



PROCEEDINGS

for

Montana's Water Resources: Water Management in the Face of Uncertainty

**Montana Section American Water Resources Association
2012 Conference**

**October 11 – 12, 2012
Fairmont Hot Springs, Montana**

Contents

Thanks to Planners and Sponsors

Full Meeting Agenda

About the Keynote Speakers

Concurrent Session and Poster Abstracts*

Session 1. Groundwater - Geology

Session 2. Surface Water & Watershed Analysis - Part 1

Session 3. Water Quality - Part 1

Session 4. Water Management/Development - Part 1

Session 5. Climate

Session 6. Water Quality - Part 2

Session 7. Surface Water & Watershed Analysis - Part 2

Session 8. Water Management/Development - Part 2

Poster Session

***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**

Dave Donohue, President – HydroSolutions, Inc

Russell Levens, Vice President – Montana Department of Natural Resources and Conservation

Katherine Chase, Treasurer – USGS Montana Water Science Center

- **Montana Water Center – Meeting Coordination**

Duncan Patten, Nancy Hystad

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



David Donohue



Russell Levens



Katherine Chase



Duncan Patten



Nancy Hystad

A special thanks to our generous conference sponsors!



WEDNESDAY, OCTOBER 10, 2012

REGISTRATION

Entrance

10:00 am – 7:00 pm **REGISTRATION**
Pre-conference registration available at <http://water.montana.edu/awra/registration/>

FIELD TRIP

1:00 pm – 5:00 pm **Montana AWRA 2012 Clark Fork Valley Field Trip**
Ranching, Flooding, and Restoration along the Clark Fork River and Silver Bow Creek
Bus leaves Fairmont Hot Springs promptly at 1 pm, returns at 5 pm

HYDROPHILE 3-MILE RUN

6:00 pm – 7:00 pm **Hydrophile 3-mile Run**
Leave from Fairmont after the field trip

Dinner – on your own

THURSDAY, OCTOBER 11, 2012

REGISTRATION

Entrance

7:30 am **REGISTRATION** - coffee and snacks provided
Preconference registration available at <http://water.montana.edu/awra/registration/>

OPENING SINGLE SESSION

Pintlar Room

8:00 am **WELCOME, INTRODUCTIONS & ANNOUNCEMENTS**
Dave Donohue – *Montana Section AWRA President*
Russell Levens – *Montana Section AWRA Vice President*

8:15 Duncan Patten – *Montana Water Center Director*

8:25 John Metesh – *Montana Bureau of Mines and Geology Director*

8:35 **KEYNOTE SPEAKER**
Dr. Robert M. Hirsch – *Research Hydrologist, USGS*
Changing Hydrologic Systems - Thinking About Nonstationarity of Streamflow and Water Quality

9:35 **BREAK**

9:50 **SPECIAL SPEAKERS**
Mary Sexton – *DNRC Director*; Richard Oppen – *DEQ Director*
Reflection on Montana Water and Environmental Policy Issues

10:50 **SPECIAL SPEAKERS**
Seth Makepeace – *Hydrologist for the Confederated Salish and Kootenai Tribes*; Jay Weiner – *Montana Assistant Attorney General, Staff Attorney for the Montana Reserved Water Rights Compact Commission*
Water Rights Compact - Confederated Salish and Kootenai Tribes

LUNCH

Gregson Room and Whiskey Joe's Lounge

11:45 am **Lunch** - cost included in registration

ORAL PRESENTATIONS

**SESSION 1 (Concurrent)
GROUNDWATER - GEOLOGY**

Pintlar Room

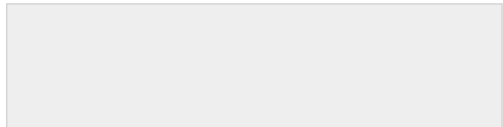
Moderator: David Nimick

- 12:30 pm Robert Alexander. *Dye Tracer Study At The Susie Adit/Upper Valley Forge Mine Area, Upper Tenmile Creek Mining Area Superfund Site, Lewis & Clark County, Montana.*
- 12:50 Julie Ahern Butler. *Boulder River Valley Groundwater Investigation: Designing The Groundwater Flow Model.*
- 1:10 Melissa Schaar. *Challenges in Characterizing a Fractured Rock Aquifer System, Landusky Mine Site, 2012.*
- 1:30 Christine Miller. *Water Quality And Groundwater Age In An Isolated Shallow Aquifer Of The Judith River Basin, Montana.*
- 1:50 Kevin Chandler. *Stream-loss Recharge To The Madison Aquifer In Central Montana.*
- 2:10 Nick Tucci. *An Examination of the Northern Summit Valley Organic Silt Paleosol, Butte, MT.*
- 2:30 BREAK

**SESSION 2 (Concurrent)
SURFACE WATER & WATERSHED ANALYSIS - PART I**

Mt Haggin Room

Moderator: Duncan Patten

- 12:30 pm Karin Boyd. *The 2011 Musselshell River Flood - Assessing Impacts And Developing Rehabilitation Strategies.*
- 12:50 David Feldman. *Evaluating Macroinvertebrate Responses To Sediment In Mountain Streams Using Biometrics.*
- 1:10 Doris Fischer. *Fish & Wildlife Recommendations For Subdivision Development Along Montana's Waterways.*
- 1:30 Les Perkins. *German Gulch Fish Screen Project: Lessons Learned.*
- 1:50 Robert Thomas. *Baseline Assessment of Riparian Function of Long Creek, Centennial Valley, Southwest Montana.*
- 2:10 
- 2:30 BREAK

**SESSION 3 (Concurrent)
WATER QUALITY - PART I**

Pintlar Room

Moderator: Mark Reinsel

- 2:45 pm Laura Alvey. *Overview And Update: July 2011 Silvertip Crude Oil Release To The Yellowstone River.*
- 3:05 Ray Armstrong. *Wastewater Effluent Disposal Through Snowmaking.*
- 3:25 Mark Deutschman. *Development Of Nutrient Criteria For Lakes And Reservoirs In The Northern Plains States Of Montana, Wyoming, North Dakota And South Dakota.*

**SESSION 4 (Concurrent)
WATER MANAGEMENT/DEVELOPMENT - PART I**

Mt Haggin Room

Moderator: Duncan Patten

- 2:45 pm 
- 3:05 Catherine Love. *Using The Data We Collect: Environmental Data Management.*
- 3:25 Ada Montague. *Private Equity Ownership Of Municipal Water In Montana.*

3:45 Katie Kleehammer. *Assessing Differential Transport Of Chemical And Biological Constituents In Ground Water Impacted From A Municipal Waste Water Treatment Lagoon.*

4:05 David Nimick. *The Fate Of Geothermal Mercury In The Madison And Missouri Rivers, Montana And Wyoming.*

3:45 Todd Myse. *Canal Seepage Loss in the Lower Beaverhead River Basin.*

4:05 Tom Osborne. *Solar Powered Groundwater Development Project In Uganda.*

POSTER SESSION & SOCIAL HOUR

Lobby

5:00 – 7:00 pm AWRA 2012 POSTER PRESENTATIONS

1. John Anderson. *Characterizing The Role Of Subsurface Flow To The Upper Boulder River, MT.*
2. Jason Blythe. *Hydrogeologic Framework Of Carbon And Stillwater Counties, Montana.*
3. Jason Brown. *Calibrating Conceptual Hydrologic Models With Approximate Bayesian Computation, Sequential Monte Carlo, And Flood Duration Curves.*
4. Sharon Bywater-Reyes. *Scour Susceptibility Of Black Cottonwood On The Bitterroot River, Montana: Insights For Successful Restoration Of Riparian Areas.*
5. Camela Carstarphen. *Recharge Patterns In The Upper Madison Valley Aquifers, Madison Valley, Montana.*
6. Katherine Chase. *Paleoclimatic And Paleohydrologic Approaches For Examination Of Hydroclimatic Extremes - Implications For Missouri River Reservoir Management.*
7. Erika Colaiacomo. *Downstream Spatial And Temporal Response To Dam Removal: Reach-Scale Variations In Transport Capacity On The White Salmon River, Washington.*
8. Rainie DeVaney. *Gasoline Remediation Impacts On Aquifer Microbial Communities, Ronan, Montana*
9. Mari Eggers. *Elevated Uranium And Lead In Wells In Big Horn County - A Potential Problem.*

10. Paige Evans. *Comparing State Regulations For Residential Greywater Reuse :Approaches To Appropriate And Adaptive Local Management.*
11. Fred Kellner. *Snow Distribution at the Landscape Scale from an Ensemble of Models: Central Bitterroot Range, Montana.*
12. Shawn Kuzara. *Results From A Ten Year Study Of An Off-channel Infiltration Pond Coal Creek Study Site, Ucross Wyoming.*
13. Heiko Langner. *Mercury Concentrations in Sediments of Flint Creek and Tributaries.*
14. James Madison. *Potentiometric-Surface Map Of The Madison Group In Part Of Cascade County, Montana.*
15. Thomas Matthews. *Examining Trends In Snow Accumulation & Water Availability Using SNOTEL And Streamflow Observations In The Missouri River Headwaters.*
16. Elizabeth Meredith. *Measuring Baseflow To Powder River Basin Streams.*
17. Luke Osborne. *Tri-State Water Quality Council: Collaborative Water Quality Monitoring In The Clark Fork Pend Oreille Watershed.*
18. Roy Sando. *Climate And Geological Factors Influencing Stream Intermittency In Alpine And Subalpine Watersheds In Western Montana.*

THURSDAY, OCTOBER 11, 2012 (continued)

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| <p>19. Sean Sullivan. <i>The Influence Of Dam Removal On A Mine-Impacted River: Downstream Effects On Macroinvertebrate Communities.</i></p> <p>20. Jen Titus. <i>Lower Wise River Watershed Investigation; Tracking Water In The Largest Tributary To The Big Hole River.</i></p> <p>21. George Williams. <i>Assessing Sources Of Acidic Drainage In Three Creek Drainages In The Judith Mountains.</i></p> | <p>22. Diane Winter. <i>Diatoms And Biological Monitoring Of Acidification In Aquatic Systems.</i></p> <p>23. Brett Woelber. <i>Soil And Energy Controls On Stream Recharge From Diurnal Snowmelt Events, Lost Horse Canyon, Bitterroot Mountains, MT</i></p> |
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BANQUET

Mt Haggin/Gregson Room

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| 7:00 pm | Banquet |
| 8:00 | Banquet Speaker
Jim Sheldon: <i>Mega Floods in Montana</i> |
| 8:30 | Photo Contest |
| 8:45 | Closing Announcements |

FRIDAY, OCTOBER 12, 2012

7:00 am Coffee and snacks in Atrium

SESSION 5 (Concurrent) CLIMATE

Pintlar Room

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|---------------------------|---|
| Moderator: Nicholas Tucci | |
| 8:15 am | Chris Brick. <i>Stream Temperatures On The Lolo National Forest: Analyzing The Past And Forecasting The Future.</i> |
| 8:35 | Larry Dolan. <i>Modeling The St. Mary River And Milk River Basins Under Historic And Future Climate Conditions.</i> |
| 8:55 | Phil Farnes. <i>How Variable Is Our Water Supply?</i> |
| 9:15 | Ian Magruder. <i>Climate Cycles, Dewatering A Gold Mine, And Human Perception Of Normal Streamflow.</i> |

SESSION 6 (Concurrent) WATER QUALITY - PART 2

Mt Haggin Room

- | | |
|-------------------------|---|
| Moderator: Mark Reinsel | |
| 8:15 am | Mark Reinsel. <i>From Phosphorus to Fish: Floating Island Case Study at Fish Fry Lake.</i> |
| 8:35 | Glenn Shaw. <i>Critical Loads Of Acidification In High Elevation Wilderness Lake: Sierra Nevada, CA.</i> |
| 8:55 | W.Adam Sigler. <i>Judith Basin Nitrogen Project: Landform Influence On Nitrate In Groundwater.</i> |
| 9:15 | Joanna Thamke. <i>Brine Contamination To The Prairie Pothole Region From Energy Development In The Williston Basin.</i> |

FRIDAY, OCTOBER 12, 2012 (continued)

9:35	Vicki Watson. <i>Seeley And Salmon Lakes - Historic And Current Condition And Risk Of Declining Water Quality.</i>	9:35	Courtney Young. <i>ARD Remediation with Slag: An Application to Berkley Pitlake Water.</i>
9:55	BREAK	9:55	BREAK

SESSION 7 (Concurrent) *Pintlar Room* SURFACE WATER & WATERSHED ANALYSIS - PART 2

Moderator: Ian Magruder

10:10 am	Vicki Watson. <i>River Response To 10 Years Of Nutrient Reductions On Montana's Clark Fork River.</i>
10:30	Kelsey Jencso. <i>Distributed Assessment of The Spatio-temporal Controls on Stream Discharge in the Tenderfoot Creek Experimental Forest, MT.</i>
10:50	Sam Carlson. <i>Quantifying Watershed Storage Dynamics Using Long Duration, High Frequency Measurements Of Precipitation, Runoff, And Evapotranspiration.</i>
11:10	Vicki Watson. <i>Updating Numeric Nutrient Criteria For Montana's Wadeable Streams And Rivers.</i>
11:30	Bruce Sims. <i>Post Wildfire Changes In Watershed Conditions And Response Adapting Management To A Frequent Disturbance Regime.</i>

SESSION 8 (Concurrent) *Mt Haggin Room* WATER MANAGEMENT/DEVELOPMENT - PART 2

Moderator: Glenn Shaw

10:10 am	Jon Reiten / Joanna Thamke. <i>Energy Development and Water Needs in the Williston Basin.</i>
10:30	Roy Sando. <i>The Use Of Remote Sensing As A Technique For Estimating Agricultural Evapotranspiration In West-central Montana.</i>
10:50	David Naftz. <i>Using Thermocline Manipulation to Remediate Mercury-contaminated Reservoirs In the Southwestern United States.</i>
11:10	W. Adam Sigler. <i>Citizen Water Monitoring: Building And Maintaining An Effective Program.</i>
11:30	Grant Zimmerman. <i>Effect Of Changes In Ambient Water Quality On Agricultural Production In The Tongue River Valley.</i>

CLOSING PLENARY

Pintlar Room

12:15 am	CLOSING PLENARY
	Announcements - Elected Officer, Photo Contest Awards, Student Awards
12:45 pm	ADJOURN

GROUND WATER ASSESSMENT PROGRAM STEERING COMMITTEE MEETING

1:00 pm	Ground Water Assessment Program Steering Committee Meeting
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KEYNOTE SPEAKER

Dr. Robert Hirsch

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Robert M. Hirsch currently serves as a Research Hydrologist at the USGS. From 1994 through May 2008, he served as the Chief Hydrologist of the U.S. Geological Survey. In this capacity, Dr. Hirsch was responsible for all U.S. Geological Survey (USGS) water science programs. These programs encompass research and monitoring of the nation's ground water and surface water resources including issues of water quantity as well as quality. From 2003 - 2010 he has served as the co-chair of the Subcommittee on Water Availability and Quality of the Committee on Environment and Natural Resources of the National Science and Technology Council, and in this role he has been instrumental in developing interagency priorities for water science and technology.

Hirsch earned a Ph.D. from the Johns Hopkins University Department of Geography and Environmental Engineering. He began his USGS career in 1976 as a hydrologist and has conducted research on water supply, water quality, pollutant transport, and flood frequency analysis. He had a leading role in the development of several major USGS programs: 1) the National Water Quality Assessment (NAWQA) Program; 2) the National Streamflow Information Program (NSIP); and 3) the National Water Information System Web (NWISWeb). He has received numerous honors from the Federal Government and from non-governmental organizations, including the 2006 American Water Resources Association's William C. Ackermann Medal for Excellence in Water Management, and has twice been conferred the rank of Meritorious Senior Executive by the President of the United States. He is a recipient of the USGS "Eugene M. Shoemaker Award for Lifetime Achievement in Communications." He is co-author of the textbook "Statistical Methods in Water Resources." Dr. Hirsch is a Fellow of the American Association for the Advancement of Science and an active member of the American Geophysical Union and the American Water Resources Association. He has testified before congressional committees on many occasions and presented keynote addresses at many water-related meetings across the nation.

Since returning to a research position he has focused his efforts on describing long-term changes in streamflow and water quality. This includes exploring century-scale trends in flooding nationwide. It also includes the development of new methods for tracking nutrient transport trends for Chesapeake Bay, Lake Champlain, and the Mississippi River Basin. A major goal of this research is to improve communication of hydrologic trends in a manner that is helpful to water policy and management.

Abstract

Changing Hydrologic Systems - Thinking about Nonstationarity of Streamflow and Water Quality

Change is a pervasive fact recognized by all who study hydrologic systems. Including consideration of hydrologic change is crucial to effective planning for future actions aimed at managing water supplies, enhancing water quality, mitigating flood losses, or providing flow (and flow variability) to sustain aquatic ecosystems. Any approach to planning our actions for the future must entail projections about how the hydrologic system

will behave over the planning horizon. We need to have, and to use, appropriate tools to try to identify the changes that have been happening. Only by looking backwards at the changes that have taken place can we gain confidence that our planning tools are reliable. In this process we need to use the unplanned global- and watershed-scale experiments that are now underway to test our models of how change drivers influence various hydrologic variables. The drivers to consider include, at least, the following: changes in the cycling of nutrients and other elements through large scale land-use practices associated with agriculture, energy extraction and urbanization; regional groundwater depletion; and flow modification through storage and diversion. Another driver that is expected to have large impacts on water is enhanced greenhouse forcing of the global atmosphere, although these impacts are presently difficult to identify or quantify in comparison to the other drivers mentioned above. The impacts of enhanced greenhouse forcing on water resources can be very hard to distinguish from the impacts of quasi-periodic oscillations of the atmosphere-ocean system, and in the western US, from the impacts of increased dust deposition on snow. The driving philosophy of this presentation is captured in a quote from Ralph Keeling (Science, 2008) in which he said: “The only way to figure out what is happening to our planet is to measure it, and this means tracking changes decade after decade and poring over the records.” The scientific tools for poring over the hydrologic records must be advanced if we are to manage our planet successfully. The hydrologic science and engineering community must step up the effort to track the changes that are going on around us and relate them to potential change-drivers.

SPECIAL SPEAKERS

Water Rights Compact - Confederated Salish and Kootenai Tribes

Jay Weiner, Attorney

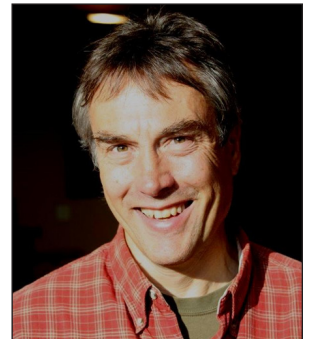
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PO Box 201601
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Helena, MT 59620-160
Phone: 406-444-6844
Email: jweiner@mt.gov



Jay Weiner has worked for the State of Montana since 2004, first as a staff attorney for the Montana Reserved Water Rights Compact Commission, and since 2008 for the Montana Attorney General's Office, which loans him back part-time to the Compact Commission. Jay has represented the Compact Commission and the State of Montana in various aspects of reserved water rights negotiations with the tribes of the Blackfeet, Crow, Flathead and Ft. Belknap reservations, as well as with the U.S. Fish and Wildlife Service, the U.S. Bureau of Land Management, and the U.S. Forest Service. He also practices regularly before the Montana Water Court, mainly regarding issues of abandonment and non-perfection of water rights. Prior to coming to work for the State, Jay worked for a law firm in Sacramento, California, that specialized in federal Indian law, served as Court Counsel to the Supreme Court to the Republic of Palau, and clerked for U.S. District Judge Charles C. Lovell in Helena. Jay will discuss the off-reservation water rights issues that are a unique feature of the CSKT Water Compact negotiations.

Seth Makepeace

CSKT Hydrologist
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Pablo MT, 59855
Phone: 406-675-2700 x6255



Seth Makepeace, hydrologist for the Confederated Salish and Kootenai Tribes. Seth has been involved in negotiations for a federal reserved water right for water on and off the Flathead Indian Reservation. He will be providing information about the water rights compacting process for the Confederated Salish and Kootenai Tribes (or CSKT), including how the Compact is proposing to deal with uncertainties (model, climate variability, etc.) by means of adaptive management. Seth is working with the public involved in this process, and will share some thoughts on the intersection of science and society, and how the science is being received by the public.

SPECIAL SPEAKERS

Mary Sexton

DNRC Director
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Helena, MT 59620
Phone: 406-444-2074
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Since 2005, Mary Sexton has been Director of the Montana Department of Natural Resources and Conservation focusing much of her efforts on revenue enhancement from State Trust Lands, water use and permitting, and, most importantly, future needs of Montana's treasured lands and water. Growing up in Great Falls and Choteau, Mary Sexton spent a good deal of time at the family ranch and in the Bob Marshall Wilderness. Working for area ranches, the Forest Service in the Bitterroot and outfitters in the Bob, Sexton recalled, is where she gained her appreciation of Montana's stellar landscapes and bountiful resources. Her 25 years invested in managing a family agriculture and range property is where she gained firsthand knowledge of the pressures on land uses in Montana.

Sexton majored in languages and minored in environmental studies at Stanford University and the University of Montana. She taught high school in Hamilton and became the administrator of the Nature Conservancy's Pine Butte Swamp Preserve (west of Choteau). Sexton was also an active board member of the Public Wildlife/Private Lands Council, BLM Resource Advisory Council and the Ravalli County Planning Board. All of this led to her tenure as Teton County Commissioner from 1999-2004. As a commissioner, she gained valuable insight into the relationships among private property owners, local government, state agencies and federal entities as it related to natural resource management.

Richard Opper, Director

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Richard Opper was appointed as Director of the Montana Department of Environmental Quality in 2005 by Governor Brian Schweitzer. As Director of the Montana DEQ, Opper oversees his department's pursuit of its mission to protect, sustain, and improve a clean and healthful environment. DEQ works on superfund site cleanups, environmental enforcement, water quality planning, energy conservation, alternative fuels promotion, and environmental permitting.

Opper received a Master's Degree in Environmental Science in 1979 from Montana State University, where his research focused on mined land reclamation. Before working for state government, Opper worked on natural resource issues for a variety of non-profits. Most recently, he served as Director for the Missouri River Basin Association, a coalition of the basin's states and tribes that addressed policy issues regarding the management and recovery of the Missouri River system. Richard is also the author of a sadly little-known novel.

BANQUET SPEAKER

James Sheldon

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The second son of a Missouri raised surveyor making the 7.5 minutes topographic maps and a real deal cowgirl from Chilly Flats near Mt. Borah, he was raised in many places throughout the western US attending 26 grade schools (some multiple times) and 4 high schools in 15 states. Since new mapping to support the then new porphyry copper industry was a national priority, this include all the great old mining districts in the southwest and many in the northern tier.

A Graduate of the University of Idaho He is retired following a 35 year career in BLM and the US Forest Service as a mineral specialist and mineral law administrator culminating in a 20 year stint as the Regional Geologist of Region I and supervisor of the national training unit for geosciences and mineral law. As regional geologist, duties included groundwater, paleontology, caves, and data management.

Married with two children, he lives in Missoula doing pretty much what he wants including the current president of the Ice Age Floods Institute Lake Missoula Chapter. The Ice Age Floods Institute (IAFI) is an educational nonprofit founded in 1995. Major accomplishments since inception are the formation of ten chapters across Oregon, Washington, Idaho and Montana with a large and diverse membership. Federal designation legislation passed in 2009, authorizing the National Park Service to establish the Ice Age Floods National Geologic Trail (IAFNGT), is a significant milestone which elevates the IAFI scope of work as primary private sector partner in development and implementation of the Trail management plan.

Abstract

Mega Floods in Montana

At the end of the last Ice Age about 12500 years ago to about 15,000 years ago as the climate moderated and the great ice sheets began to melt, Montana was host to one of the larger ice marginal lakes, Lake Missoula. This lake was formed by the damming of the Clark Fork River near Sandpoint Idaho. This lake recieved the waters from the flathead and Clark fork drainages plus the water from the melting ice sheets to the north.

This lake was about the size of Lakes Erie and Huron combined and was deep about 2000 feet at the dam. Crater Lake the deepest in North America is a little over 1000 feet deep.

Periodically the ice dam would fail catastrophically unleashing the highest and flow rate floods known on earth.

Lake Missoula was the first of these mega-floods recognized and was the center of intense controversy within science and responsible for a major rethinking of how things could work and what was possible. As a result many mega floods are recognized and their role in geology and climate change is just beginning to be understood.

A new round of review, new evidence and new thinking is causing a new look at this story. This presentation empahasizes local Montana features and reviews some of the new lines of evidence.

Dye Tracer Study At The Susie Adit/Upper Valley Forge Mine Area, Upper Tenmile Creek Mining Area Superfund Site, Lewis & Clark County, Montana

Robert Alexander, Environmental Scientist, CDM Smith, 50 West 14th Street, Suite 200, Helena, MT, 59601, (406) 441-1436, alexanderrr@cdmsmith.com. Additional authors: Chapin Storrar, CDM Smith.

Since 2001, adit discharge sampling has been conducted at the Upper Tenmile Creek Mining Area Superfund Site. Adit discharge of poor water quality contributes to the metal loadings in Tenmile Creek, via tributaries and other surface flow. By determining the sources of the adit discharge, measures can be potentially taken to evaluate cost-effective ways to reduce or eliminate this source of contamination to Tenmile Creek.

The Susie Adit is one of several key contributors of contaminated discharge to Tenmile Creek. One of the recommendations from a 2010 source control investigation was to conduct a tracer study to determine if there is a connection between a series of upgradient surface water features in the general area of the Upper Valley Forge Mine and flow from the Susie Adit that exits near the base of a steep slope within the community of Rimini. Several surface water sources were considered and it was decided to limit the tracer study the uppermost reach of Moore's Spring Creek and to two potential source ponds (i.e., the "BMP Pond" and "Pond 2"). The selection of these sources was, in part, imposed due to the limited number of dye tracers that can be reliably analyzed simultaneously; in this case, three: Eosine, Fluorescein, and Rhodamine WT. If any of these dyes is present in the Susie Adit discharge after injection, a hydraulic connection between the surface water source and the mine workings could be assumed. Methods of source control could then be designed to reduce infiltration into the mine workings, thereby reducing the volume of poor quality water discharging from the Susie Adit. A sampling program was conducted from Fall 2011 through Spring 2012 with the primary goal to qualitatively determine whether Pond 2, BMP Pond, and Moore's Spring Creek are contributing water that is ultimately discharged from the Susie Adit. A secondary goal was to qualitatively determine other locations where water from these surface features also may ultimately discharge (e.g., other nearby mine sites, springs used for drinking water, etc). In September 2011, Eosine was introduced in the uppermost reach of Moore's Spring Creek (in a losing stream reach), Rhodamine WT was introduced into the BMP Pond, and Fluorescein introduced into Pond 2. Six down-gradient sample stations, including the Susie Adit discharge, were monitored for the study. As might be expected, Eosine was detected early in the program where Moore's Spring Creek enters Tenmile Creek, followed by a significant period of no detections. In mid-Spring 2011 a possible detection of Rhodamine WT was found in Moore's Spring Creek; however, throughout the period of study, none of the dyes was detected in any of the samples from the Susie Adit discharge.

Boulder River Valley Groundwater Investigation: Designing The Groundwater Flow Model

Julie Ahern Butler, Hydrogeologist, Montana Bureau of Mines and Geology, Groundwater Investigations Program (GWIP), 1300 West Park Street, Montana Tech, Butte, MT, 59701, 406-496-4854, jbutler@mtech.edu. Additional authors: Andy Bobst, Montana Bureau of Mines and Geology; Luke Carlson, Montana Bureau of Mines and Geology; John Anderson, Montana Bureau of Mines and Geology.

The Boulder River Valley study area is located in the lower part of the Boulder River watershed, between Boulder and Cardwell, Jefferson County, Montana. The study focuses on the alluvial aquifer, which provides baseflow to the Boulder River. The Boulder River is often dry during late summer, eliminating the ability to irrigate even for senior water-rights holders and causing concern that continued groundwater development will further adversely impact senior water rights. This GWIP study examines the flux of water between the alluvium and the river, the magnitude of impacts expected from existing and potential housing developments, and potential mechanisms to increase water availability throughout the year. GWIP is using a numerical groundwater flow model to meet study objectives. The design and hydrogeologic evaluation of a numerical model depends on a well-defined conceptual model. Because previous hydrogeological investigations have been very limited, the first step was to define conceptual model components such as aquifer types, aquifer properties, and recharge from precipitation. The numerical model design includes grid discretization,

boundary-condition selection, and aquifer-property inputs. The resulting model is one layer and covers the near-stream alluvium, Quaternary and Tertiary basin-fill deposits, and fractured bedrock. Model calibration is underway and involves a combination of manual adjustments, automated parameter estimation, and sensitivity analysis; observed water levels and stream flows serve as calibration targets. The primary calibration goal is to establish a well-constrained range of aquifer-property and recharge values approximating field conditions. Once calibrated, the model can be used to predict impacts of future scenarios such as new housing developments, or structures intended to increase baseflow to the river.

Challenges In Characterizing A Fractured Rock Aquifer System Landusky Mine Site 2012

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Prior to declaring bankruptcy in 1998, Pegasus Gold Corporation conducted open pit mining at the Zortman and Landusky mines in the Little Rockies Mountains of north-central Montana. The Department of Environmental Quality now operates the sites' water treatment systems. Improved source controls and in-situ treatment could significantly reduce long term costs. The State of Montana and Bureau of Land Management have sponsored intensive hydrogeological, geophysical, and engineering investigations of the Landusky mine site and Swift Gulch throughout the past decade. These investigations were targeted at understanding the sources and pathways associated with the worsening quality of groundwater within the former Landusky pit complex, the seeps along Swift Gulch, and Swift Gulch surface water. Groundwater flow in and around the Landusky Pit is dominated by a complex shear zone system. Major fractures are oriented in a northeast-southwest direction, but the connectivity of the major and secondary fractures in the bedrock is not fully understood. Understanding fracture flow at the north end of the Landusky Pit is important in order to evaluate pathways for discharge of groundwater and acid rock drainage (ARD) constituents to Swift Gulch. The fractures are apparent major conduits of ARD movement from the mine site to Swift Gulch. In 2012, a seven day aquifer test was completed with the purpose of estimating the hydraulic properties of the fractured bedrock providing information to help assess the potential for in-situ source control technology for ARD movement to Swift Gulch. In conjunction with the aquifer test, a forced gradient dye tracer test was performed to assess the connectivity of monitoring wells believed to be completed in the shear zone. Rising groundwater levels due to spring recharge during the duration of the aquifer test, combined with the complex fractured system, produced anomalous test results. Monitoring wells believed to be connected by fractures showed immediate response but minimal drawdown from pumping, where all other monitoring wells showed no response. The dye tracer test confirmed fracture connectivity. Dye was detected in the discharge water from the pumping well 6 to 12 hours after start of pumping where calculated travel times based on prior aquifer test results predicted greater than 6 days. Therefore, recharge that likely dampened aquifer response, combined with the inherent difficulties in interpreting fractured aquifer test data, resulted in anomalous and unexpected results requiring unique interpretations. A more comprehensive understanding of the fracture flow system and ARD pathway at the north end of the Landusky Mine has been gained from the study.

Water Quality And Groundwater Age In An Isolated Shallow Aquifer Of The Judith River Basin, Montana

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Land management is an important driver of water quality, yet soil-groundwater systems are often poorly characterized, making management decisions difficult. In the Judith River Basin (JRB) of Central Montana, nitrate in some groundwater and surface water samples has exceeded the U.S. EPA's human health standard (10 mg nitrate-N L⁻¹) since the 1970's, and groundwater monitoring well data indicate an increase in groundwater nitrate concentrations since that time. Thin soils overlying shallow unconfined gravelly

aquifers provide a likely conduit for rapid groundwater recharge and transport to domestic wells and surface water. Vulnerable landforms associated with high groundwater nitrate in the JRB include alluvial fans and strath terraces variably connected to mountain front stream recharge. Here we focus on an extensive (~600 km²) strath terrace surrounding the area near Moccasin, MT, where dryland cultivation for cereals is the dominant land use. Because the shallow, unconfined aquifer on the Moccasin terrace is isolated from mountain front stream recharge (MFSR), we hypothesize that recharge of the shallow aquifer occurs exclusively from diffuse infiltration of precipitation over time scales of days to decades, with a very limited influence from deeper and older aquifer water. Nitrate from soil reaches shallow groundwater in locations where infiltration is not limited by evapotranspiration or spring rainfall drives rising water tables that capture accumulated nitrate. In support of this conceptual model, tritium analyses indicate that distinctly young water (~0 to 60 years since recharge) is associated with high nitrate concentrations generally ranging from 5 to 20 mg NO₃--N L⁻¹ in shallow wells and emergent streams of this landform. A three dimensional model of groundwater flow based on the conceptual model provides clues about landform scale relationships of subsurface flow relating nitrate concentrations and groundwater mean residence times. Based on preliminary data, we present a strategy for ongoing solute and water isotopic analysis that will be used to test our working model of subsurface reaction and flow dynamics. This work will help to identify and quantify sources of nitrate in water resources of the JRB, and begin to quantify the time required to observe a change in local water quality as a result of change in land management practices.

Stream-loss Recharge To The Madison Aquifer In Central Montana

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The Madison aquifer in central Montana supplies water to residential, municipal, and agricultural users yet the recharge sources are poorly understood. Recharge to the Madison Aquifer is currently being studied as part of a Montana Bureau of Mines and Geology project, Sustainable Water Supplies from the Madison Aquifer sponsored by the Cascade County Commission. It is believed that a significant component of the recharge to the Madison aquifer comes from streams originating in the Little Belts and the Big Snowy mountains. Stream-flow losses have been recorded where streams cross the Madison Group limestone in this area (Feltis, 1977; Zimmerman, 1966). Stream-flow and water quality measurements on streams crossing outcrops of the Madison Group were conducted as part of the current project in the summer and fall of 2011. Our measurements confirm the findings of earlier studies and expand on the number of streams measured. Repeat synoptic flow measurements are being conducted on the Judith River, Cottonwood Creek, and on the Smith River in the summer and fall of 2012 with hopes to better understand and quantify the recharge to the Madison aquifer from surface water sources. The stream-flow data collected on the Smith River in the fall of 2011 showed gaining and losing reaches which seem to be linked with mapped faults. The 2011 measurements pointed out the complexity of the system and the areas where we need to gather additional data. Only a small part of the stream recharge picture would be seen if flows were just measured above and below the Madison outcrop. The entire flow of the South Fork of the Judith River near Utica and Cottonwood Creek near Lewistown disappeared into the middle of Madison outcrop when the flows were measured in September. Losses to the Madison will likely be different if the measurements are made at a higher stream stage. The findings of our field work will be discussed and compared to previous studies in this presentation.

An Examination of the Northern Summit Valley Organic Silt Paleosol, Butte, MT

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The Blacktail-Silver Bow Creek confluence near Butte, Montana is a low-flow, low-gradient groundwater discharge area demarked by numerous groundwater-fed wetlands. The creeks drain the Summit Valley, a small 128 mi² intermontane valley in southwest Montana (Botz, 1969).

Historically, the confluence area was known to the early Butte settlers as a “swampy and peaty” area, presenting a challenge to work around (Meinzer, 1914). The confluence and about three miles of upstream valley bottom has been heavily impacted by more than a century of mining, milling, and smelting activities, in addition to physical changes due to urbanization. The area is of interest because it traverses the southern boundary of the Butte Priority Soils Operable Unit. A review of lithologies reported on 160 water well logs demonstrates the existence of a black, 0.5 to 15-ft thick, near-surface silty unit containing > 50 percent organic materials (in selected samples) within the Blacktail-Silver Bow Creek flood plain. Today, the organic silt unit is used by geoscientists as a marker for the floodplain’s pre-mining soil horizon, and is of interest because;

- It is near land-surface and typically overlain by mine-waste, fill, or other anthropogenic land-fill material.
- It is unique in the lithologic record, and is not repeated in deeper sequences.
- It contains > 50 percent organic materials in select samples; significantly higher than deeper sediments (< 5 percent organic materials).
- Where it is overlain by tailings or other mine wastes and after 100+ years of weathering and leaching of these primary source materials, contaminants, such as Cu and Zn have readily sorbed onto its organic components. The unit is typically located in the vadose zone, often within the capillary fringe in hydrologic communication with the aquifer. Leaching tests indicate that this unit has become a secondary source material for groundwater contamination in areas overlain by tailings. The unit appears to be derived from a wetland depositional environment, confined to the Blacktail/historic Silver Bow Creek floodplain in low-lying areas of the Summit Valley. The areal extent of this unit may be a window into the past, with the presence and thickness of the unit depicting areas where groundwater historically expressed itself as surface water in the valley. Well logs indicating the presence of the organic silt in several areas no longer exhibit adjacent wetlands. Interestingly, the absence of the organic silt from well logs may indicate that the environment was not a pre-mining groundwater discharge area to surface water.

SESSION 2 SURFACE WATER & WATERSHED ANALYSIS - PART I

The 2011 Musselshell River Flood – Assessing Impacts And Developing Rehabilitation Strategies

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During the spring of 2011, the Musselshell River experienced unprecedented flooding that resulted in extensive damage to irrigation infrastructure, roads and bridges, residential structures, and productive agricultural fields. Flood-induced changes in river morphology include 59 avulsions and abandonment of 37 miles of channel. In an effort to characterize these impacts and develop response strategies, the Musselshell Watershed Coalition (MWC), which is a partnership of water association, conservation districts, and agencies, secured a Reclamation and Development Planning Grant to assemble and support a River Assessment Triage Team (RAT Team).

This effort is the result of unprecedented cooperation among landowners, communities, local, state, federal agencies, private consultants, and Montana’s full congressional delegation who created this opportunity to develop strategic approaches to flood damage rehabilitation and long-term river management. An objective of the MWC is to continue to pursue collaborative basin-wide water management using this historic event as a means to secure more cost-effective and resilient irrigation infrastructure, while improving riverine function and ecological sustainability. From fall 2011 through early winter 2012, the RAT Team visited 43 field sites accompanied by local agency personnel and landowners to assess flood impacts on each property, develop response strategies, and identify conservation opportunities. The types of sites visited included avulsions, abandoned or damaged irrigation infrastructure, excessive bank erosion, damaged fields, damaged siphons, and lost access to property. System-wide flood impacts were evaluated using pre-flood (2009) and post-flood (2011) air photo base maps that were supplemented by low altitude aerial photographs from flights between May 2010 and November 2011. The main objectives are to document flood impacts on the river, its floodplain, and producers in the corridor, and to develop strategies to support the livelihoods of those producers while integrating long term recovery and ecological function of the Musselshell River.

Evaluating Macroinvertebrate Responses To Sediment In Mountain Streams Using Biometrics

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The Montana Department of Environmental Quality currently uses macroinvertebrate populations as indicators of water quality (i.e. biometrics). In order to accurately depict biometric responses to different stressors, data must be collected along a gradient from high quality (i.e. reference sites) to low quality (i.e. stressed sites). This study focused on evaluating how well an improved DEQ fine-sediment assessment method can predict changes to aquatic macroinvertebrate communities. The purpose of this presentation will be to provide an overview of the DEQ sediment assessment method and how we can use the assessment results to develop a sediment-specific biometric for use in mountain streams.

Fish & Wildlife Recommendations For Subdivision Development Along Montana's Waterways

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Montana is known as The Treasure State. Among our treasures are the water resources that provide essential "habitat" for people, fish, and wildlife. Proposals for subdivision development along Montana's waterways often illustrate the competing demands upon our water-based habitats. Simply put, people want to live close to water! Aside from the potential hazards associated with waterfront development, the presence of permanent structures, roads, and human activity can interfere with the natural processes of riverine systems and, in turn, compromise the health of fish and wildlife populations. People's desire to live near water is unlikely to diminish anytime soon. So how can we accommodate new development near rivers, streams, wetlands, and riparian areas in ways that both protect water quality and conserve aquatic and terrestrial habitats? This question can stump land developers and plague local governments, who are required under Montana law to consider the effects of subdivision development on fish and wildlife. City and county planners routinely ask Montana Fish, Wildlife & Parks (MFWP) biologists to review and comment on proposed subdivision applications. Thanks to a four-year effort by a technical working group of biologists and land use planners, MFWP biologists now have a consistent, science-based set of recommendations to guide them as they offer input into the local subdivision process. While the recommendations are primarily designed to support MFWP in its advisory role as a subdivision review agency, they may also provide useful information to local governments, landowners, developers, and all those interested in conserving Montana's water, fish, and wildlife resources.

German Gulch Fish Screen Project: Lessons Learned

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In 2008, a fish screen was installed on a tributary to Silver Bow Creek at a site known as German Gulch. The project was a collaborative effort headed up by Montana Fish Wildlife and Parks and including Farmers Conservation Alliance, the landowner, PBS&J Engineering, and a private contractor. In the years between 2008 and 2011, the project had a series of issues and problems that threatened to derail the entire project. With some additional help from TU, the project partners were able to work together to identify solutions and implement them, ultimately creating a successful outcome. Miscommunication and incorrect assumptions created what appeared to be insurmountable problems. Patience and a willingness to keep working resulted in a project that has many valuable lessons that can help make future fish screening projects successful.

Baseline Assessment Of Riparian Function Of Long Creek, Centennial Valley, Southwest Montana

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Environmental Field Studies classes at the University of Montana Western (UMW) in Dillon, Montana have been conducting assessments of stream morphology, in-stream macroinvertebrates, riparian vegetation and stream habitats on Long Creek in the Centennial Valley in southwest Montana since 2009. The goal of the project is

to assess the health and function of the riparian system and provide recommendations for restoration efforts that will enhance the streams potential for fluvial and/or adfluvial Arctic grayling. Long Creek has primarily been degraded by ranch activities, including bank degradation and siltation caused by cattle grazing, dewatering for irrigation, removal of bank vegetation through grazing and human activities and mechanical manipulation, including the placement of culverts and the straightening of sinuous channels. This stream channel is particularly vulnerable to human activities, because it is cut into fine-grained, Pleistocene lake sediments and entrenched as a result of tectonic uplift of the region. The assessment data from surveys conducted in 2009 and 2011 show that the stream is functioning as an E4b stream, based on Rosgen's classification system. The in-stream macroinvertebrate data show relatively poor diversity and moderate richness, with a low number of individuals for a functioning stream of this type. The riparian vegetation is relatively robust and diverse, but the percentage of willow is extremely low for a stream of this type. The stream habitat data show a very high percentage of non-vegetated stream banks and an overall morphology that is lacking in riffles. The low percentage of coarse-grained sediment, coupled with significant bank erosion has resulted in the absence of riffles in many parts of the stream. Riffles are an important habitat type for the reproduction of fluvial Arctic grayling, and so the UMW team recommends that pebble-sized material be mechanically added to the streambed in order to create riffles. Based on sediment transport calculations, this sediment size will not be moved out of the system under the highest, predicted boundary shear stress for the stream and will provide a long-term solution to the riffle habitat problem on Long Creek.

SESSION 3

WATER QUALITY - PART I

Overview And Update: July 2011 Silvertip Crude Oil Release To The Yellowstone River

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On July 1, 2011, near the City of Laurel, ExxonMobil's Silvertip Pipeline broke in the Yellowstone River, releasing approximately 1,500 barrels (63,000 gallons) of crude oil. Visual signs of oil were present along the shores of the river as far as approximately 70 miles downstream of the release. The spill elicited a massive response effort, requiring the coordination of Federal, State, and local governmental agencies with ExxonMobil and its many contractors. At its peak, an estimated 1,500 people per day were working on the response. On September 9, 2011, the U.S. Environmental Protection Agency handed oversight authority for the response to the Montana Department of Environmental Quality (DEQ). Emergency cleanup work at the site ended in late fall of 2011, although longer-term investigation, monitoring, and cleanup (if necessary) continues. The Silvertip oil spill occurred near the peak of flooding along the Yellowstone River, and the flood affected response efforts and how the oil was distributed in the environment. This presentation provides an overview of the spill's impacts, the behavior of the crude oil in the river system, and the response efforts (both short and long-term). Throughout the presentation there will be a focus on "lessons learned" to highlight what went well and what could be improved upon in future response efforts.

Wastewater Effluent Disposal Through Snowmaking

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The Big Sky County Water and Sewer District (District) currently disposes of all of its treated wastewater by irrigation on two local golf courses, the Big Sky Golf Course in Meadow Village and the Yellowstone Club course. As development continues, the effluent flow from the District will exceed the irrigation capacity of these golf courses. Because of this capacity limitation and an ongoing commitment to wastewater reuse, the District is interested in evaluating snowmaking as a disposal option. Several studies have demonstrated that 50% to 80% of the contaminants in snowpack can be contained in the first 20% to 30% of the melt water. There is also evidence that volatilization of gases or microbial action in the aging snowpack may result in a significant decrease in ammonia. A pilot test conducted by the District in 1997 of a snowmaking process showed

a reduction in ammonia from 43 mg/l-N in the applied snow to 20.6 mg/l N in aged snowpack and to 1.2 mg/l-N in the melt water. Over the winter of 2011-2012, a pilot snowmaking project was conducted on a high elevation slope in the South Fork of the West Fork of the Gallatin Watershed. Approximately 1 million gallons of wastewater was disposed of through snowmaking onto the test site over a one month period. The following samples were collected over the study period: 1) liquid wastewater effluent prior to snowmaking, 2) freshly made snow from wastewater, 3) monthly samples of the aging snowpack, 4) surface runoff, and 5) soil water from six lysimeters. All samples were analyzed for total nitrogen, nitrate+nitrite, ammonia+ammonium, E.coli, total coliform, pH, conductivity, and total suspended solids. Data analysis will determine the concentration of contaminants that percolate through the soil profile, the concentration of contaminants in surface runoff and any reduction of key contaminants that occur during the snowmaking and snow aging processes. Results will be used to determine the feasibility of using snowmaking as a disposal option in the Big Sky area. The presentation will discuss the results from the pilot project.

Development Of Nutrient Criteria For Lakes And Reservoirs In The Northern Plains States Of Montana, Wyoming, North Dakota And South Dakota

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Lake and reservoir water-quality conditions are heavily affected by present-day land-use activities. This makes it challenging to identify reference conditions from which to determine numeric water-quality criteria because of the lack of a reference condition. This presentation focuses on the development of a method to establish nutrient criteria for lakes and reservoirs in the plains regions of Montana, North Dakota, South Dakota and Wyoming. The method consisted of the use of linked watershed and receiving water Monte Carlo models to simulate the annual variability in reservoir and nutrient concentrations. Numeric criteria are then based on the probability that a given total phosphorus or chlorophyll-a bloom concentration is exceeded. Results from the analysis show how the modeling results can also be used as a guide for establishing nutrient loading capacity.

Assessing Differential Transport Of Chemical And Biological Constituents In Ground Water Impacted From A Municipal Waste Water Treatment Lagoon

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The extent and severity of groundwater contamination from human wastewater disposal is an issue of growing concern in Montana and globally. Constituents of concern include chemical parameters such as nitrate and biological constituents such as E. coli O157:H7, Pseudomonas aeruginosa, and Hepatitis A which pose risks for waterborne disease. The diversity of organisms capable of causing waterborne disease and the complexity in detecting or enumerating these organisms has given rise to the use of indicator organisms such as total coliform, fecal coliform and E. coli. While E. coli is the preferred indicator organism for risk of waterborne disease by the US Environmental Protection Agency and the World Health Organization, it is often not detected in groundwater even when wastewater contamination is present. This makes E. coli a less than ideal indicator of wastewater contamination in groundwater. This project evaluates groundwater quality impacts downgradient from the River Rock waste water lagoons which treat wastewater for over 1200 homes. Four wells oriented progressively downgradient from the lagoons are evaluated for chloride, nitrate, boron, total coliform, E. coli, Bacteroides, dissolved oxygen and conductivity over the 2012 summer season. Relationships between these variables are evaluated in the context of time and movement along a flowpath away from the lagoons. Chloride is evaluated as a conservative tracer and each of the other parameters are related to. Loss of nitrate through denitrification will be assessed in the context of dissolved oxygen concentrations and $\delta^{15}N$ values. Transport of viable total coliform and E. coli bacteria will be evaluated using IDEXX and presence of Bacteroides DNA will be assessed with quantitative PCR using both general and human specific primers.

Bacteroides have been used in many surface water microbial source tracking studies since 2000. However, only a few studies have looked for Bacteroides in ground water and no study has used Bacteroides to assess impacts from groundwater contaminated with sewage effluent. Potential utility of Bacteroides as an alternative biological indicator of groundwater contamination will be assessed.

The Fate Of Geothermal Mercury In The Madison And Missouri Rivers, Montana And Wyoming

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Mercury is a worldwide contaminant derived from natural and anthropogenic sources. River systems play a key role in the transport and fate of mercury because they drain widespread areas affected by aerial mercury deposition, provide downstream transport for mercury from point sources, and are sites of mercury biogeochemical cycling and bioaccumulation. The Madison and Missouri Rivers provide a natural laboratory for studying the fate and transport of the substantial headwater input of mercury contributed by geothermal discharge in Yellowstone National Park. Assessing mercury in these rivers also is important because they support fishery-based recreation and irrigated agriculture. A field study during 2002-06 determined (1) the relations among mercury concentrations in water, sediment, and fish, (2) the geothermal mercury load to the Madison River, and (3) the overall fate of mercury along 378 km of the river system. Samples were collected from the main stem, 7 tributaries, and 6 lakes. Geothermal mercury was the primary source of elevated total mercury concentrations in unfiltered water (6.23-31.2 ng/L), sediment (148-1,100 ng/g), and brown and rainbow trout (0.121-1.23 µg total mercury/g wet weight skinless fillet) upstream from and in Hebgen Lake (the uppermost impoundment on the Madison River). About 7.0 kg/y of geothermal mercury was discharged from the park in the Madison River, and an estimated 87% of that load was lost to sedimentation in and volatilization from Hebgen Lake. Consequently, mercury concentrations in water, sediment, and fish from main-stem sites downstream from Hebgen Lake were not elevated and were comparable to concentrations reported for other areas affected solely by atmospheric mercury deposition. Some mercury was sequestered in sediment in the downstream lakes. Bioaccumulation of mercury in fish along the river system was strongly correlated ($R^2 = 0.76-0.85$) with unfiltered total and methyl mercury concentrations in water and total mercury in sediment.

SESSION 4 WATER MANAGEMENT/DEVELOPMENT - PART I

Using The Data We Collect: Environmental Data Management

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Whether it's for a remediation project, a water/wastewater facility, or on-going monitoring, environmental based projects generate a large amounts of analytic data. To be useful for analysis or modeling activities this data must be consistently maintained in an accessible manner. This presentation will explore the process of managing environmental data and the benefits of using the EQulS 5.6 environmental data management system. EQulS 5.6 is a leader in the environmental data management software and has the power to directly connect to mapping and modeling software.

Private Equity Ownership Of Municipal Water In Montana

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International attention on issues surrounding the private control of public water has grown in recent years due to controversies resulting from poor management and increased rates. The sale of Missoula, Montana's municipal water supply from Mountain Water Company ("Mountain Water") to the Carlyle Group ("Carlyle") in 2011 raised similar questions about the equitable provision of drinking water in the United States.

Understanding the implications of the sale involves both the specific history of the city's water supply and the terms of the sale itself. In addition, the purchase of a water utility by a private equity firm is a new trend in the private provision of public drinking water. As a result, reevaluating Montana's governing rules and regulations is necessary in order to understand how to handle this new type of acquisition model. Investigating where improvements could be made will provide Montana, and potentially other communities facing similar sales, a more comprehensive way to address related public interest concerns. The sale of Mountain Water to Carlyle is a way to explore the currently limited information on private equity ownership of municipal water. This article, in Part I, provides the factual background of the sale. It begins with the history of Missoula's municipal water supply, and traces the ownership from its origins through the recent sale to Carlyle. Part I then details the terms of the sale and the government review involved in its approval. Part II addresses the issue of what it means for a private equity firm to own a municipal water supply in Montana. To do so, Part II provides a global, national, regional, and local context for the sale. It investigates the evolving nature of water privatization and the differences between privatized municipal water and private equity ownership of municipal water. It also discusses three comparable sales to Carlyle's purchase of Mountain Water and tracks the conditions of approval for each one. Part III next turns to an analysis of the Montana laws and regulations implicated. It begins with the background legal principle of the public trust doctrine, explores the relevant portions of the Montana Constitution, as well as Montana's statutory law and administrative regulations. Part III concludes with opportunities for improvement in Montana's laws governing the review and approval of private equity ownership of municipal water utilities.

Canal Seepage Loss In The Lower Beaverhead River Basin

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Seepage losses from canals and ditches can provide a significant source of recharge to groundwater. Those losses have become an important component of the localized groundwater flow regime. The East Bench and West Side Canals provide irrigation water for a portion of the lower Beaverhead River watershed between Dillon, Montana and Beaverhead Rock. The connection between these canals and groundwater was evaluated as component of the water budget calculated for this study area. Two sites along the East Bench and West Side Canals were studied by installing nested wells to examine seasonal changes in groundwater elevations and geochemical changes with depth. Canal and groundwater specific conductivity, deuterium and ^{18}O were collected weekly or biweekly through the irrigation season. Chemistry was compared with water elevation changes in both the canals and monitoring wells to qualitatively investigate the canal water interaction with the groundwater system. Canal flow rates and diversion amounts were used to calculate average seepage losses along both canals. Groundwater elevations rose in response to water being diverted into the canals and declined at the end of the irrigation season. Generally, specific conductivity and the isotopic composition of the shallow groundwater showed a similar signature with the canal water. Geochemical mixing of canal and groundwater was less with depth. Average seepage losses of 1.2 cfs/mile and 2.2 cfs/mile were calculated for the West Side and East Bench Canals, respectively. Many factors affect how much the canals leak and initial groundwater depth is a factor in how the canal water and groundwater interact, with a more delayed response of canal influences on groundwater as the depth to water increases. The type of geologic materials underlying the canal controls leakage, with coarser grained sands and gravels allowing for a more responsive connection.

Solar Powered Groundwater Development Project In Uganda

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At the 2010 AWRA Conference, we reported on the rehabilitation of a failing well and installation of a small solar powered pump that output 3,500 liters/day (l/d) for residents of a refugee farm in Central Uganda. There are typically 40 to 80 families who are refugees of the LRA War living on the Family Empowerment Uganda- Canaan Farm (FEM). Most of the FEM residents are women and children, many of whom have

been widowed or orphaned due to the LRA war or disease. The 2010 pilot-scale system operated with about 80% reliability throughout the following 1.5 years, including dry and wet seasons. Working through the Hope 2 One Life Foundation of Billings, Montana (<http://www.hope2onelife.org>) we installed a state-of-the-art solar powered well and water delivery system at the FEM farm in 2011. The installed cost of the borehole and well was \$8,630, and the solar pumping system with storage tank was \$18,370. In addition to funds raised directly by Hope 2 One Life, major grants were obtained from the Atkinson Foundation and the National Ground Water Research and Education Foundation. The geology of the region is Basement Complex rocks consisting of undifferentiated gneiss and granite, mantled with red laterite soils and regolith. Groundwater occurs in the regolith and in the fractured bedrock although low yields and dry wells are common. Existing district records indicate well depths of 49 to 79 meters (m), static water levels of 27 to 67 m and yields of 0.6 to 3.0 m³/hr (DRACO Ltd 2011). The subject borehole was located using a vertical electric resistivity method which assists in finding depth to bedrock and water-bearing zones. The drill hole encountered fractured white quartzite and oxidized granite at 24-42 m. Following well completion, the static water level was 20.02 m below surface. A 12-hour pumping test sustained a yield of 8.0 m³/hr, with 6.57 feet of drawdown. According to the drilling contractor, it is one of the largest yielding wells in this region of Uganda. Laboratory analysis of a water sample found a pH of 6.45, EC of 677 µS/cm, TDS of 118 mg/l, alkalinity of 184 mg/l, and nitrate of 0.02 mg/l. The well was completed to permit dual installation of a solar-powered DC submersible pump and a hand pump on the well head. The pump, powered by two 175-watt panels produces an average of 13,000 l/d. The solar pump, panels and components were manufactured by Lorentz. Water is pumped to an elevated 10,000 liter water storage tank. A “tap stand” with two valved outlets for filling water containers is fed by a subsurface pipe connection to the elevated tank. Additional connections serve other facilities on the FEM farm, such as the clinic, kitchen and toilets. The yield of this well is large enough that, with more funds, the pumping system could be upgraded to produce water for cash crops served by drip irrigation, and could feed ponds for fish farming. Women on the farm already utilize excess water for drip irrigation of vegetables and orchards.

SESSION 5 CLIMATE

Stream Temperatures On The Lolo National Forest: Analyzing The Past And Forecasting The Future

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The Lolo National Forest (LNF) is embarking on an analysis of forest-wide stream temperatures by (1) compiling all historic stream temperature measurements into a single database for analysis, and (2) establishing a new long-term, year-round, and forest-wide monitoring program to better understand patterns and trends in stream temperature in the future. Both programs are being accomplished through partnership agreements with the Clark Fork Coalition and Trout Unlimited. Stream temperature is a simple-to-measure parameter that is critical for understanding and addressing the effects of climate change and management decisions on stream health and fisheries. Over the past several decades, various units within the LNF have collected climatic and hydrologic data for specific resource needs, but there has not been a sustained effort to collect year-round stream temperature data on a forest-wide basis. Most of these legacy data cover the summer season only, but there is a growing recognition of the need for year-round monitoring to better understand the effect of temperature on all life cycle phases of the fishery. The LNF program dovetails with a region-wide effort by the Boise-based USFS Rocky Mountain Research Station to develop a regional stream temperature database and climate vulnerability assessment for sensitive fish and aquatic biota across all streams in the Great Northern Landscape Conservation Cooperative. The LNF legacy data have been compiled into a single database along with data from other stream monitoring programs including USGS, PIBO, and FWP. The legacy database contains summer monitoring data for 46 stations with records dating back to 1969 that contain minimum and maximum temperature (including 15 stations with average temperature), and 299 stations

with records dating back to the late 1990's that contain 30-minute interval data. Most of these records are temporally discontinuous, but some stations with longer records are being analyzed for discernible trends and these results will be presented. The new monitoring network consists of 79 automatic samplers that collect continuous, annual stream temperature in stream systems across the forest for at least the next five years. The monitoring locations for this sampling program were determined by several criteria including: bull trout critical habitat, 303d streams listed as temperature-impaired, preference for sites with a history of existing data, preference for avoiding duplication with other monitoring programs, non-biased representation of stream segments on the LNF based on the distribution of elevation and contributing drainage area, 5% replicates, and budget. In addition, the sampling program addresses the need to assess current and long-term temperature changes in a representative set of larger stream systems, such as Rock Creek, Thompson River, and Fish Creek, to allow for comparisons in water quality and fish species composition changes over time, and to monitor longitudinal stream temperature patterns. Temperature sensors were placed in August 2011, and the first round of data collection will occur in September 2012, so we will report on lessons learned from the first year.

Modeling The St. Mary River And Milk River Basins Under Historic And Future Climate Conditions

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The St. Mary and Milk Rivers originate in Glacier National Park and the Blackfeet Indian Reservation. Water is diverted from the St. Mary River to the Milk River to supply water for irrigation to as far east as Glasgow, Montana. The Montana Department of Natural Resources and Conservation and U.S. Bureau of Reclamation recently completed a study of the St. Mary and Milk River Basins as part of the Reclamation WaterSMART Basin Study Program. The study developed a model of the river systems, examined how climate change might affect water supplies and demands, and assessed the performance of various alternatives for meeting future water needs. The river system model was built with the RiverWare software and contains the various components of the system including river reaches, reservoirs, canals, and diversion structures. Rules were used in the model to simulate operations of the system on a daily time-step for a 52-year period. Using climate and precipitation-runoff models, water supply and demand input data to the river system model were developed for historic climate conditions and for five future climate scenarios. The river system model was then used to evaluate streamflows, reservoir levels, water deliveries, and water shortages throughout the basins under the various climate scenarios. For all future-climate scenarios, basin temperatures were predicted to warm, with the rate of warming varying by projections from about 1.5 to 6 degrees Fahrenheit by the year 2050. A moderate increase in precipitation was predicted for most of the scenarios, with a trend towards greater variability between wet and dry years. From the river system model results, irrigation shortages were predicted to increase substantially when compared to historic under all future climate scenarios, mostly due to increases in crop irrigation requirements. A range of possible water management and infrastructure alternatives were modeled to evaluate their potential for reducing future water shortages. Increasing irrigation efficiencies, which was modeled to reduce average irrigation water shortages by about 20,000 AF per year, was found to be the single most effective alternative.

How Variable Is Our Water Supply

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Montana's water supply varies from 50 to 150 percent average. This is due to a large variability in the mountain snowpack, spring and summer precipitation and temperature. Time of various climatic events in Montana, such as when snowpack starts to accumulate, when it reaches its season's maximum, when it melts out, when streams reach their annual peak flow, and when plants break dormancy have had a historical variation spanning about eight weeks. Water managers need to take this variability into account when managing current water supply or planning for future water supplies. Tools to help assess the potential water supply and timing of various hydrologic and phenological parameters will be presented.

Climate Cycles, Dewatering A Gold Mine, And Human Perception Of Normal Streamflow

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This case study from Silver Creek near Helena, Montana presents a comparison of climate influences on streamflow versus that contributed by discharge of mine water and investigates public perception of normal streamflow. From the early 1980's through 2007 Silver Creek experienced a pro-longed period of low flow and infrequent flooding. During this time residential development encroached on the floodplain and local residents became accustomed to low flows in the creek. In 2009 the Drumlummon Mine began dewatering underground workings, discharging an average 0.4 cfs to shallow groundwater adjacent to Silver Creek. Contemporaneous with the mine's dewatering effort the region recovered from a 7-year severe drought and experienced much greater than normal precipitation, snowpack, and streamflow. The residents along lower Silver Creek questioned whether the mine was the cause of flooding and dramatically different stream conditions. This investigation looks into long-term records of precipitation, snowpack, and streamflow for this region of Montana and points to relationships between streamflow and cyclic drought. In addition, climate influences consistent with the pacific decadal oscillation are examined. The discussion compares the time-scale of human perception of normal Silver Creek streamflow with the time-scale of natural cycles.

Seeley And Salmon Lakes – Historic And Current Condition And Risk Of Declining Water Quality

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The Clearwater River Basin lakes support recreation and tourism, water supply, and critical habitat for bull trout, common loons, and a variety of other wildlife. They are key to the local economy, lifestyle and sense of place. Increasing population and urbanization have focused debate on land use planning, wastewater treatment, and collaborative restoration. Recent concerns about lake water quality have been voiced in the community and local TMDLs. Although there have been periodic studies of the Clearwater lakes in the past 30 to 40 years, the available data and results have never been analyzed as a whole. This study assessed evidence and risk of changing trophic condition. Increased growth of algae (in open water) and rooted plants (along shorelines) leads to reduced water clarity and reduced dissolved oxygen in deep water. Increased growth in aquatic plants is usually a result of increased loads of nutrients (N & P) from the surrounding watershed and human activities. The objectives of this work were to:

- Summarize existing information on the past and present condition of Seeley and Salmon lakes and determine whether conditions are getting better or worse.
- Consider the potential sources of nutrients that may influence the lakes and how they may have changed since the 1970s.
- Use scientific models to determine whether the lakes are at risk of worsening condition in the future.

Recommend future monitoring, studies, and actions to minimize degradation of the lakes. The study provided these conclusions:

- There are no apparent trends in water quality data since the 1970's. Conditions vary from year to year, but have not become noticeably worse (or better). However, inconsistency in sampling methods, timing and sites may have obscured trends.
- Most indicators of lake condition put both lakes in the middle range of trophic condition (mesotrophic). Some recent observations of algae blooms, low oxygen in deep water and rising nutrient levels in the lakes, groundwater and some streams, are worrying.
- Modest increases or even the continuing input of nutrients from human sources could push the lakes past a tipping point, making restoration of better conditions very difficult. The lack of evidence of much change in these lakes is not a guarantee that they are not changing. Their response may be hidden or delayed as it has been in other lakes.

And some recommendations:

- Careful and consistent monitoring should continue; better information should be developed on nutrients entering the lakes from different sources, especially via groundwater;
- The densest housing areas closest to the lakes should be sewered;
- The vegetation buffering stream and lake side areas

should be protected. The report ends with a note of caution. Although Seeley and Salmon lakes are still in good condition, they are not that different from other lakes and communities that have experienced sudden dramatic declines in water quality that became extremely expensive if not impossible to reverse. The full report is available at: www.crcmt.org/.

SESSION 6 WATER QUALITY - PART 2

From Phosphorus To Fish: Beneficial Use Of Excess Nutrients

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The U.S. EPA is implementing new, more stringent TMDL standards across the nation in response to water quality issues including harmful algae blooms, hyper-eutrophication of lakes and increases in game fish mortality. Estimates project that compliance with new standards may cost Montana municipalities as much as \$1 billion over the next decade. Floating Island International is interested in transitioning phosphorus from water into biofilm into fish, and then harvesting fish to keep pace with nutrient inflow rates. One of our goals was to measure the fish harvest that could be achieved by introducing and managing substrate and circulation/aeration technology in the form of floating islands. A related goal was to use phosphorus as a marker nutrient and track the potential ability to comply with new TMDL standards. A third goal was to track the impact on other water quality parameters such as water clarity, temperature, dissolved oxygen levels and benthic organic accretion. A 6.5-acre lake fed by the Billings Bench irrigation ditch was the primary study site. During a four-month period in the summer and fall of 2011, fish growth rates, catch rates and fish productivity were measured at the study site based on fish tagging, otolith and scale aging, and harvest of 1,928 northern yellow perch, black crappie and (rarely) Yellowstone cutthroat trout. An average catch rate of one fish per two minutes of fishing time was achieved at the study site. Fish harvest of 110 pounds per month kept pace with calculated phosphorus inflow rates during the study period, which implies that today's federally mandated clean water standards can potentially be achieved via fishery enhancement stewardship strategies.

Critical Loads Of Acidification In High Elevation Wilderness Lake: Sierra Nevada, CA

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Two hundred eight lakes were sampled during summer in the Sierra Nevada between 2000 and 2010 to investigate the vulnerability of lake-acidification in Class I and II wilderness areas. Most lakes were sampled once, and thirteen of the lakes have been monitored for at least six years. Water samples were collected during the summer and analyzed for major ions, ANC, pH, and conductivity. The majority of these lakes are characterized by low ANC, but no temporal trends were identified for lakes sampled during the time of this investigation. In order to assess the potential for acidification, the critical loads of acidification (CL(A)) were estimated for all samples collected from the 208 lakes using the Steady State Water Chemistry (SSWC) model. A critical load is defined as, "A quantitative estimate of exposure to one or more pollutants at or above which harmful acidification-related effects on sensitive elements of the environment occur". Ranging the ANCLimit between 0 and 10 $\mu\text{eq/L}$, the median critical load for acid anions were 208 and 152 eq/ha/yr respectively. The values of critical loads for these catchments are similar to other estimates in montane systems within western United States. Median exceedances for these ANCLimit values ranged from -98 and -42 eq/ha/yr. These results also suggest that 38 to 60 of the lakes may have already exceeded their critical loads. Previous studies in the Sierra Nevada suggest that no lakes have undergone chronic acidification, but the number of episodic acidification occurring within the Sierra Nevada may increase with time. Lake exceedances observed in this study could be from model uncertainties in the model and/or episodic acidification.

Judith Basin Nitrogen Project: Landform Influence On Nitrate In Groundwater

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Nitrogen contamination of groundwater is widespread globally and in many cases, is strongly associated with fertilizer management for agriculture. In the Judith River Basin of central Montana (JRB), elevated groundwater nitrate has been observed since the 1960s but explicit source attribution has not been undertaken. Here we present a novel approach including source attribution concurrent with evaluation of farming practices for dryland cereal production that are designed to reduce nitrate leaching. Our approach centers on plot studies initiated in the context of understanding the larger scale groundwater system and associated nitrate dynamics. In undertaking this work, we have benefitted dramatically from active engagement with local farmers in developing and implementing our research approach and design. We first evaluate influence of landform characteristics on nitrate concentrations in terms of both shallow aquifer character and connection to mountain front stream recharge (MFSR). Shallow aquifers are developed in gravel mantled terraces and alluvial fan deposits extending from the Little Belt and Big Snowy Mountains. The underlying suite of marine shales perch shallow aquifers beneath thin soils, making them vulnerable to contamination. We hypothesize that groundwater nitrate concentrations in the alluvial fan near Moore, MT are lower than those in a nearby isolated strath terrace (Moccasin, MT) because: 1) the unconfined aquifer is deeper at the head of the fan, limiting dispersed recharge that leaches agricultural N; and 2) the fan aquifer is connected to MFSR, diluting groundwater N concentrations. Groundwater within the Moccasin terrace is derived exclusively from infiltration through shallow soils, resulting in generally higher nitrate concentrations except following high water years when flushing may occur. We present the results of groundwater flow models developed for both landform types as a means of evaluating our conceptual models of aquifer character, recharge sources and residence times as a function of landform type. Based on these working models, tritium inventories, Rn-222 concentrations and tritium-helium dates will be used to evaluate residence times in the shallow and deeper confined aquifers. Host lithologies for groundwater will be evaluated using geochemical indicators such as Ca/Sr ratios. The spatial distribution of solutes and isotopic character of groundwater will be used to test whether nitrate reaches groundwater through downward leaching by rain, or capture by seasonally rising high water tables. Water mass balance will be evaluated for each landform based on isotopic data (δD , $\delta^{18}O$), continuous recording of water levels, and discharge measurements in emergent surface streams.

Brine Contamination To The Prairie Pothole Region From Energy Development In The Williston Basin

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The central portion of the Prairie Pothole Region, a wetland-rich area that is critical to North America's migratory waterfowl, overlies oil-rich formations of the Williston basin. Substantial volumes of brine have been co-produced with oil contaminating the potholes and connected groundwater. Using a contamination index developed by Montana Bureau of Mines and Geology and enhanced by USGS, wetlands can be rapidly assessed for brine contamination by using a ratio of field chloride to specific conductance. While there might be variations in other parts of the Williston basin, a water contamination index greater than 0.035 in Sheridan County, Montana is a predictor of brine contamination. Factors such as the age and number of nearby oil wells, proximity of oil wells to wetlands and streams, and presence of coarse outwash deposits that hydraulically move contaminants at greater rates can increase a wetland's vulnerability to brine contamination. Brine contamination can persist in the glacial deposits for at least several decades. Additional details about this work are available on the project web page: <http://steppe.cr.usgs.gov/>.

ARD Remediation With Slag: An Application To Berkeley Pitlake Water

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Treating waste water, particularly acid rock drainage from both active and inactive mines, is critical worldwide for many reasons but usually for environmental purposes. Being part of a superfund site, the Berkeley Pitlake (BPL) in Butte MT may be the most famous acid-rock drainage (ARD) clean-up project in the world, let alone the United States. Currently, its treatment consists of a two-stage lime precipitation for processing only Horseshoe Bend Water which is the only adit to the BPL. Research has shown that another waste product, namely slags from pyrometallurgical operations, can be substituted for lime either wholly or in part. Three locally available slags from closed smelting sites were investigated: Rhone Poulenc/Stauffer Chemical Company slag from a phosphorous plant in Ramsay, MT; ASARCO slag from a lead blast furnace in East Helena, MT; and ARCO/Anaconda Copper Company slag from copper operations in Anaconda, MT. Each slag differed in iron, silica and calcium content and therefore reacted differently to remediate BPL water. Results were analyzed and modeled using statistical analyses of experimentally designed-tests and are presented in regards to pH and metal concentration as a function of amount added and particle size. Results indicate that slags can be used to either supplement or replace lime, depending on the application. Conceivably, the process could also be done in-situ. Aside from remediating ARD, an added socio-benefit, often referred to as dual ecosystem enhancement, is the removal of the slag piles.

SESSION 7

SURFACE WATER & WATERSHED ANALYSIS - PART 2

River Response To 10 Years Of Nutrient Reductions On Montana's Clark Fork River

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In the 1980's much of western Montana's Clark Fork River was identified as impaired by nuisance benthic algae as a result of excess nutrients. Basin stakeholders developed a voluntary nutrient reduction plan (VNRP) which the EPA substituted for a mandatory TMDL. Nutrient and algae studies, mass transport models, public surveys, and best professional judgment were used to set targets for acceptable algae levels and to estimate nutrient levels (saturation breakpoints) and loads expected to meet those targets. The 10 year plan was adopted in 1998 and ended in 2008. Monthly monitoring of nutrient levels and summer attached algae levels along 383 km of the river used standard methods and an EPA approved QA/QC plan. During the VNRP, the major point source dischargers to the river reduced Total Nitrogen loads by 18% and Total Phosphorus loads by 66%. While new homes were being built with septic systems, the river's largest city Missoula connected many more old homes to the sewer, resulting in a net reduction of over 3,000 septic systems. The Tristate Water Quality Council funded nonpoint nutrient reduction programs on the river's tributaries. Over the decade, significant declines were observed in TP but not TN along the entire river. Downstream of the city of Missoula, TP declined below a literature-derived TP saturation breakpoint and met program targets after 2005; TN has met targets since 2007. Algal biomass also declined significantly below Missoula. Trends there likely relate to the city's wastewater facility upgrades, despite its 20% population increase. Upstream of Missoula, nutrient reductions were less substantial; still, TP and TN declined toward saturation breakpoints, but no significant reductions in algal biomass occurred, and program targets were not met. The largest P-load reduction to the river was from a basin-wide phosphate laundry detergent ban set 10 years before, in 1989. We document that nutrient reductions in rivers can be successful in controlling algal biomass, but require achievement of concentrations below saturation and likely close to natural background.

Distributed Assessment OfThe Spatio-temporal Controls On Stream Discharge InThe Tenderfoot Creek Experimental Forest, MT.

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Understanding how water is stored and redistributed in mountain watersheds is an important consideration for water planning efforts yet often poorly understood and conceptualized. In mountain regions strong gradients in watershed structure (topography and geology), vegetation and climate can lead to distinct spatio-temporal differences in the “hydrologic connectivity” between landscapes and streams. We quantified the variability of groundwater gains and losses (using dilution gauging methods) at 200m reach increments in a 590 ha catchment of the Tenderfoot Creek Experimental Forest, MT. Measured gains and losses were further compared to observations of hillslope-stream hydrologic connectivity derived from transects of recording groundwater wells installed across 30 hillslope-stream positions. During wetter time periods, groundwater inputs and changes in stream discharge were related to hillslope topography and the degree of hydrologic connectivity across each reach. During drier times vegetation distributions along hillslope flow paths and surface geology became more important as shallow hydrologic connectivity decreased. In this presentation we will discuss the factors contributing to space-time variability of stream flow generation and the implications of these findings for watershed management and water resources forecasting in the Rocky Mountain West.

Quantifying Watershed Storage Dynamics Using Long Duration, High Frequency Measurements Of Precipitation, Runoff, And Evapotranspiration

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Quantifying water storage and redistribution in mountain watersheds is critical for water resources planning and improving fundamental catchment hydrology understanding. Previous studies have estimated watershed storage, but have often been poorly constrained, relying on modeled evapotranspiration (ET) for calculation. Vegetation and landscape heterogeneity often make modeling of ET complex and uncertain. In this study we calculated dynamic catchment storage using a direct, fully empirical water balance approach. We utilize ET measurements from an eddy covariance tower located in Tenderfoot Creek Experimental Forest, Montana. Measured ET was combined with hourly precipitation (P) and runoff (Q) to calculate ΔS , using the mass balance equation $\Delta S = P - (Q + ET)$. Relationships between S, ET, and Q measurements elucidate the relative influence of vegetation and topography on soil water redistribution across variations in watershed S. Topographic controls on lateral soil water redistribution and S dynamics were corroborated with water table data from 30 hillslope – riparian – stream well transects (180 recording wells). This study provides new insights into the interplay between vegetation and soil water redistribution and their influence on watershed scale storage and runoff through time. This understanding is valuable for prediction of watershed scale response and for understanding water resources sensitivity in the context of climate change.

Updating Numeric Nutrient Criteria For Montana’s Wadeable Streams And Rivers

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Excess nutrients and associated nuisance algae are among the top 5 causes of impairment of Montana’s wadeable streams. In 2008, the state of Montana developed ecoregion-specific numeric criteria for nutrients and nuisance algae, based on stressor-response studies and reference stream data. Harm to beneficial uses was associated with nutrient levels from about the 73rd to 99th percentiles of reference (mean: 86th), hence numeric criteria were set at the 75th & 90th percentiles for the plains and mountains respectively. Since 2008, more Montana reference streams have been characterized, and more stressor-response studies have been conducted (both in and out of the region). These studies suggest that some of the ecoregion-specific

criteria developed in 2008 were overly restrictive (e.g., in the Canadian Rockies) while other criteria were insufficiently protective (e.g., in the Middle Rockies). Updated criteria take newer studies into account and focus on total nitrogen and total phosphorus, and on their ratio in comparison to Redfield. Water quality standards based on control of a single nutrient (i.e., P) could result in unwanted ecological consequences in Montana's rivers and streams. Background nutrient levels in our western reference streams are usually quite low and have TN:TP ratios close to the Redfield ratio (7:1 by mass). The nuisance diatom *Didymosphenia geminata* has, in recent years, produced nuisance growths in low P streams, thriving in waters where N:P ratios are high (34:1 on average). In contrast, nuisance levels of the green alga *Cladophora glomerata* are often found in high P streams with low N:P ratios. Updated ecoregion-specific criteria for the summer growing season for TN and TP and recommendations for N:P ratios are presented for 18 ecoregions (6 level IIIs and 12 level IVs) in Montana. As an example, criteria for various subregions of the Middle Rockies ecoregion range from 30 to 105 ppb TP and from 250 to 300 ppb TN.

Post Wildfire Changes In Watershed Conditions And Response Adapting Management To A Frequent Disturbance Regime

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Recent wildfires throughout the Rocky Mountain states have altered watershed conditions. Grazing, fire suppression, a relatively wet 20th Century, and a warming climate have worked in concert to produce conditions for increased wildfire activity. Loss of vegetation and protective duff layers covering forest soils and in many cases increased soil surface water repellency set the stage for altered watershed response. Post fire watershed conditions and examples of runoff response are discussed using recent examples from Montana, Idaho, and New Mexico.

SESSION 8 WATER MANAGEMENT/DEVELOPMENT - PART 2

Energy Development And Water Needs In The Williston Basin

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Energy development within the Williston structural basin, an important source of oil and gas for the Nation, provides a critical opportunity to study the water-energy nexus within a groundwater context. Thousands of oil and gas wells are drilled annually within the Williston basin. Unconventional oil and gas development generally requires between a half and 10 million gallons of fresh water per well to hydraulically fracture the Bakken and Three Forks Formations. Fresh water resources to be used for development will be obtained from streams, ponds, and/or wells completed in glacial and bedrock aquifers. The Montana Bureau of Mines and Geology, the North Dakota State Water Commission, the Idaho National Laboratory, and the U.S. Geological Survey are working collaboratively to quantify current groundwater resources in the bedrock aquifers most frequently used within the basin as potable water sources and to provide tools to better understand groundwater system response to future demands and stresses. This collaboration will yield new information on aquifer properties, baseline conditions, and support regional aquifer models.

The Use Of Remote Sensing As A Technique For Estimating Agricultural Evapotranspiration In West-central Montana

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The analysis of remotely-sensed data is shown to be a potentially accurate, defensible, and consistent method to estimate irrigated acreage and evapotranspiration (ET) use. Remote sensing methods can provide a geographically-consistent means of data compilation and analysis; the ability to examine temporal changes

in consumptive-water use; and the ability to estimate consumptive-water use on irrigated lands at various spatial scales. ET estimates calculated using two separate remote sensing methods (METRIC - Mapping EvapoTranspiration at high Resolution with Internalized Calibration and SSEB - Simplified Surface Energy Balance) were compared to conventional crop-coefficient methods. ET estimates for agricultural fields in the Smith River watershed and surrounding area were calculated using Landsat Thematic Mapper data (Bands 3, 4, and 7) for the growing season of 2007. Results derived using the two remote sensing methods generally agreed with one another, and were consistently 21 – 31 percent lower than values derived using standard crop-coefficient methods. Advantages of using remote sensing techniques in place of conventional techniques for the estimation of ET include the ability to visualize and analyze historical water-use estimates over large time periods, to make estimates independent of political (county and state) boundaries, to analyze at varying spatial and temporal resolutions, and to provide investigators with raw, a priori data rather than reported water-use estimations. Disadvantages of remote sensing methods include a requirement for substantial computing power, image obfuscation by cloud cover, reduced accuracy in complex terrains, and potentially higher monetary costs than conventional methods. Rodney Caldwell, U.S. Geological Survey, Kyle Blasch, U.S. Geological Survey.

Using Thermocline Manipulation To Remediate Mercury-contaminated Reservoirs In The Southwestern United States: Pilot Project Results

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Mercury (Hg) analyses of fish-tissue samples collected by the State of Utah from 268 lakes and streams between 2000 and 2008 have resulted in the issuance of consumption advisories for 16 water bodies. Five of the 16 listed water bodies are clustered in southwestern Utah and include four small reservoirs. Recent work in Finland (Rask et al., 2010) has found that thermocline/oxycline manipulation was successful in decreasing methyl Hg concentrations in water and biota. In June 2010, the State of Utah and USGS initiated a Hg remediation project in Newcastle Reservoir, a small reservoir (66 hectares) with elevated methyl Hg levels in fish and water. Pre-remediation water-quality data collected during 2010 found suboxic conditions and elevated methyl:total Hg ratios and nutrient concentrations in the lower 2 meters (m) of the water column. A three-dimensional hydrodynamic model of Newcastle Reservoir was constructed to simulate within-reservoir pumping scenarios. Boundary conditions used in the model included detailed reservoir bathymetry, 15-minute weather station data, 15-minute water inflow and temperature data from Pinto Creek, and hourly reservoir outflow data. Vertical pumping simulations using a 5,700 liters/minute pumping rate from the bottom of the water column indicated a 130-m diameter pumping influence. Model simulations also indicate that elevated nutrient concentrations contained in the near-bottom water will be dispersed by persistent wind-induced currents after reaching the surface. A solar-powered pump was installed and began operating in the reservoir during July 2011. The pump is designed to operate 24 hours a day at a rate of 5,700 liters/minute, pumping hypolimnetic water to the reservoir surface. Monitoring activities to document remediation progress after pump installation have included: (1) automated continuous temperature profiling from a thermistor string about 60 m from the pump; (2) hydroacoustic water-velocity profiling; (3) water-quality profiling in transects outward from the pump; and (4) detailed water-quality mapping using an autonomous underwater vehicle (AUV). Results from the thermistor string indicate a sharp increase in the temperature gradient in the near-bottom waters likely resulting from pump-induced circulation (Fig. 1). Pre-remediation Hg concentrations in the water column, sediment, phytoplankton, and fish-tissue samples from Newcastle and Enterprise (control site) Reservoirs will be compared to similar samples collected after the solar pump has operated for 12 months. Rask, M., and others. 2010. Does lake thermocline depth affect methyl mercury concentrations in fish?. *Biogeochem* 101:311-322.

Citizen Water Monitoring: Building And Maintaining An Effective Program

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The collection of water monitoring data by citizen scientists is gaining momentum throughout Montana and ongoing efforts are helping refine an understanding of the recipe for creating and maintaining successful programs. Success hinges on striking an appropriate balance between technical rigor and intensity of sampling with the interest level and capabilities of volunteers and local coordinators. The right balance can create quality data to help answer questions and tell an interesting story which produces positive feedback to the personal fulfillment volunteers receive from being involved. MSU Extension Water Quality (MSUEWQ) has been working with the Madison Watershed Group (MWG) to strike this balance with the development of the Madison Stream Team (MST) for the last few years with very encouraging outcomes. By starting off with level 2 training of volunteers to build capacity and interest and then moving to the more advanced level 3 training with more advanced equipment, the quality of the data and the capacity and interest of volunteers has continued to grow. Strong engagement from the local watershed coordinator has been an invaluable part of this success. The MWG has lead the effort to align monitoring efforts with local interests, to recruit and retain volunteers, to work with local landowners on access, and to distribute the monitoring results to the volunteers and the greater community. MSUEWQ provides technical support for these efforts in the form of assistance with writing of SAPs/SOPs, conducting trainings, assisting with equipment procurement, reviewing reports, and assisting with data management. The placement of a Big Sky Watershed Corp (BSWC) member with the MWG for the 2012 data collection season has played a critical role in the advancement of these efforts and the BSWC is a very promising program for development of future programs in other watersheds. With data collection for the TMDL process beginning in the Upper Madison in the summer of 2012, the MST is providing a framework of citizens that Montana Dept. of Environmental Quality is working with for data collection and community engagement. MSUEWQ and the MWG believe that this model of engaging the community from the beginning of the planning process will ultimately result in more effective mitigation of nonpoint source pollution issues.

Effect Of Changes In Ambient Water Quality On Agricultural Production In The Tongue River Valley

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Perceived water quality changes in the Tongue River in southeast Montana have concerned irrigators in the region that crop yields will be adversely affected. Agronomic studies (Brown et al. 2008, Osborne et al. 2010) have concluded that these concerns are misplaced and confounded with drought. This study examines the issue in aggregate: as water quality has changed, has aggregate agricultural production changed as well? By constructing a unique measure of watershed-specific agricultural activity, these results can be applied to the watershed as a whole instead of particular test tracts. The first step was to develop yearly estimates of the total agricultural product of the Tongue River Valley (TRV). Nearly all available data is at the county level, not watershed. County and watershed boundaries do not conform. By combining agricultural survey, census, and remote sensing data, we estimate the total agricultural product of the TRV. This output provides an upper bound on potential damages to the agricultural sector from water quality change. Water quality measures are then regressed on output to investigate the magnitude of effect that water quality has on output and thus economic welfare. The actual crop choices and practices of local irrigators are subsumed into the aggregate estimate. The next step of this project will disaggregate the total agricultural value of the TRV into smaller sections, allowing for inferences about heterogeneous effects throughout the watershed. For example, different soil types have varying susceptibility to yield reductions from saline water. Since water quality changes over the course of the river, we might expect impacts to be geographically concentrated as well. By examining the entire

watershed, we can draw more general conclusions than those reached on a single test plot over a relatively short time span. Our preliminary results indicate that changes in ambient water quality have little effect on agricultural output in aggregate. This finding is in line with the National Academy of Sciences report (2010). We expect to find that water quality changes have affected specific areas with susceptible soil types.

Brown, D.M., Harvey, K.M., Fehring, Neal, 2008 2008 Irrigated Crop and Forage Test Report Prepared for the Montana Board of Oil & Gas Conservation, Montana Department of Natural Resources and Conservation by the Tongue River Information Program. Fisher et. al. 2010. Management and Effects of Coalbed Methane Produced Water in the United States. Committee on Management and Effects of Coalbed Methane Development and Produced Water in the Western United States; Committee on Earth Resources; National Research Council. Osborne, T. J., W. M. Schafer, and N. E. Fehring. "The Agriculture-energy-environment Nexus in the West." *Journal of Soil and Water Conservation* 65.3 (2010): 72A-6A. Print.

Characterizing The Role Of Subsurface Flow To The Upper Boulder River, MT

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The role of groundwater and other subsurface flow paths in stream flow generation within the mountain block is poorly understood. In this study, we established sites in the Boulder River from the headwaters, in mountainous terrain, to the USGS gauging station near Boulder, MT, in the alluvium-filled valley. The purpose of this project was to geochemically identify and separate source waters to the Boulder River and to investigate how mixing between these source waters varies spatially and temporally. Bi-monthly samples were collected from May 2011 until May 2012 for water quality, major ion chemistry, alkalinity, and stable isotopes of the water molecule. Three endmembers were identified, and used in an endmember mixing analysis (EMMA). They are overland flow (or fresh snowmelt), lateral subsurface flow, and groundwater. During spring runoff the majority of the streamflow is comprised of overland or near-surface flow. As snowmelt decreases during summer both lateral subsurface flow and groundwater become increasingly important to streamflow. By late summer and early autumn, groundwater becomes the dominant source of water to the Boulder River (approximately 65-85% of total flow). During late autumn and throughout the winter months until spring runoff 2012, lateral subsurface flow appears to mix at higher proportions than groundwater, with overland flow remaining virtually nonexistent. Results between May 2011 and October 2011 are similar to findings in other montane catchments, but results between November 2011 and May 2012 are unique, and may be a result of the relatively mild winter during the study period. Snowpack at all monitoring sites was not constant and continually melted after snow storms. The large amount of lateral subsurface flow and absence of overland flow may be a result of snowmelt infiltrating into the shallow alluvium overlying bedrock and eventually discharging to the Boulder River. These findings illustrate the complexity of streamflow generation occurring within the mountain block, and illustrate that streamflow is a composite of regional groundwater, aggregates of hillslope hydrological pathways and overland flow.

Hydrogeologic Framework Of Carbon And Stillwater Counties, Montana

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This plate presents the Montana Bureau of Mines and Geology Groundwater Characterization Program's Hydrogeologic Framework for Carbon and Stillwater counties. The eastward flowing Yellowstone River splits the Carbon-Stillwater County study area. In the south, the Beartooth Plateau and Pryor Mountains dominate the physiography. Northward flowing Yellowstone River tributaries drain these highlands and are deeply incised into the bedrock formations. North of the Yellowstone River, topography is subdued and even though tributary drainage basins are less extensive, they still are cut into bedrock. North of the Yellowstone, the internally drained Lake Basin dominates surface water hydrology (hereinafter referred to as the "Lake Basin subarea"). Area residents rely heavily on groundwater; most domestic and stock wells are completed in bedrock aquifers within 400 feet of the land surface. Although there is some development of sand and gravel deposits underlying terraces along major tributary valleys and the Yellowstone River, most wells are completed in Tertiary or Cretaceous aquifers. The Tertiary Fort Union Formation is the youngest bedrock unit in the area. It is exposed at the land surface across nearly 600 square miles (mi²). The median reported yield for Fort Union wells visited by the Assessment Program is 11 gallons per minute (gpm). Tertiary intrusive rocks crop out across 80 mi² near the western Beartooth Front and are locally used as aquifers. Wells completed in these rocks have a median reported yield of 15 gpm. The Cretaceous Hell Creek Formation crops out across 400 mi² in a northwest trending swath south of the Yellowstone River, and along a broad topographic divide just north of the river where it is the Lake Basin subarea's southern boundary. The Hell Creek Formation is from 350 to 1,000 feet thick and wells have a median reported yield of 10 gpm. The Cretaceous Bearpaw Shale confining unit crops out across 200 mi² (mostly in the Lake Basin subarea) and has a thickness of 100 to 800 feet. The Bearpaw Shale is generally not an aquifer, but near areas of surface exposure does yield water to a few wells. Those wells have a median yield of 15 gpm. The Cretaceous Judith River Formation crops out across 315 mi² in a southeast-to-

northwest wedge, mostly north of the Yellowstone River, and is between 700 and 1,000 feet thick. The median reported well yield for this aquifer is 10 gpm. The Cretaceous Eagle Sandstone and Telegraph Creek Formation (combined into one hydrogeologic unit) are the oldest of the major hydrogeologic units and are exposed at land surface across 150 mi² south of the Yellowstone River, and in the margins of the Lake Basin subarea to the north; their combined thickness ranges from 300 to 450 feet. Wells in the Eagle Sandstone and Telegraph Creek Formations have a median reported yield of 12 gpm. The Claggett Shale and Colorado Group confining units sandwich the Eagle Sandstone and Telegraph Creek Formations. Both units are exposed across.

Calibrating Conceptual Hydrologic Models With Approximate Bayesian Computation, Sequential Monte Carlo, And Flood Duration Curves

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Conceptual hydrologic models provide a means of predicting streamflow response to observed precipitation. Nearly all conceptual hydrologic models require some type of model calibration to estimate the optimal values of model parameters. Approximate Bayesian Computation, combined with Sequential Monte Carlo (ABC-SMC) is a methodology for parameterizing conceptual models that allows the distributions of the model parameters to be estimated while explicitly accounting for model uncertainty. ABC-SMC works by pushing candidate parameter sets through a series of intermediate distributions until they converge to a stationary distribution. A threshold based rejection region is used to filter unsuitable parameter sets based on a statistical measure of how well the predicted data matches the observed. In this study, we demonstrate the use of ABC-SMC for a conceptual rainfall-runoff model using synthetic data and data from a study catchment. We introduce a novel objective function that is based on the observed catchment Flood Duration Curve (FDC). The study demonstrates the ability of ABC to represent model uncertainty and to derive appropriate parameter distributions.

Scour Susceptibility Of Black Cottonwood On The Bitterroot River, Montana: Insights For Successful Restoration Of Riparian Areas

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Riparian areas provide valuable ecosystem services, including buffering sediment pulses, reducing flooding hazards, improving water quality, and maintaining ecological diversity. Cottonwood (*Populus*) species populate riparian areas in much of the world, and their success depends heavily on recruitment on river bars. Floods coincident with seed dispersal provide scoured, moist surfaces on which the pioneer species can recruit. With earlier spring snow melt predicted for Montana, seed dispersal may no longer coincide with receding spring runoff, requiring planting of cottonwoods to ensure the longevity of cottonwood forests. Restoration attempts often fail because of scour and uprooting by subsequent flooding events. In order to conduct successful restoration of cottonwood riparian areas, an understanding of the mechanisms associated with scour and uprooting is required. Most studies assessing the influence of in-stream vegetation on fluvial processes focus on the above-ground architecture (frontal area) of plants, which causes drag during flooding events. Roots counterbalance the drag force, acting as anchors and adding cohesion to bars. Anchoring depends on root architecture, which is influenced by a variety of environmental factors, including water table fluctuations. We will investigate the scour and uprooting susceptibility of germinated black cottonwood (*Populus balsamifera* ssp. *Trichocarpa*) trees of various growth stages on a sand and gravel bar on the Bitterroot River, Montana to test the following hypotheses: 1. Root architecture of black cottonwood seedlings will be a function of average water table elevation 2. Seedlings with shallower roots will be more susceptible to scour and uprooting in subsequent flooding events 3. The sensitivity of roots to changes in water table elevation will vary as a function of substrate grain size 4. For plants of comparable root architecture, those with the greater frontal area will be more susceptible to scour and uprooting We will monitor river stage and water table elevations using transducers installed in stilling wells and mini-piezometers. Bar topography will be characterized with a

digital terrain model constructed from topography points obtained with high-resolution surveying equipment. Plots of cottonwoods will be chosen by common growth stage. A sub-sample of the plot will be excavated and the root architecture and frontal area characterized by digital photographic analysis. Substrate grain size will be characterized with pebble counts and bulk sample sieving. Plots will be resurveyed after anticipated 2013 spring flooding to assess the occurrence of scour and uprooting. The drag force exerted on plants will be modeled using measured flood data and plant frontal area. The experiment will be repeated yearly for three years, allowing for stochastic and temporal components of scour and uprooting susceptibility to be assessed. This study will inform riparian management by revealing what factors contribute to scour susceptibility, allowing restoration efforts to be concentrated in the areas with the highest likely success.

Recharge Patterns In The Upper Madison Valley Aquifers, Madison Valley, Montana

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The upper Madison River Valley is located in the eastern half of Madison County, Montana, and extends 34 miles south from Ennis Lake to where prominent Tertiary benches pinch the Madison River's course. The valley is framed by uplifted and faulted Precambrian granite, schist and gneiss along with minor exposures of Paleozoic sedimentary formations. Elevated and dissected Tertiary benches, overlain by Quaternary alluvial fans flank the Madison River floodplain; the floodplain contains Quaternary terraces adjacent to, but higher in altitude than the alluvium immediately adjacent to the river. Within the valley major aquifers occur in: (1) the fractured Precambrian and Paleozoic bedrock, (2) the fine to coarse Tertiary valley-fill deposits that have both shallow and deep producing intervals and (3) the near-surface alluvium in the river's floodplain. Minor aquifers include discontinuous Quaternary terraces and a Tertiary freshwater limestone of limited geographic extent. The Ground Water Assessment Program selected 14 wells within the upper Madison River Valley to create a spatially distributed water-level data set representing the study area's major aquifers. This water-level data set consists of monthly water levels collected over a three year period. Fractured bedrock aquifer wells show sensitivity to climate and development; those in less developed areas show annual fluctuations driven by seasonal melt events but little overall change, whereas wells completed in more highly developed areas are more likely to be affected by seasonal water use. During the period of record these wells show an overall increased seasonal change likely due to water withdrawals. Wells that are more remote from development show apparent impacts from seasonal water use but also rising water levels tied to above-average annual precipitation. Precipitation and runoff cause water levels within floodplain alluvial aquifers adjacent to the Madison River to peak annually in the spring. However, wells completed within the Tertiary materials that underlie upland benches show elevated groundwater levels throughout the summer, indicating impact from irrigation practices. The Ground Water Assessment Program installed two sets of deep/shallow nested monitoring wells into mid-valley Tertiary aquifers. A well set located 9 miles south of Ennis shows that at this location the vertical groundwater gradient is upward; this supports the observation that this is an area of groundwater discharge. At the well pair located three miles north of Ennis there is a downward vertical gradient, and low permeability silt and clay observed between the shallow and deep producing zones would suggest that these two producing units are not in direct communication.

Paleoclimatic And Paleohydrologic Approaches For Examination Of Hydroclimatic Extremes – Implications For Missouri River Reservoir Management

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Unprecedented flooding throughout the Missouri River Basin during 2011 highlights the need for additional information regarding hydroclimatic extremes. Management challenges for the main-stem reservoir system and many smaller reservoirs located along numerous tributaries throughout the Missouri River Basin most notably are affected by either drought conditions or flooding. Observed streamflow and climate records generally are too short to accurately describe long-term variability, especially for hydroclimatic extremes. Paleoclimatic and paleoflood techniques can be applied to obtain detailed information regarding extreme hydroclimatic conditions that pre-date observed records by as much as hundreds or thousands of years. Application of

such techniques could provide large-scale, basin-wide information that would be highly beneficial for operation and management of reservoirs throughout the Missouri River Basin. Paleoflood techniques were applied during a recent investigation in the Black Hills of western South Dakota, where flash flooding of June 9–10, 1972, resulted in at least 238 deaths. Paleoflood data indicate that floods of similar or larger magnitude to the 1972 flood have occurred relatively frequently over the course of the past several thousand years. Similar paleoflood techniques and various paleoclimatic techniques could be useful in understanding past flood events and variability in hydroclimatic cycles (both wet and dry) in the Missouri River Basin.

Downstream Spatial And Temporal Response To Dam Removal: Reach-Scale Variations In Transport Capacity On The White Salmon River, Washington

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Dam removal is becoming a more common restoration alternative, but sediment response to dam removal is still largely unknown. The removal of Condit Dam from the White Salmon River, Washington provides a unique opportunity to study how a bedrock-confined, gravel-bed river responds to the disturbance of a large influx of fine reservoir sediment. On October 26, 2011, the 98-year-old Condit Dam on the White Salmon River was breached, releasing a mudflow downstream. Within hours, fine silt and sand had draped the 5.3 river kilometers between the dam site and the confluence with the Columbia River. Our study investigates the spatial and temporal controls on geomorphic response to this fine sediment loading. In particular, we examine how the transport capacity of reaches influences their sensitivity to change and how changes in transport capacity influence reach response. We quantify transport capacity by repeat surveys of slope, grain size, and topography before and after the dam breach. This poster will present our initial results regarding these surveys and measured changes.

Gasoline Remediation Impacts On Aquifer Microbial Communities, Ronan, Montana

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Electrical Resistance Heating (ERH) is a remediation technology used to treat gasoline contaminated groundwater. ERH increases the subsurface temperature in excess of 100° C to volatilize the gasoline components. Research suggests that during the cooling phase the increased temperatures associated with the remediation process creates environmental conditions that can promote biodegradation of residual gasoline components. However, currently available microbial data are sparse and show conflicting results including decreases in species richness and abundance at some sites, and increased overall microbial populations at others. This research will be conducted at a tank leak site in Ronan, Montana. It will attempt to answer the following research questions: 1) How does the indigenous microbial community composition, density, structure and function respond to ERH treatment? ; 2) Is microbial remediation of residual fuels likely to occur during post-ERH cooling? To examine post heating microbial communities and to document the initial and long-term response to ERH treatment, we will collected soil cores from ERH treated and non-ERH treated aquifer sediments, and are using molecular techniques to document changes in the microbial community's density, composition structure and function. We will monitor changes of temperature, geochemical conditions, and soil properties in order to establish the overall environmental conditions influencing microbial growth. Research results will be used to inform remediation users if post-heating microbial community rebound occurs and if identified microbial communities could promote further remediation of residual fuel contaminated aquifer after ERH treatments. We will present preliminary results of microbial community diversity and major taxa identification work along with temperature, geochemical conditions, and soil characteristics at the research site.

Elevated Uranium And Lead In Wells In Big Horn County - A Potential Problem

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NURE (National Uranium Resource Evaluation) data shows several wells with elevated U (uranium) and Pb (lead) in Big Horn County, Montana. Wells with elevated U and Pb might pose health risks if the designated use is for drinking water. The EPA national primary drinking water standard for uranium is 30 ug/L and 15 ug/L for lead. Values of uranium in the NURE data base exceed the standard in several wells in the county. The highest value in the data set is 404 ug/L located south of Reno Creek in a 12' deep well near interstate 90. Lead data in the NURE data base is questionable due to instrumentation problems at the time the data was analyzed. The GWIC (Ground Water Information Center) data from the Montana Bureau of Mines and Geology also shows some elevated uranium and lead values in Big Horn County. The GWIC data for Big Horn County has 1286 entries recorded. Of these, 600 sites were tested for lead and 169 for uranium. The GWIC data base shows 102 wells that exceed the 15 ug/L value for lead, with 55 wells exceeding 80 ug/L, and the highest value is 585 ug/L. Most of these wells are monitoring wells that are proximal to the Decker mining area and may be related to the coal, especially the Tongue River member of the Fort Union Formation. The elevated uranium from the GWIC data base has a strong correlation with Tertiary and Pleistocene age gravels. Many of the high values in the streams and springs on a GIS (Geographic Information System) generated map of NURE data are in the Quaternary terrace deposits. Many wells on the reservation are only drilled in these shallow Pleistocene deposits and most were not tested for lead or uranium. The administration of wells drilled on the Crow Indian Reservation, Big Horn County, is by the Indian Health Service. Most of these wells are not reported to the GWIC. These wells may pose health risks if the primary use is for drinking water, further testing may be implicated.

Comparing State Regulations For Residential Greywater Reuse :Approaches To Appropriate And Adaptive Local Management

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This study compares how states regulate greywater reuse through statutes and agency rules. Approaches including agency authority, greywater definitions, plumbing code provisions, onsite wastewater treatment rules, greywater system design criteria, and local ordinance authority are used to assess how greywater reuse practices are regarded in each state as a means for water conservation and efficient local resource management. Montana's regulatory authority and provisions are compared with other states to evaluate considerations that may be made to promote more appropriate and adaptive local management.

Snow Distribution At The Landscape Scale From An Ensemble Of Models: Central Bitterroot Range, Montana

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An ensemble of snow accumulation models are used to examine the spatial distribution of snow water equivalence (SWE) within the Central Bitterroot Range of Montana. Because of the unverifiable nature of landscape scale snow accumulation models, an ensemble modeling approach is employed to provide a greater range of results. This suite of model results will allow for inter-model comparison and analysis to determine if and where model results agree or diverge. Model results are used to examine how factors such as elevation and aspect account for the spatial variability of SWE accumulation at the landscape scale. Initial analysis of results from using two different models indicates that aspect and elevation account for less than 50% of the variability in the spatial distribution of SWE at the landscape scale. Further research will involve SWE accumulation modeling using model output from the Weather Research and Forecasting (WRF) Model. Using WRF model output is a new method that has not been previously employed in Montana.

Results From A Ten Year Study Of An Off-channel Infiltration Pond Coal Creek Study Site, Ucross Wyoming

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In 2003, an off-channel coal bed methane infiltration pond was constructed in a gently sloping uplands area near Ucross, Wyoming south of Coal Creek. The pond was excavated into interbedded sandstone, clay, and coal layers. Monitoring wells were installed within the pond and surrounding the pond at various depths. During July, 2003 CBM-production water began to be discharged to the infiltration pond and continued through October, 2003. Groundwater levels directly beneath the pond responded to CBM-production-water discharges to the pond in less than one month, and increased water levels were measured in all shallow wells. Changes in groundwater levels were not seen in the deeper monitoring wells. Groundwater levels returned to near baseline levels within 2 to 3 years after CBM-water production ended. Prior to discharge of CBM-produced water to the pond, shallow groundwater was generally dominated by near-equal concentrations of calcium, magnesium and sodium with moderate levels of total dissolved solids (TDS). A well sampled within the pond showed an increase in all cations and in SO_4 after only one month of discharge to the pond. The highest TDS value of 17,367 mg/L was measured at a well immediately down gradient from the pond. This well was dry prior to filling the pond, and became dry again early in 2006 as the pond stage was decreasing. The increases in TDS are likely associated with the dissolution of minerals present in the overburden material and are not directly associated with the constituents in CBM production water. After nearly ten years, the increased salinity observed in some down-gradient shallow monitoring wells has returned to near baseline conditions. In 2010, the infiltration pond was reclaimed and final water level and water quality samples will be collected in the summer of 2012. After the samples are collected, the Coal Creek monitoring wells will be reclaimed and properly abandoned.

Mercury Concentrations in Sediments of Flint Creek and Tributaries

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Mercury Concentrations in Sediments of Flint Creek and Tributaries Matthew Young and Heiko Langner University of Montana-Missoula, Geosciences Department Contributions from Flint Creek cause mercury levels in Clark Fork River sediments to increase from about 0.7 mg/kg above to over 4 mg/kg downstream of the confluence near Drummond, Montana. This six-fold increase in sediment mercury concentration is associated with highly elevated mercury levels in local biota such as invertebrates, fish and fish-eating predators in the Clark Fork River. Levels in Flint Creek are higher yet, as a relic of extensive historic mining and processing of precious metals, although limited data is available to identify the specific sources of mercury in the watershed. The objective of this study is to isolate the tributaries with major sources for mercury in the lower Flint Creek watershed. We collected 27 in-stream fine sediment samples.

Potentiometric-Surface Map Of The Madison Group In Part Of Cascade County, Montana

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Potentiometric-Surface Map of the Madison Group in part of Cascade County, Montana James P. Madison and Camela A. Carstarphen Montana Ground Water Assessment Program Montana Bureau of Mines and Geology jmadison2@mtech.edu The Madison Group aquifer is an important source of groundwater in Cascade County, Montana. Not only does it supply water to about 975 wells for public supply, self-supplied domestic, self-supplied industrial and livestock purposes, it is also the source of water for Giant Springs, the largest spring in Montana (157, 100 gallons per minute) and amongst the largest in the United States. As part of the Montana Bureau of Mines and Geology's Ground Water Characterization Program, water levels were measured in wells completed in the Madison Group aquifer in Cascade County to assess directions of regional groundwater flow. The Madison Group is composed of two formations, the Mission Canyon and the underlying Lodgepole

Limestone. Karst development occurred in the upper part of the Madison during Mississippian and into the Jurassic time when Mission Canyon rocks were subaerially exposed. The Madison Group thickness ranges from about 1,200 to 1,700 feet. North of the Little Belt Mountains, a broad northwest-plunging anticline, the Sweetgrass Arch, gently folded the Madison Group and associated underlying and overlying sedimentary rocks. The axial trace of the Sweetgrass Arch extends from the Little Belt Mountains through Great Falls and northwestward into Canada. The Madison Group crops out along the northern flanks of the Little Belt Mountains in the southern part of the county. North of the Little Belt Mountains, Madison Group rocks, along with underlying and overlying sedimentary rocks, dip gently to the west-northwest on the west flank of the Sweetgrass Arch and gently to the north-northeast on the east flank of the Sweetgrass Arch. At Great Falls, the depth to the top of the Madison Group is less than 500 ft below land surface; east and west of the Sweetgrass Arch the depth to the top of the Madison Group is greater than 1,000 ft below land surface. The potentiometric map was constructed by hand contouring water-levels that were measured mostly in 2012; most measuring point altitudes were surveyed to the nearest 0.5 ft with a survey-grade GPS. Measuring point altitudes not surveyed were estimated from U.S. Geological Survey 1:24,000 topographic maps. Groundwater flow direction is from recharge areas in the Little Belt Mountains northward towards Great Falls. Near Great Falls, there is a cone of depression in the potentiometric surface loosely centered near Giant Springs. The 500 square mile area between the Missouri River and the 3,300 ft potentiometric contour shows about 40 feet of water level altitude difference with the lowest altitudes in a 50 square mile area near Giant Springs; this broad and relatively flat area of the potentiometric surface is interpreted as being composed of well-connected caverns and voids that developed when Madison rocks were subaerially exposed.

Examining Trends In Snow Accumulation & Water Availability Using SNOTEL And Streamflow Observations In The Missouri River Headwaters

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The Missouri River headwaters are located in the mountains of southwestern Montana, and serve as a water source for 10 states and approximately 10 million people. A key component of the annual water budget in this headwater region is from snowfall, comprising between 50 and 70% of the total annual flow. The Western U.S. is comprised of semi-arid to arid regions that exhibit a high degree of inter-annual to multi-decadal variability. Changing trends in water availability due to climate change and yearly variations must be understood and quantified for proper allocation and forecasting of water resources. Here we use snow, temperature and precipitation records from the Natural Resource Conservation Service (NRCS) and streamflow records from the U.S. Geological Survey (USGS) in a coupled analysis designed to assess recent changes in these temperature sensitive high alpine headwaters over the last 40 years of record. Snow depth, snow water equivalence, temperature and stream flow are key metrics that can be indicative of change in these headwater regions and are useful in determining the amount, timing and duration of hydrologically important snow-driven events. These data are being examined to determine what role inter annual and decadal drivers such as the El Niño Southern Oscillation (ENSO), the Pacific North American Pattern (PNA), and the Pacific Decadal Oscillation (PDO) play in controlling the amount and timing of water availability in this catchment.

Measuring Baseflow To Powder River Basin Streams

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The 2012-2013 Ground Water Investigation Program (GWIP) priority list includes the Powder River Basin in southeastern Montana because of its concentration of coalbed methane (CBM) wells. Coalbed methane production requires the extraction of large quantities of groundwater from coal aquifers, which provide baseflow to streams and are used throughout the region for domestic and stock purposes. The Montana Bureau of Mines and Geology will conduct an isotope, geochemistry, and incremental stream flow study on the Tongue River, Hanging Woman Creek, Otter Creek, and the Powder River to identify and quantify the coal aquifer baseflow to these Powder River Basin streams. Groundwater withdrawal during CBM production

has the potential to reduce baseflow to streams. The volume of water contributed by coal seams to surface drainages in the Powder River Basin is unknown, which has created an environment of discord between the many water users in both Montana and Wyoming. Depending upon focus, area stakeholders wish to preserve in-stream flows, groundwater availability, and/or resource development. Additional divergence in priorities stems from Montana's requirement for a water right prior to putting produced water to beneficial use, such as irrigation. However, for industry to acquire a water right it must be shown that they will either not adversely impact down-gradient water users, or compensate users who are impacted. The presence or magnitude of impact is difficult or impossible to show without a better understanding of the relationship between coal aquifers and surface streams in the Powder River Basin. Isotopes of carbon and strontium have been shown to effectively fingerprint the groundwater contribution to surface water in the Powder River Basin. These geochemical parameters will be combined with traditional in-stream flow measurements to identify and potentially quantify the coal aquifer baseflow contribution to Powder River Basin streams. Isotope and chemistry samples and flow rate measurements will be taken during baseflow to maximize the proportional contribution of groundwater to the surface water hydrograph. Wells completed in coals and near outcrop will be utilized for geochemical characterization of groundwater. Surface water sampling will be conducted at locations where the flow measurements indicate a gaining reach. The ability to quantify the impact to surface water from up-gradient energy development will aid in the acquisition of the necessary permits that will allow the energy producers to use the coproduced water for beneficial purposes, rather than treat it as a waste product. Defining and quantifying the relationship between the coal aquifers and streams will allow stakeholders to have science based discussions of best management practices.

Tri-State Water Quality Council: Collaborative Water Quality Monitoring In The Clark Fork Pend Oreille Watershed

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The Tri-State Water Quality Council (Council) is a partnership of citizens, businesses, industry, tribes, government, and environmental groups working together to improve and protect water quality throughout the Clark Fork-Pend Oreille watershed. The Council was formed as a result of the Clark Fork-Pend Oreille Watershed Management Plan, which was released in 1993 by the states of Montana, Idaho, and Washington, in conjunction with the EPA Regions 8 and 10. The Management Plan was based on studies mandated by Congress under Section 525 of the Amendments to the 1987 Clean Water Act over citizen concerns of increased aquatic vegetation and attached algae in the Clark Fork River and Lake Pend Oreille. The Council established four primary management goals and seven associated monitoring program objectives designed to control eutrophication and to restore and protect designated beneficial interstate water uses from impairment within the watershed. As a means to achieve defined management goals, the Council championed target nutrient concentrations for the Clark Fork River watershed through the creation of the Voluntary Nutrient Reduction Program (VNRP). Also underpinning the Council's management goals was their work in developing and advocating recommended nutrient targets and apportioning nutrient loads to Lake Pend Oreille as part of the 2002 Montana and Idaho Border Nutrient Agreement. The Council also manages limited heavy metals monitoring at 3 stations in lower Clark Fork River in support of the Clark Fork Settlement Agreement under the Federal Energy Regulatory Commission. The Council's monitoring program was started in 1998 and continues today. The monitoring program consists of measuring field parameters and collecting samples at monitoring locations on the Clark Fork River and selected tributaries, Lake Pend Oreille, and the Pend Oreille River within the Clark Fork-Pend Oreille watershed of western Montana, northern Idaho, and northeastern Washington. The monitoring stations are divided among multiple organizations and agencies that form the Council's Monitoring Committee. Monitored nutrient parameters include total phosphorus (TP), soluble reactive phosphorus (SRP), total persulfate nitrogen (TN), and total soluble inorganic nitrogen (TSIN) which consists of soluble ammonia nitrogen as N and soluble nitrate and nitrite as N. Monitored metals included total recoverable and dissolved copper and zinc, as well as dissolved cadmium. Attached algae (periphyton) in the Clark Fork River are monitored for chlorophyll-a and ash free dry weight (AFDW). During the summer months, locations on the Clark Fork River are monitored for nutrients and attached algae for compliance with the state of Montana nutrient standards and VNRP nutrient targets. The current monitoring program

represents the third continuous five-year monitoring cycle managed by the Council. The previous five-year monitoring programs, conducted from 1998-2002 and 2003-2007, provided the basis for a statistical analysis of water quality time trends reflected in the Council's and the state agencies' data. Water quality monitoring and data reporting are completed annually to culminate in the next trends analysis report for the years 2008 to 2012.

Climate And Geological Factors Influencing Stream Intermittency In Alpine And Subalpine Watersheds In Western Montana

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Within the alpine and subalpine watersheds tributary to the lower Clark Fork River in western Montana dewatering of streams (channel recharge) at the end of the snowmelt season produces dry reaches, subsequently reducing available aquatic habitat for critical salmonid species. Planned watershed restoration and enhancement to improve salmonid habitat and maintain in-stream flows requires an understanding of the prominent environmental factors contributing to streamflow losses and gains. Multivariate exploratory data analyses were conducted on datasets including satellite imagery, climate, land use, and glacial geology to determine the environmental factors correlated with streamflow losses and gains in the lower Clark Fork tributaries. Snowpack extent, classified from satellite imagery, was the most important variable and was positively correlated with gaining or no-loss reaches (perennial reaches). Of the 60 perennial reaches in the study area, 58 of the perennial reaches were correctly classified using average monthly snowpack extent. Moreover, 23 of 27 ephemeral reaches were correctly classified. Underlying glacial geology was the next crucial environmental factor. Perennial reaches were negatively correlated with Glacial Lake Missoula sediments and positively correlated with topography dominated by crests and spurs of mountains that bore many Pleistocene-age glaciers. All of the reaches associated with the crests and spurs of mountains that bore Pleistocene-age glaciers were perennial. Reaches with streamflow loss were positively correlated with the occurrence of Glacial Lake Missoula sediments, and negatively correlated with topography dominated by crests and spurs. Eighty-one percent of reaches associated with the Glacial Lake Missoula sediments were losing.

The Influence Of Dam Removal On A Mine-Impacted River: Downstream Effects On Macroinvertebrate Communities

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Long-term monitoring data were used to evaluate possible disturbance effects associated with removal of Milltown Dam on the Clark Fork River, a large mining Superfund site in Western Montana. Metal concentrations in bed sediment and Hydropsyche larvae measured over 15 years at sites above and below the dam were examined prior to drawdown, and compared to 4 years following the final breaching of the dam. The year of the drawdown, Cu concentrations in sediment at the site below the dam doubled (509 ± 39 ug/g) from earlier years and Cu in Hydropsyche increased by almost 35% (84.5 ± 12 ug/g). Copper in sediment has declined in recent years but bioavailable Cu, as indicated by concentrations in the bioindicator Hydropsyche, remain elevated. Possible effects of dam removal on benthic invertebrate assemblages were also assessed by comparing annual changes in invertebrate compositional similarity for two 4-year periods before and after dam removal. Above the dam compositional similarity decreased post-dam removal but increased during that same period downstream, corresponding to ~60% overall reduction in invertebrate relative abundance at the downstream station.

Lower Wise River Watershed Investigation; Tracking Water In The Largest Tributary To The Big Hole River

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The Wise River watershed is well documented to be an important cold water resource for the Big Hole River, especially in late summer when the Big Hole water temperatures rise to critical points for fish. Part of

the Big Hole Watershed Committee's mission is to conserve and restore water quality and water quantity for the Big Hole Watershed. The Pattengail flood of 1927 altered the native lower Wise River to have few pools for fish habitat. The altered stream bed of the Wise River and the documented importance as a coldwater source are causes for the lower Wise River to become a priority watershed for our work. In 2003 we hosted a Wise River monitoring study that provided an initial look at conditions of the Wise River. In 2010 we hosted a prioritization study to review the lower Wise River for conditions and potential sources of improvement. This conducts an investigation that includes monitoring groundwater, stream flow, groundwater-surface water interaction, stream habitat, stream water temperature, and fish populations. The study occurred 2011 to 2012 (some components of the project will continue past 2012). Data is collected through 5 surface water flow and temperature data loggers, 1 groundwater data logger, 14 groundwater elevations points, groundwater and surface water quality, habitat inventory, and 4 fish population estimates. Initial results show groundwater mimicking flood irrigation schedules. Understanding water and stream habitat will help us to determine the best course of action for water management projects, estimate potential resource benefits with proposed projects and document benefits to the resource after projects are completed, and incorporate the Wise River into drought management. We are partnered with Montana Department of Natural Resources and Conservation (DNRC), Natural Resource Conservation Service (NRCS), US Forest Service (USFS), Montana Fish, Wildlife and Parks (MT FWP), and the Montana Bureau of Mines and Geology (MBMG). The project is funded by the Montana Department of Environmental Quality (DEQ) under the 319 program, which funds projects to improve water quality.

Assessing Sources Of Acidic Drainage In Three Creek Drainages In The Judith Mountains

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The purpose of this research is to investigate natural and mining influenced acidic water in streams draining the Judith Mountains, central Montana. In recent years, a number of new field methods and concepts have been developed to better evaluate the water quality of streams draining mine lands. These ideas can be used to assess how mining activities impact surface waters and further develop improved sampling and monitoring plans for agencies, such as the BLM, who are charged with mitigating historical mining impacts and minimizing effects of future mining activities. This project is taking place over a two year period in order to determine seasonal influences on the study area. Here we present the preliminary results of all the sampling activities that took place during the first year of this study, which was completed in August of 2012. Analytical results will be summarized and discussed as well as sampling techniques and procedures used to evaluate the water quality of the streams. Within this context, the specific objectives of this project include: 1) Conduct continuous tracer injection studies of the impacted streams and tributaries to quantify longitudinal changes in the concentrations and loads of contaminants of concern. This method will allow us to identify the major zones of metal or acid loading, and whether these areas are natural or disturbed by mining. This will also help us determine the best locations for long-term water-quality monitoring stations. 2) Perform seasonal and diurnal (24-h) water quality sampling at selected monitoring sites. This will quantify temporal variations in water quality, and will allow us to determine the optimal times of the year and times of the day that long-term monitoring samples should be collected. 3) Collect samples of ferricrete deposits for trace metal analysis, to compare with modern Fe-oxide precipitates. This method may be used to compare pre-mining vs. post-mining water quality where no pre-mining baseline data exist. 4) A set of field parameters, including temperature, pH, ORP (oxidation-reduction potential), specific conductance and dissolved oxygen, will be taken at every location where a water sample is collected. Each water sample will be analyzed for major and trace elements, low-level trace metals, and major anions. Acidic drainage is one of the greatest environmental challenges to the mining industry. There is a critical need to better understand the causes and effects of acidic drainage related to hard rock mining. The outcomes of this study have potential use for identifying long term impacts of mining on surface water and monitoring remedial efforts at mine sites.

Diatoms And Biological Monitoring Of Acidification In Aquatic Systems

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Mining activities have a substantial negative impact on the health of our surface water systems and drinking water quality and availability. The concern over availability of potable water will only increase in the upcoming decades making it ever more urgent an issue to resolve. The drainage of water from mine sites, especially abandoned ones, can result in extreme acidification of the surface waters. This is accomplished through the bacterially facilitated oxidation of pyrite (FeS_2) to sulfuric acid. This lowering of the pH of the stream results in the incorporation of dissolved minerals such as arsenic, lead and zinc. The pH and elemental content of water influenced by mining activity and wastes is easily measured, though precipitation events can cause the values of these to be periodically high. Monitoring the in situ and downstream biota from a mine site allow for a more complete picture of the seasonal or long-term influence. Diatoms (Bacillariophyceae), a siliceous algal group, are increasingly utilized for assessing damage to a stream resulting from acidification due to anthropogenic activities as well as determining the effectiveness of remediation efforts. The inclusion of acid-tolerant species and genera in a diatom assemblage (e.g. Eunotia, Pinnularia, Tabularia), lower number of species in general and the presence of teratogenic effects all indicate acidification is influencing the site and its diatom assemblage. While floristic changes are the most obvious result of alterations in pH, species richness and overall algal biomass will increase as acidic impact on a site is reduced. Numbers of species ranging from 25-35 are common at sites influenced by acid mine drainage, while uninfluenced sites nearby can have species richness in the range of 60-70. It has also been noted that reduction in pH at a site can result in increases in algal biomass, possibly resulting from decreased grazing or increased light availability due to changes in riparian cover resulting from mining activity. Diatoms have also been shown to sequester metals within their cells through the action of phytochelators, indicating the bioavailability of metals in their aquatic systems. The abundance of diatoms in all aquatic systems and their often species-specific responses to changes in ecological variables that occur with acidification resulting from anthropogenic activities make them an ideal monitoring tool.

Soil And Energy Controls On Stream Recharge From Diurnal Snowmelt Events, Lost Horse Canyon, Bitterroot Mountains, MT

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Streamflow in high, forested, snow-dominated catchments is an important metric that carries integrated information about snowmelt events within the basin at different temporal scales. High frequency snowmelt events are dominated by the day-night cycle and are reflected in the streamflow signal. Prior studies have highlighted the importance of sub-daily streamflow fluctuations in these catchments for nutrient cycling, riparian aquifer pumping, and surface water availability. However, most studies have only examined sub-daily stream and groundwater fluctuations caused by varying evapotranspiration and infiltration rates. Moreover, in studies that predict stream response to snowmelt or precipitation, soil moisture states are rarely considered. In this study we compare high frequency (hourly) atmospheric inputs to the timing and magnitude of both interflow fluctuations and streamflow. In this study we analyze air temperature and net radiation over the snowpack to approximate the energy state of the snowpack and relate it to soil moisture and streamflow response. The data shows that the snowpack is an energy sink that needs to be replenished daily during the early snowmelt season before snowmelt occurs. Until the snowmelt process is resumed, the soil water storage decreases and needs to be refilled again before efficient transmission of water to the stream occurs. We conceptualize the process as a linear series of energy and water reservoirs that fill and deplete driven by the daily atmospheric cycle. We use this conceptual model to reproduce the magnitude and timing of daily maxima. Our interpretation suggests that daily shallow soil storage and transmission as important to stream recharge rates as snowmelt during the spring melt season.