts that beaver can have on streams. In our current study, we focused primarily on East Fork of Blacktail Deer Creek (basin area: 158 km<sup>2</sup>, mean sinuosity: 1.8) which we augmented with other data from the smaller streams in the WMAs. Sediment surveys, discharge measurements, dam measurements, length of stream influenced by dams, areal extent of beaver-created wetlands and a census of all active and historic dam sites were made in the field. Sinuosity and gradient were measured from maps and imagery. We also highlighted beaver impacts on riparian function throughout the stream corridor by surveying the accumulation of beaver harvested willow cuttings that deposit on stream margins, and the ability of these cuttings to regenerate new willow plants. Results from East Fork of Blacktail Deer Creek show that beaver colonies—clusters of dams— averaged 0.7 colonies per kilometer with colonies containing between 1- 5 dams. Water and sediment were ponded upstream of dams from water surface slope reductions and subsequent declines in velocity. Up to 290 m upstream of beaver dams was impacted by the change in slope, leading to the creation of wetlands ranging in size from the bankfull channel width up to 2 hectares. 710 cm of cuttings from beaver herbivory were found at 38% of surveyed sites which is lower than other southwest Montana streams that have higher sinuosity. We are placing our data from the WMAs in the context of other streams that have been surveyed for beaver activity, adding to the understanding of beaver in a region where issues of water use and availability can have significant impacts on critically important riparian habitats.

## **When the levee breaks: A Superfund site in the middle Clark Fork River**

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Lumber mills are a founding industry for this country, particularly for Western Montana. Along with the growth of mills came the development of environmental laws and agencies charged with addressing the consequences and impacts industry was having on air, land, and water quality. The Montana Department of Environmental Quality (DEQ) and the Environmental Protection Agency (EPA) are the agencies whose mission it is to protect human health and the environment. The DEQ and the EPA define acceptable levels of pollutants into the environment along with the duty to enforce adherence to holding accountable those in violation of the Clean Air Act and the Clean Water Act.

As the paper mill west of Missoula began its operation in 1957, the impacts to air and water quality were immediately evident. Pictures of protesters outside the mill wearing gas masks were featured in Life magazine. A fish kill during the first year of operation led to the construction of a cobble dike and over 900 acres of unlined waste water and sludge ponds between the mill and the river.

The DEQ and the mill negotiated levels of waste water discharge and air pollution control as the mill expanded over its 53 years in operation. Permits were issued by the DEQ to the mill for waste water discharge over fixed periods of time to study the environmental impacts, for instance when the mill requested year-round discharge instead of only during high flows. The DEQ allowed the changes and continued to issue permits to the mill to discharge an annual average of 5.7 billion gallons of waste water and 20,000 tons of sludge into the unlined ponds.

The mill closed in 2010 and when the owners went to sell the property, they declared the site clean. The DEQ was not receiving cooperation from the owners so they requested the 'strong arm' of the EPA to help bring the potentially responsible parties to the table. In 2011-2012 the EPA took land and water samples and found dioxin and furans above EPA cancer risk assessment. Manganese and arsenic were also above screening concentrations.

It is well understood that the mill's 900 acres of unlined treatment ponds are only bound by an aged, cobble dike, leaving the waste water and the Clark Fork River vulnerable. It is further understood that the contaminants are moving through the ground and ground water and into the river. A fish consumption advisory was issued in 2013 along the area of the mill after dioxins, furans, and polychlorinated biphenyls (PCB's) were found in pike and rainbow trout.

Even after contaminants were found on site, the DEQ reissued a waste water permit to the site's new owners. A group of concerned agencies have filed suit against the DEQ for violation of the Clean Water Act and the agencies own administrative rules. It may take efforts outside the agencies to get the former mill site cleaned. The DEQ and the EPA are not taking swift or appropriate action to protect human health and the environment.

## **Promoting lipid accumulation in *Chlorella vulgaris* UTEX395 using nitrogen limitation and bicarbonate amendment under different nitrogen regimes**

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Algal cultivation requires water and nutrients (N and P), both of which may be limited in different geographic regions. The use of low quality waste streams with high nutrient content, such as municipal or agricultural wastewater, may offset the pressure placed on water and fertilizer resources. In addition, algae cultivation may present a valuable opportunity for nutrient removal from these waste streams and may prevent eutrophication of receiving water bodies. It is first necessary to understand how algae growth is affected by the different

nitrogen species present. In addition, the use of bicarbonate amendment at nitrogen depletion for enhanced lipid accumulation is well understood for algae cultures including *Chlorella vulgaris*, but has not been demonstrated with algae cultivated using nitrogen species other than nitrate. In the current study we evaluated the growth and lipid accumulation for *Chlorella vulgaris* UTEX395 using a variety of nitrogen regimes (nitrate, ammonium, urea, and a combination of the three). We also evaluated how a bicarbonate amendment at the time of nitrogen depletion affected lipid accumulation under the different nitrogen conditions. We found that UTEX 395 was able to grow using all of the nitrogen regimes evaluated. Nitrogen was consumed most rapidly in the ammonium and mixed nitrogen conditions, however similar growth rates were achieved for all cultures except those cultivated using urea as the sole nitrogen source. Cultivation using urea resulted in slower growth and the cells appeared smaller and more yellow. Lipid accumulation using the bicarbonate amendment at nitrogen depletion was similar for all nitrogen conditions.

### **Irrigation efficiencies impact on domestic groundwater supplies**

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The unintended consequences of converting flood irrigated land to pivot sprinkler irrigation are not currently part of the normal dialogue. The economic and conservation benefits of pivot irrigation are convincing many Montana irrigators to install sprinkler irrigation systems that allow for more-precise management of water and soil, and require less operator time. For malt-barley and sugar beet growers in southcentral Montana, there is specific pressure from retailers to demonstrate water conservation. However, rural residents rely on irrigation-recharged groundwater for domestic water. Reduced aquifer recharge as a consequence of more efficient irrigation will impact groundwater supplies and, in some locations, baseflow to streams. These issues have been specifically identified in the Short Term Recommendations of the Montana State Water Plan.

The Montana Bureau of Mines and Geology (MBMG), in cooperation with the USDA Natural Resources and Conservation Service (NRCS) and private landowners, initiated a pilot project outside Joliet, Montana, to begin quantifying irrigated field characteristics important to groundwater availability for consideration when converting from flood to pivot irrigation. Water quality and quantity are being measured around a field that has been flood irrigated for generations, but which will be converted to pivot sprinkler irrigation in 2017. In addition to the benefits listed earlier, the irrigator hopes to reduce soil erosion that occurs during flood irrigation.

A more extensive project that will measure the quality and quantity of recharge from flood and pivot irrigated fields, further refine important field characteristics for recharge, and provide outreach to irrigators, has been submitted for consideration to the Montana Department of Natural Resources and Conservation Renewable Resources Grant Program. If funded, and when complete, new information about where fields might be converted to sprinkler irrigation with the least impact to groundwater supplies will be provided directly to irrigators through an educational outreach program.

### **Gallatin Stream Teams - The Environmental Stewards of the Gallatin Valley, Montana.**

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Citizen science is an important data collection effort for many non-profits, including the Greater Gallatin Watershed Council (GGWC). In 2008, GGWC partnered with Gallatin Local Water Quality District (GLWQD) to create the Gallatin Stream Teams, a volunteer stream monitoring program. Because of limited organizational capacity of GGWC and GLWQD, volunteer time is fundamental in the continual assessment of seven of Bozeman's streams that do not meet applicable water quality standards. The impairments include excess sedimentation, nutrients, and pathogens (*E. coli*), which are affecting beneficial uses for aquatic life and primary contact for human recreation. The volunteers receive annual training on water quality monitoring procedures from water resource professionals to ensure the quality of their data is credible by the standards of the Montana Department of Environmental Quality (DEQ) and can be used by the City of Bozeman, GGWC, GLWQD, and other entities. The volunteer monitoring program provides the opportunity for citizens to get involved

with the community, learn about water quality, gain a sense of ownership of the streams that flow through the valley, and provide data for local decision-makers. One example of Stream Team data being used for decision-making is the addition of Mandeville Creek to the DEQ list of impaired waters and TMDLs being developed for the creek as part of the Lower Gallatin TMDL Plan. The results of the Gallatin Stream Teams data collection effort serve as baseline information and identify non-point source pollution in local waterways. As outreach and stream restoration efforts are conducted in the future, data collected by these citizen scientists fills an important need that assists in improving surface water quality in the Gallatin Valley.

### **Quantifying the spatio-temporal dynamics of groundwater recharge in a headwater basin**

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The spatio-temporal distribution of groundwater recharge on forested hillslopes influences catchment storage and stream flow response from event to millennial time scales. However, the spatio-temporal variability of groundwater recharge across mountainous hillslopes is not well characterized. Many studies have recognized the potential for increased groundwater recharge in areas with increased soil saturation due to topographic convergence and with high bedrock permeability. However, due to the logistical challenge presented when working on steep forested hillslopes, few studies have successfully tested these findings. This study aims to identify potential zones of groundwater recharge at the hillslope scale and will test the following hypotheses: 1) topographical characteristics organize locations of groundwater recharge on hillslopes and 2) the temporal and spatial dynamics of soil saturation influence the magnitude of groundwater recharge. To test these hypotheses, we are installing nested shallow and deep groundwater wells, soil moisture sensors, and collecting tracer data across three hillslopes in Lubrecht Experimental Forest (LEF), Montana. This work provides an important first step towards an understanding of how watershed organization influences groundwater recharge and the sensitivity of streamflow in mountain basins to a changing climate.

### **Remediating Mine Waste Impacted Streams: A Flexible Solution Using Natural Channel Design**

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**Background/Objectives.** Many surface water features in the western US have been impacted by mine tailings and mine water drainage from historic mining operations. Remediation of these systems typically requires the removal of the tailings from the stream bed/streambanks. Working with a large international company, an innovative channel reconstruction method using “soft” natural channel designs for improved resiliency and habitat was used. This flexible solution not only enhances both aquatic and upland wildlife habitat but is often the most cost effective choice.

**Approach/Activities.** Multiple stream reclamation projects on a legacy mining site will be presented that involve mine waste removal from the stream corridor to improve surface water quality and the overall ecosystem through development of self-sustaining vegetation and bio-engineered bank treatments to facilitate long-term system stability. Natural channel design has slowly become a proven alternative to “rigid” channel armoring on stream remediation projects. With an ever increasing value placed on streams and riparian ecosystems, permitting agencies favor the natural channel concept and recognize the dynamic nature of stream systems. As a result, permitting of a “soft” natural channel design is often streamlined and strict performance standards are avoided which reduces maintenance obligations and liability. Key advantages of natural channel design include utilization of onsite resources and field fitting yielding more sustainable and naturally aesthetic landscapes and positive public perception.

**Natural Channel Design Process** – A river segment that represents a stable channel of similar morphology is

established as the reference reach. The reference reach is used to develop natural channel design criteria based upon measured morphological relations associated with the bank full stage for a specific stable stream type. Specific data on stream channel dimension, pattern, and profile are collected and presented by dimensionless ratios by stream type. These include the following steps:

(1) Establish a temporary benchmark, (2) find and verify bank full stage, (3) complete a longitudinal profile, (4) Complete cross section surveys, (5) collect Wolman pebble counts, (6) Complete plan form measurements and ratios (measure sinuosity, radius of curvature, channel belt width, meander wave length).

Excavation Plan – Excavation of 100,000 cy of mine tailings and impacted sediment/soil from channel and near bank areas. The design “sets” the channel bottom elevation, which in turn sets the floodplain elevation. This balances cut/fill volumes and reduces expense associated with import material.

Results/Lessons Learned. Discussion includes design strategy and details, permitting challenges, and construction implementation. Remediation of impacted stream channels is a common remedial activity through the intermountain west for areas of historic mining. A flexible, natural approach to the design not only resorts in construction of a more resilient and sustainable system but has proven to be cost effective also.

### **Understanding Gallatin Valley Groundwater: The Key to Sustainability?**

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The National Groundwater Association defines groundwater sustainability as “the development and use of groundwater resources to meet current and future beneficial uses without causing unacceptable environmental or socioeconomic consequences.” Unacceptable consequences of increased groundwater use could include declining water tables and reduction in streamflow. There are now over 100,000 residents in Gallatin County. Groundwater pumped to serve municipal and commercial uses will likely increase because surface-water sources are fully appropriated and development will continue. Ongoing research projects by the Ground Water Investigation Program (GWIP) at the Montana Bureau of Mines and Geology (MBMG) in the Gallatin Valley are designed to further our understanding of the aquifer and the implications of changing water use. Tools developed from these projects, such as maps, numeric and analytical models, geologic cross-sections and monitoring and baseline data, should be considered in future sustainable management practices. How can we use our understanding and tools to evaluate and predict the effects of increased groundwater use? Can management policies be developed to help avoid “unacceptable consequences”?

### **Fitting Together the Puzzle Pieces: Building Drought Resiliency in Broadwater County**

*Katie Mumford, BSWC Member; Broadwater Conservation District*

This past year, the Broadwater Conservation District (BCD) began its first step towards drought resiliency: releasing water supply reports to the local water users in Broadwater County. The purpose of the water supply reports are to enhance drought resiliency tactics in our community and help local irrigators make informed decisions about irrigation management practices. BCD will present data on Deep Creek showing the relationship between water supply demands along the watershed and the effects it has on the stream flows, along with countywide precipitation data, snowpack, and reservoir levels, that have been used as tools to educate local water users.

### **PHYSIOGRAPHY OF NORTHEASTERN MONTANA WITH EMPHASIS ON DRAINAGE DEVELOPMENT AND AQUIFERS**

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Tertiary and Quaternary depositional and erosional events have formed distinct landscapes in the northeast corner of Montana. Gravel capped plateaus that decrease in elevation from the northwest to the south-

east are located in the northwestern half of the Wolf Point 2° quadrangle. These gravel capped plateaus form the relatively productive Flaxville and related aquifers. The plateaus are highly dissected and their edges form distinct dendritic erosional patterns where the gravel caps have been removed to expose the underlying fine-grained bedrock. The major rivers and creeks are underfit, currently occupying wide flat valley bottoms that they did not cut. Many small tributaries to the currently drainage system are connected by flat bottomed channels that cross drainage divides. For example, a broad swale (the combined Manning Lake and Medicine Lake swales) extends from Poplar, Montana, to the North Dakota border east of Dagmar. A similar broad depression extends from south of Dagmar north to Westby. Smaller swales are associated with Big Muddy Creek near Antelope, Montana, and the Missouri River between Culbertson and Bainville, Montana. The productive Clear Lake aquifer is associated with buried channels of the northeast flowing ancestral Missouri River and south flowing glacial meltwater channels that underlie the Medicine Lake and Clear Lake swales. The Clear Lake aquifer has been supplying irrigation water for producers since the mid-1970's and is part of a soon to be completed GWIP investigation. The modern drainage system is not aligned with the pre-glacial drainage of the Missouri River, which was northeast to Hudson Bay and the Arctic Ocean. The ancestral river was diverted southward by multiple advances of continental glaciers and, with the exception of a small internally drained area east of Dagmar, current drainage systems flow to the modern Missouri River.

### **Water Quality and Stream Flow Rates Within the Helena Area.**

*Ashley Rivero, Big Sky Watershed Corps, AshleyR.BSWC@gmail.com*

Lewis & Clark County Water Quality Protection District and the Lake Helena Watershed group implemented two monitoring programs for the Montana field season of 2016. A primary objective represents obtaining baseline monitoring data to evaluate the efficacy of stream management programs to address Total Maximum Daily Loads (TMDL) impairments. The first program comprised, stream flow monitoring with discharge measurements from 13 sites within the Lake Helena Watershed. Lake Helena is connected to the lakes on the Missouri River with Prickly Pear Creek, Tenmile Creek, and Silver Creek representing the major streams in the Lake Helena Watershed. Stream flow data will be presented and compared to historical data from recent years. The stream flow monitoring program is supplemented by the second program, a watershed volunteer water quality and flow monitoring program conducted during the spring and fall. The volunteer monitoring sampling network includes seven locations and extends local studies to some of the tributaries of Tenmile and Prickly Pear Creeks. Trained volunteers collected stream flow discharge measurements, samples for water quality laboratory analysis for a list of parameters including nutrients, metals, suspended and dissolved solids as well as field parameter measurements for dissolved oxygen, specific conductivity, pH, and temperature. The volunteer water monitoring program data results help identify pollutant loading contributions to the existing water quality standards for specific water bodies. Support efforts allocate contributions from different identified sources to help meet the assimilative capacity of the major water bodies. Water quality data results will be compared to current TMDL standards. The data from both monitoring programs supports development of long term restoration strategies to mitigate stream impairments to achieve identified beneficial uses. Information from these programs may serve to point restoration efforts in the right direction and help ensure efficient use of available resources.

### **Natural Amelioration in Flooded Mine Shafts and Related Changes in Arsenic Concentrations**

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Metal and sulfate concentrations have decreased in nine flooded mine shafts in Butte, Montana since mining operations ceased in 1982. In addition to our data, thirty years of groundwater monitoring data provided by the Montana Bureau of Mines and Geology (MBMG) indicated that each site continues to undergo natural amelioration -- defined as a reduction in dissolved metal and sulfate concentrations and an increase in pH without assisted remediation or water treatment. Microbiological and water samples taken from these nine mines represented three distinct geochemical zones. The groundwater divide located between these zones separates differences in sulfate and carbonate bedrock composition, which contributes to changes in water-

rock interactions. The MBMG recorded sulfate levels as high as 100 mM and metal concentrations at 375, 2.69, and 10,800 mM for Cu, Fe, and Zn, respectively, upon initial shutdown of the mines. Over time, pH values have increased by 0.5 to 2 and metal concentrations have decreased by several orders of magnitude.

Notable exceptions to amelioration were three mines (Anselmo, Steward, and Kelley) located east of the groundwater divide. These mines were lower in pH (between 3.5-6.5) than the west (between 6.0-7.5), contained trace amounts of sulfide (0.3-0.5  $\mu\text{M}$ ), were lower in dissolved inorganic carbon concentrations than the west side (an average of 100 mg/L versus 200 mg/L), and contained reduced iron(II) and arsenic(III) species. In the Anselmo and Steward, arsenic levels have been increasing at rates of 0.2 and 1.4  $\mu\text{Myr}^{-1}$  and iron levels at 29.5 and 105.3  $\mu\text{Myr}^{-1}$ , respectively. Increasing arsenic concentrations at a rate of 5.3  $\mu\text{Myr}^{-1}$  were also measured in the Kelley but iron concentrations were decreasing at a rate of 1392  $\mu\text{Myr}^{-1}$ . In addition, the pH in the Kelley mine has continuously decreased since 1990 for a total change of one pH unit, and the temperature has increased by 18°C. Combining aqueous geochemistry and microbial diversity analysis with the historical groundwater monitoring framework provides insight into natural amelioration rates as well as long-term water-rock-microbe interactions in mine shafts hosted in both carbonate and sulfate bedrock.

### **Developing a defensible local meteoric water line: some pitfalls to avoid**

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Stable isotopes of hydrogen ( $^2\text{H}$ ) and oxygen ( $^{18}\text{O}$ ) in water are useful to examine sources of groundwater recharge and evaluate groundwater/surface water interaction. These isotopes trace the amount of evaporation in water that enters groundwater systems and are a valuable tool for differentiating various recharge sources. An evaporative signal is a tracer in groundwater for irrigation return flow and surface water recharge; lack of evaporation in groundwater indicates snowmelt recharge. Stable isotope values measured in groundwater and surface water are typically plotted in reference to isotope values contained in the local precipitation presented as a local meteoric waterline (LMWL).

Because precipitation samples are sensitive to post-atmospheric evaporation, improper sampling protocol could cause bias in a LMWL. Rain needs to be immediately funneled into a sealed vessel or at least “puddled up” quickly and immediately bottled (<5 minutes from beginning of collection). One way to prevent evaporation is to trap rainfall in a steep-walled hydrophobic funnel that feeds a collection cylinder where the water is capped by mineral oil to prevent evaporation. Other efforts to prevent bias in a LMWL include collecting rainfall as monthly composites throughout the year and collecting snow cores. Failure to prevent evaporation in precipitation samples or to collect composites will cause a LMWL to plot at a lower slope than would a LMWL based on composite samples that have been protected from evaporation. Proper sample handling will produce accurate LMWLs to which stable isotope values from groundwater can be compared to help differentiate the isotopic signatures of possible recharge sources. Use of isotopic data in hydrologic studies is increasing because it is valuable and affordable; many entities collect isotopic data in basins with no LMWL and a proper, standardized, defensible method is necessary.

### **Understanding human influence on a stream network ecosystem through analysis of diel and seasonal patterns of metabolic regimes in stream water.**

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Human activities influence stream ecosystems via both indirect (e.g., climate change) and direct (e.g., adjacent land use) effects. High-elevation watersheds that are under land use development pressures represent regions where the interactions of both climate and land use effects are likely to be most evident. Therefore, we suggest that the West Fork of the Gallatin watershed, encompassing the community surrounding the Big Sky

resort area in southwestern Montana, represents an ideal case study for understanding the relative importance of climate and land use changes on the trajectory of stream ecosystems into an uncertain future. We are focusing specifically on the interactive influences of temperature, nutrient loading, and changing hydrologic regime on the fundamental energetics of the stream ecosystem (i.e. metabolic function). We are combining a continuous whole stream metabolism data set with hourly sampling to characterize changes in water chemistry, nutrients, dissolved organic carbon, and dissolved organic matter over diel cycles. We are completing hourly sampling for 12 to 36 hours at two locations along the West Fork of the Gallatin River, located above and below a golf course known to be located in a region of substantial nitrate-nitrogen loading. These sites allow for an effective experimental treatment due to the consistent spatial variation in nitrogen loading between them. Sampling campaigns are occurring simultaneously at each location, once a month for six months. The months of May through October 2016 were chosen to capture variability in ecosystem function over the course of the growing season (i.e. from peak flow through the base flow recession). Diel cycles, including cycles of metal concentrations have been well documented in streams and tied biogeochemical or physical processes relating to sunlight. We anticipate ecosystem function including the quality of dissolved organic matter and nutrient concentrations will also express diel patterns within the small high productivity sections of the lower West Fork, with potential variation resulting from the level of human influence on the stream reach. Preliminary results show substantial diel changes in nutrient concentrations, with increasing total nitrogen during the nighttime dormant periods for photosynthesis.

### **Isotope Hydrology of Helena Area Aquifers**

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The Helena Valley Aquifer, located in an intermontane basin in Southwest Montana, represents the primary source of drinking water for over 20,000 residents in the area. The unconfined aquifer provides relatively high yields from high permeability semi to unconsolidated sediments, with relatively shallow water levels. Outside of the Helena Valley, bedrock aquifers characterized by fracture flow systems represent the primary water source for low-density residential areas. A third aquifer system comprising semi-consolidated, clay-rich Tertiary deposits providing limited yield has been identified in the area east of the Helena Valley and other localized areas.

A water isotope dataset was compiled concurrent with sampling programs during several recent water quality studies for nutrients, trace metals and major ions. The isotope sampling objective was to develop a method to track recharge sources for ground water, supplementing conclusions from other water chemistry data. The primary recharge methods include direct infiltration of precipitation and stream loss, with a strong connection in the subsurface between bedrock aquifers and the Helena Valley Aquifer. Irrigation water from the Missouri River system is utilized in the valley, bringing waters from outside the Lake Helena Watershed drainage basin into the central part of the Helena Valley. Samples were collected from surface water bodies, tile drain discharge points and ground water wells.

The results show generally distinct populations from irrigation waters from outside the valley compared with streams and stream loss recharged ground water. Data results for the Tertiary aquifer show some areas with a distinctly lighter signature. These areas correspond with previously identified locations of ground water depletion within Tertiary aquifers from pumping from potable wells. The reason for the lighter signature has not been identified; however, it must be associated with aquifer recharge. It is possible that the results represent Pleistocene aged fossil waters; however, more data is required to confirm this. The identification of the specific isotopic signature for these waters, regardless of recharge source, may be used as an indicator to locate areas where the risk of depletion from overpumping from wells is significant.

### **POST-RESTORATION ASSESSMENT OF POINDEXTER SLOUGH IN THE BEAVERHEAD RIVER DRAINAGE NEAR DILLON, MONTANA**

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Students in Environmental Field Studies class at the University of Montana Western (UMW) in Dillon, Montana conducted a post-restoration assessment of Poindexter Slough, a former channel of the Beaverhead River located approximately 3.0 miles south of Dillon, MT. During the period of September 21st to October 14th, 2015, the students assessed stream morphology, in-stream macroinvertebrates, riparian vegetation and stream habitat for the entire 4.73-mile length of Poindexter Slough, which was mechanically restored in the spring of 2015 from the Beaverhead River diversion to the Dillon Canal. The study was a follow-up analysis designed to assess the restored section and make recommendations based on these observations.

The study area included twenty-two cross-sections placed from the diversion of the slough from the Beaverhead River to its confluence back with the river. The cross sections were chosen to achieve a good assessment of the entire slough. The cross sections were placed across riffle-pool pairs and their positions recorded with GPS. This was a follow-up study from an identical analysis conducted by UMW in 2014, and was designed to (1) assess the restoration work and its downstream impacts, and (2) make recommendations about the final phase of the restoration. The restoration involved replacing existing irrigation infrastructure, mechanically modifying channel dimensions, and transplanting riparian vegetation to improve fisheries habitat and restore natural processes of habitat formation and maintenance of the slough.

The restored section of Poindexter Slough functioned as an "A4" stream pre-restoration, but is now functioning as a "C4" stream, with a better width-depth ratio, greater sinuosity and far less fine-grained sediment load. In-stream macroinvertebrates have come back very rapidly, with greater abundance and diversity than in 2014. The riparian vegetation has also come back, with improving abundance and greater diversity than in 2014. The stream habitat data may be the most impressive, showing a dramatic increase in the depth of pools, lengths of riffles and total number of riffle-run-pool-glide segments than was recorded in the 2014 survey. Our primary recommendation is to let the water into Poindexter Slough from the top of the diversion canal gate to minimize sediment input from the Beaverhead River going forward. Since most of the sediment is in the coarse silt to fine sand range, it moves as bedload and can be kept out of Poindexter Slough by letting the water in over the gate. The student-produced report will be submitted to Montana Fish, Wildlife and Parks to be used to assess their restoration work.

### **Ownership of Islands in the Yellowstone River**

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At 692 miles in length from the headwaters in Yellowstone National Park through the plains of Eastern Montana before the confluence with the Missouri, the Yellowstone River remains the longest undammed river in the contiguous United States. The Yellowstone River is a precious landmark to the state of Montana. In certain areas, however, public access to the river, for both shore- (e.g. birding/ picnicking/ hiking) and river-based recreation (e.g. fishing/floating/paddling) is constrained by lack of public land and/or uncertainties about land ownership. The proposed poster will present the results of a study designed to contribute to ongoing efforts to make the river more accessible to the public via a systematic, GIS-based study of historic change island condition and ownership along a stretch of river in the vicinity of Pompeys Pillar, Montana. The project is built around the following research question: What is the ownership status of islands within a Yellowstone River study area extending approximately 10 miles upstream of Pompeys Pillar (hereafter referred to as the Pompeys Pillar study area as or PPSA)? The proposed project has two objectives: 1.) Determine the ownership of the islands within the PPSA; 2.) Develop a tutorial style report of archival and GIS workflows involved so that the study may be reproduced along other stretches of the Yellowstone.

Upon Montana's inception as a state in 1889 the Federal Government declared the bottom of the Yel-

lowstone River as state owned meaning that all islands emerging from the bottom of the river are also state owned. The Public Land/Water Access Association rules for island ownership state the following: any island formed or land accumulated in a navigable stream/river belongs to the state if there is no title or prescription to the contrary; in cases where an island is formed by the division of a stream- if a stream divides itself and surrounds land belonging to the owner of the shore and thereby forms an island, - the island belongs to such owner. Keeping these laws in mind, the project traces changes in PPSA island status and ownership using initial patent records beginning in 1884 and aerial photos taken at various times (1950, 1976, 2013-15) . Preliminary findings suggest that as many as seven islands in the PPSA that are not currently classified as such could be publicly owned. Many of these islands are large enough to accommodate day camping, picnicking, fishing, sight-seeing, and hiking (on islands and/or public lands). If it is discovered that some of these islands and lands are in fact state owned, managing them as parks could dramatically improve floaters' and other recreationalists' experience on the Yellowstone. In the end, our hope is that this project will contribute to development of clearer understandings of the historical human relationship with the river, by providing a genuine and accurate map showing evolving ownership status of islands within the Yellowstone, which could, in turn result in increased public access to and interest in the area while also serving as a resource for managers.

### **Traditional Ecological Knowledge and Tribal Water Governance at Fort Peck Indian Reservation, MT**

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The Fort Peck Indian Reservation is located in northeast Montana and is home to the Assiniboine and Sioux Tribes. Conventional oil and gas development and the disposal of produced water has led to the contamination of 15-37 billion gallons of groundwater within the aquifer that had historically been the only source of drinking water for reservation community members (Thamke, 2014). Currently, remediation of the southeast corner of the contamination plume is underway, yet the majority of the plume--while monitored--remains in contact with groundwater resources. Although the tribes are aware of the contamination plume, exploiting newly accessible shale resources has become a viable option as the tribes continue to try to alleviate the 50.6% unemployment rate and the 29.6% poverty rate of tribal members (Fort Peck Tribes, 2013). Even so, tribal members and authorities also understand the importance of ecological health in fostering a healthy community. In addition, a strong movement of cultural resurgence has been in motion, with tribal members looking to traditional stories and lessons--otherwise known as traditional knowledge-- passed down through generations in order to guide the future of the community and create community cohesion. One type of traditional knowledge--traditional ecological knowledge (TEK)-- is defined as a "cumulative body of knowledge, practice, and belief, evolving by adaptive processes and handed down through generations by cultural transmission, about the relationship of living beings (including humans) with one another and with their environment" (Berkes, 2012). TEK has been heralded throughout contemporary governance literature as an important resource for indigenous communities that deal with difficult decisions involving resource management. Using a TEK framework and interviews with tribal members, this research seeks to answer the following questions: 1) What is the TEK that surrounds water and its use for the Assiniboine and Sioux tribes? 2) How is TEK reflected and incorporated into the existing tribal water governance structures at Fort Peck? 3) How does unconventional oil and gas development fit within the tribes' TEK framework, specifically in terms of the production and disposal of produced water (brine)?

The results of this study will be compiled and presented to relevant entities within the tribal environmental governance structure, stored in community archives, and shared with the participants and their families.

# **END OF PROCEEDINGS**