Hydrologic Investigations by the U.S. Geological Survey Following the 1996 and 1997 Floods in the Upper Yellowstone River, Montana
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ABSTRACT: The Yellowstone River, which originates in Yellowstone National Park and flows through Montana, provides a diverse water resource important to local and regional economies and individuals. In 1996 and 1997, floods with recurrence intervals close to 100 years at Livingston caused substantial geomorphic changes to the upper Yellowstone River through streambank erosion, channel scour and deposition, and damage to the riparian corridor. The upper Yellowstone River floods prompted a number of investigations to address the potential cumulative effects of existing and future streambank-stabilization projects. Oversight and coordination of the various investigations is being provided by a task force appointed by the Governor of Montana. Hydrologic investigations by the U.S. Geological Survey included data collection and interpretation and hydraulic modeling related to sediment transport and flood-plain delineation. The investigations focused on the river reach from Livingston upstream about 60 river miles to Gardiner.

As part of these investigations, 145 river cross sections were surveyed and related to a common horizontal and vertical datum. The cross-section data were used in the sediment-transport modeling and flood-plain delineations. Twenty-five cross sections were resurveyed after two runoff seasons to compare with sections originally surveyed. Bedload and suspended-sediment data were collected during three runoff seasons for flows ranging from about 2,200 to 25,000 cubic feet per second. Data interpretation and analysis resulted in development of a general sediment-discharge curve relating total sediment discharge to stream discharge. Individual transport equations also were developed relating sediment discharge to stream discharge for selected sediment size classes ranging from cobbles to fine sand. The sediment-discharge curve and equations then were used in a sediment-transport model, where different hydrologic conditions and river management scenarios for an 11-mile subreach of the study area were simulated and compared. A hydraulic model for flood-plain delineation was used to determine the 100- and 500-year flood limits in the 45-mile subreach from just above Livingston to about Tom Miner Creek, and the 100-year flood limits for the 15-mile subreach from Tom Miner Creek to Gardiner. Results are planned for publication and inclusion in a report on the results from the overall cumulative effects study addressing streambank stabilization, and will provide useful background information for resource-management decisions related to the upper Yellowstone River.

Crossing the Yellowstone–Evaluation of Equations for Estimating Pier Scour for Coarse-Bed Streams in Montana
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ABSTRACT: More than 25 highway bridges cross the Yellowstone River as it meanders across Montana. Historically, floods have damaged or threatened some of these bridges, typically by scouring bridge foundations. For bridge design and repair, engineers commonly choose from several pier-scour equations, which generally are based on data from laboratory flumes and from sand- and silt-bottom streams. Many of these equations tend to overestimate pier scour for coarse-bed streams like the Yellowstone River. Although equations that account for coarse-bed characteristics have been published, verification of equation performance under actual conditions is needed. Therefore, the U.S. Geological
Survey and the Montana Department of Transportation evaluated five commonly used scour equations for piers to determine their applicability for streams having gravel and cobble bed materials. For this evaluation, researchers compiled scour-depth, bridge-geometry, bed-material, and velocity measurements from coarse-bed streams across Montana and five other states. Then, measured scour was compared with scour estimated by the five equations. Of the five pier-scour equations studied, the equation recently proposed by the Federal Highway Administration (which includes a correction factor for bed-material sizes) most reliably predicted scour. This equation seldom underestimated pier scour, and estimates were more accurate than for the other four pier-scour equations.

Aerial Assessment of the Yellowstone River Corridor
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ABSTRACT: The Yellowstone River Conservation District Council (YRCDC) will present the results of its work completed in 2001 to perform an aerial assessment and subsequent ground-truthing of the physical features on the Yellowstone River corridor, from Gardiner to the Missouri River confluence.

The YRCDC is the local contact group for participation in a congressionally mandated study being conducted by the Army Corps of Engineers. The YRCDC’s aerial assessment and ground-truthing work serve as a basis for prioritizing Corps of Engineers study areas. The YRCDC will use the data collected to develop Best Management Practices for all types of projects on the river.

This so-called Rapid Aerial Assessment (RAA) was completed in October 2001 using a helicopter with four crewmembers using GPS devices to map the corridor. This portion of the work resulted in excellent photographic documentation, including color slides and video coverage.

The YRCDC’s goal in conducting the RAA was to collect information on the nature of the Yellowstone River corridor to characterize baseline conditions in order to better inform local residents, affected conservation districts, and the YRCDC about the Yellowstone River and for the information to become a foundation for prioritizing future data collection efforts and land/water improvement projects.

The features identified and mapped during the RAA include:
- Exiting stream stabilization structures (riprap, jetties, dikes, flow detectors, etc.)
- In-channel structures (irrigation diversions, head gates, pump sites)
- Stream crossings (bridges)
- Irrigation return flow points
- Accelerated bank erosion
- Significant natural sediment sources

After the RAA phase was completed, an on-the-river inventory of the mapped features from Springdale to North Dakota was conducted. Ground-truthing was conducted to determine on-site evaluations of the effectiveness of existing stream stabilization projects and to begin characterization of adjacent land use. Hand-held digital video and/or digital camera photos provided documentation of these features.

The results of this activity provided the foundation for local landowner workshops, more detailed geomorphic investigations on priority sections of the river, and future land/water improvement projects.
Assessing flood plain dynamics using cottonwood ages on the Yellowstone River
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ABSTRACT: The life history of cottonwood makes it a useful indicator of flood plain dynamics. As cottonwood is an early colonizer of new stream deposits, the spatial pattern of aged cottonwood trees allows a reconstruction of flood plain development history that pre-dates aerial photography. Cottonwood in northern temperate climates like the Yellowstone River corridor can live to 300 hundred years more. Channel migration rates can be inferred from mapped locations of aged cottonwood trees that are typically in distinct, uniform stands. A synoptic metric of channel migration, flood plain turnover, indicates the storage time of flood plain sediments. Cottonwood tends to colonize new channel deposits in an elevation zone between base flow and the highest bar surfaces that have adequate moisture to allow seedling survival. Subsequent floods can deposit sediments around cottonwood stems, which is part of normal vertical accretion. The thickness of this sediment stack, from the flood-plain surface down to the original cottonwood establishment surface, yields an alluviation rate when combined with cottonwood age.

Examples from ongoing research on the Yellowstone River are shown and put in context to other large rivers in the western USA.

Recruitment of Populus angustifolia along the Upper Yellowstone River: sexual or asexual?
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ABSTRACT: Cottonwood trees are a proven indicator of river migration and deposition. Because cottonwood seedlings rely on new deposition from spring flooding to establish themselves, the location and age of cottonwood stands can be used to reconstruct channel migration history and floodplain turnover rates. Cottonwood establishment years, obtained with increment cores, correlate closely with historic discharge records and historic channel movement. Thus the cottonwood can be used to both confirm and extrapolate historical records and provide useful information on river movement and vegetation dynamics of the system. In an attempt to apply this technique on the Upper Yellowstone River however, many surprising discrepancies emerged. Narrowleaf cottonwood (Populus angustifolia) is the primary riparian tree along the Upper Yellowstone River. This study along the Upper Yellowstone River included the flood plain and subdivided the study reach into six strata based on flood plain morphology. Increment core samples were taken at ground level to attain tree ages within distinct cottonwood stands. Tree establishment years had no clear correlation to historic flood records for the study area. Comparison of aerial photographs of the floodplain and ground observations of the trees as well as sampled tree ages suggest that cottonwoods have established in areas that are not the typical flood deposits necessary for seedling survival. The implication of these findings is that a great deal of cottonwood reproduction along the Upper Yellowstone may be asexual (root sucker origin) rather than sexual (seedling origin). If that is the case tree ages will not necessarily correlate to when the area was a new deposit making the mapping of river movement with this technique very difficult or impossible. The dependence on asexual reproduction has important implications to management issues surrounding the floodplains of the Upper Yellowstone River. The use of genetic analysis will be needed, however, to further establish to what extent asexual reproduction is actually present. Once the extent of asexual reproduction is known, the mechanisms and relative importance of vegetative reproduction will be investigated.
Good Science Should be the Foundation for Water Management Decisions in Montana
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ABSTRACT: Over the past twenty-five years, water management decisions in Montana have become more complex. The state must protect traditional water uses for irrigation, hydropower, industry and municipalities under the prior appropriation doctrine, and at the same time find innovative ways to meet new and future demands for limited water supplies. Besides the above uses, water is needed for reserved water rights of Native Americans and Federal agencies, water quality, endangered species, recreation, instream flows and riparian habitat.

This paper describes a number of research areas where better information and data are needed to guide water managers and politicians into the 21st century. The research areas encompass hydrology and hydrogeology, policy and law, and specifically include the following: TMDLs and water quality, monitoring and mitigating the short and long term impacts of coalbed methane development, the surface and groundwater interconnection within alluvial valleys, the effects of groundwater appropriations on existing surface water users, standards and procedures for implementing the Salvage and other Montana water laws, problems and solutions with the Yellowstone River Compact, more responsive drought triggers to initiate appropriate response actions, effects of wintertime releases on under-ice river scouring, various types of cumulative impact assessments from river channels to large watersheds, instream and other habitat requirements of certain fish species, the cost and benefits of the on-going state-wide adjudication, and the sustainability of water resources in rapidly developing parts of the state (e.g. evaluating the merit of proposed controlled ground water areas) and the impacts of contaminated baseflow (i.e. septic effluent from concentrated areas along streams or lakeshores) to surface water sources.

Water Quality Data Access in Montana via the Internet
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ABSTRACT: The Montana Natural Resource Information System (NRIS) was established in 1985 by the Montana Legislature. It was designed to simplify the task of identifying and acquiring natural resource information for Montana and making this information readily available to potential users. NRIS has built an extensive Internet based information clearinghouse for use by its patrons. Historically, NRIS has provided access to data through its web site in the form of static files, links to other sites, or static informational pages. For GIS users, this meant NRIS was a great place to come to obtain key coverages for a project or analysis (county boundaries, hydrography, abandoned mines, etc) but the end-user was still required to post process the data into the areal extent they were interested in and perform the analysis on their own machine to get the desired outcome. This required the end user to be GIS literate, have significant computer resources, and have access to GIS software.

In the past 2 years or so, NRIS has been developing a class of applications that allow for powerful information retrieval and analysis functions, with GIS capability, over the world wide web. This development effort culminated this summer with the deployment of a new web based GIS interface that provides access to a broad suite of watershed and other natural resource data.

The mapping application allows for a broad spectrum of spatial queries: new users can use a simple image map to query by county, watershed, or other administrative boundary while more advanced users can customize their own queries, such as show me a 2 mile buffer around highway 93 in the Bitterroot

watershed. Data from the system can also be accessed from the NRIS TopoFinder (an interactive access application for topographic map data in Montana).

Once the user has made their query, the system provides ad-hoc mapping and reporting to a broad spectrum of data for their area of interest. Data themes available include ADMINISTRATIVE data such as land ownership and use and, STREAM/WATER data such as fisheries information, TMDL data, public water supplies, groundwater wells, dams, and Corps of Engineers 404 permit locations, and POTENTIAL WATER QUALITY THREATS such as Superfund sites, wastewater dischargers, abandoned mine sites, and septic tank density.

The user can pick and choose the maps they want to see by category and the mapper application produces the interactive map and reports for that data category. The map is active with pan/zoom and identify features and can utilize the 24K USGS quad maps as backgrounds. The data category being viewed can be downloaded as a shapefile.

The system is built using Microsoft SQL Server with ESRI's Spatial Database Engine (SDE), ESRI's MapObjects and MapObjects Internet Map server (IMS), Visual Basic, and Active Server Pages. The system runs on a 3 machine array of NT servers; one web server, one application server, and one data server.

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Introduction: Coal bed methane (CBM) development in the Powder River Basin of Montana and Wyoming has been characterized as the hottest play in the nation. The production of CBM requires withdrawal of ground water in order to lower the pressure in the coal bed so methane can flow out of the coal. Production of the water affects the quantity and quality of Montana's water resources. The regulation of water quality and water quantity in the context of CBM development is described in this presentation.

Water Quality: Montana's water quality is affected by the decisions of several governments, including the State of Wyoming, the Northern Cheyenne Tribe, and the federal government, in addition to the State of Montana.

Regulatory activities that affect Montana's water quality include:
- issuance of national or state pollutant discharge elimination system permits;
- enforcement of narrative and numeric water quality standards and nondegradation requirements;
- development of numeric water quality standards for electrical conductivity (EC) and sodium adsorption ratio (SAR);
- development of total maximum daily loads (TMDLs) for impaired water bodies;
- permitting of impoundments; and
- determination of effluent limitations that represent the best available technology economically achievable for water produced from CBM wells.

Water Quantity: The primary regulatory mechanisms that affect water quantity in Montana include:
- the statutory requirement that water mitigation agreements be offered to water right holders by developers of CBM wells;
- the requirements established by the Department of Natural Resources and Conservation and the Board of Oil and Gas Conservation for the Powder River Controlled Groundwater Area; and
- for water that is subsequently put to a beneficial use, the permit requirements of the Water Use Act.
**Ground Water / Surface Water Interactions and Source Water Protection in Montana**
Perri Phillips May, Jim Stimson, Russell Levens, Joe Meek, Jeffrey Herrick, and Carolyn DeMartino, Montana Department of Environmental Quality; pphillips@state.mt.us

**ABSTRACT:** The Montana Source Water Protection Program (SWPP) is tasked with identifying significant potential contaminant sources in the vicinity of all Montana Public Water Supply Systems (PWSs), and assessing the susceptibility of PWSs to these sources. The SWPP is in the process of compiling or providing oversight on contaminant inventories and susceptibility analyses in Source Water Delineation and Assessment Reports (SWDARs) for each PWS. Information compiled in SWDARs is intended to be used by local governments or other entities to support voluntary efforts to reduce contamination threats. Inventories for potential contaminant sources are conducted within a delineated control zone, inventory region, recharge region, and/or surface-water buffer associated with each PWS well. In accordance with SWPP requirements, a surface-water buffer is warranted for a PWS well if a stream, lake, irrigation canal, or reservoir is in contact with or overlies an unconfined alluvial valley aquifer or a carbonate or fractured rock aquifer outcrop within the PWS well's delineated inventory region. A surface-water buffer is also necessary if a PWS source has been identified as Ground Water under the Direct Influence of Surface Water (GWUDISW). Based on preliminary PWS assessment results specific to the Surface Water Treatment Rule, there appears to be a very small percentage of PWS sources in Montana that qualify as GWUDISW. Furthermore, a number of PWS sources have been identified as under the influence of surface water predominantly based on a lack of available information on well construction, rather than hydrogeologic data. In many instances, a surface-water buffer will be delineated for a PWS well pursuant to the SWPP based on ground-water, surface-water, and/or geologic data demonstrating the existence of hydraulic connections, even if a PWS source has been determined not to be GWUDISW pursuant to Montana's PWS rules.

In accordance with SWPP requirements, surface-water buffers encompass an area extending one-half mile on either side of a surface water in connection with a PWS source aquifer, and extending ten miles upstream or to the watershed divide, whichever distance is shorter. Surface-water buffer inventories focus on potential sources of nitrate and pathogenic contaminants associated with acute health effects, such as concentrated animal feeding operations, septic tanks, class V injection wells, municipal sanitary sewers, and wastewater treatment facilities. Additional significant potential contaminant sources are inventoried within the watershed upstream from a PWS source aquifer that is hydraulically connected to surface water. Management recommendations are made for potential contaminant sources located in surface-water buffer and recharge regions. These recommendations, such as best management practices, are included in SWDARs. Total Maximum Daily Load (TMDL) plans containing similar management recommendations afford additional protection to PWSs in connection with a TMDL-listed water body. Watershed stakeholders are responsible for management of contaminant sources impairing surface-water quality within TMDL-listed watersheds.

**Landscape Influences on Watershed Dynamics**
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**ABSTRACT:** The hydrologic behavior of forested watersheds in the northern Rocky Mountains is closely related to the composition and structure of the forest canopy. Changes in canopy characteristics influence interception, evapotranspiration and incident solar radiation, which can alter downstream water quality, water yield, and the magnitude and timing of both peak and low flows. The structure and configuration of the forest canopy is shaped by disturbance events such as fire, insect and disease outbreaks, as well as human-induced changes. Some forest disturbances propagate spatially and may be enhanced or retarded by physical and vegetative patterns of the landscape. To quantify influences of the
surrounding landscape on watershed dynamics, spatially explicit vegetation processes were modeled one hundred years into the future, across roughly 3.5 million acres in west-central Montana.

Eight fifth-code watersheds, bounded by exterior basins (i.e. the surrounding landscape) were modeled in two ways: 1) in isolation from other watersheds, and 2) in the context of the surrounding landscape. Lodgepole pine, Douglas-fir, mixed Douglas-fir and lodgepole pine, and ponderosa pine were the dominant forest cover types and occurrence suggested that stand-replacing fire, mountain pine beetle, and fir beetle were likely landscape-altering forces. When the two types of simulations were compared strong relationships (p < 0.05) became evident between terrain features, vegetation configuration, and the propensity of canopy-altering disturbances to spread across watershed boundaries. Terrain ruggedness explained seventy five percent of the variation in non-forest cover and eighty percent of the variation in spread propagation. As topographic relief and drainage density increased, the spread of catastrophic disturbances across watershed divides decreased. These results indicate that canopy dynamics in watersheds with gentle topography and continuous forest cover are more likely to be influenced by disturbance processes originating outside of their hydrologic divides than those with steep, dissected terrain and non-forested components along their boundaries. In long-term planning scenarios, watersheds susceptible to spread should not be modeled in isolation but rather in the context of their surrounding landscape.

Tales from the Floodplain Wars – The Gallatin County Theatre
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ABSTRACT: Increasing development pressure and high real estate values for land along river corridors is causing many Montana communities to question the adequacy of their existing floodplain regulations and the enforcement thereof. Gallatin County, taking their lead from Missoula and Ravalli Counties, is taking steps to alter the pattern of what appears to be unwanted and hazardous development in flood prone lands. An investigation of current and past floodplain management practices has revealed just how complex good floodplain management can become. Decisions based on questionable and outdated FEMA floodplain maps, differing interpretations of floodplain boundaries, questions of liability, motivated developers with large land investments, ignorance of existing regulations, lack of enforcement, unpermitted private levees and berms, private property rights arguments, dueling HEC-RAS studies, and professional disagreements are a regular occurrence. This situation does not appear to be at all unusual in rapidly growing areas of the western U.S. and Montana, and is often compounded by under-staffed planning offices without trained floodplain managers. This presentation discusses some specific examples of the general chaos and briefly discusses the proposed changes to Gallatin County floodplain regulations that would alter the way these scenarios unfold in the future.
Hydrogeology in the National Forests
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ABSTRACT: Groundwater resources on National Forest lands have been largely ignored in the past; however, a new awareness of the value of groundwater and the agencies responsibility to protect this resource appears to be emerging. With the pending completion of a groundwater handbook, the Forest Service will have some direction on how to approach groundwater resource inventory and protection issues. Several interesting hydrogeology/geochemistry related projects have been completed, or are planned, in the National Forests of Montana. They include:

- Sediment toxicity evaluation in the Stillwater River. Custer NF
- Fluorescent dye tracing to determine subsurface hydrologic connections between mine water and a nearby stream. Lewis & Clark NF
- Study of groundwater exchange in wilderness lakes overlying the Rock Creek deposit for the Rock Creek Mine EIS. Kootenai NF
- Recharge area delineation and contamination susceptibility assessment for a large karst spring used for water supply at the Anaconda Job Corps Center. Beaverhead-Deerlodge NF
- Baseline water resource monitoring program for springs and wells that may be affected by coalbed methane development. Custer NF
- Slurry wall installation at a placer mine reclamation project to reestablish surface flow in reconstructed stream channel. Helena NF
- Hydrogeologic study of alluvial aquifer to determine cause of stream flow depletion in endangered bull trout stream. Beaverhead-Deerlodge NF
- Estimation of pre-mining water quality in streams of the New World area using ferricrete geochemistry. Gallatin NF
- USGS metal loading studies and diel variation in water chemistry for streams impacted by mining.

Assessment of Water Resources of the Paradise Valley, Park County, Montana
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ABSTRACT: Ground-water in the Paradise Valley is encountered in water-saturated unconsolidated alluvial and glacial deposits and bedrock units. Depth to ground water ranges from about 10 to 20 feet near the Yellowstone River to several hundred feet near the valley margins. The primary source of ground-water recharge is from tributary stream infiltration during the spring melt of the high altitude snow pack. This is demonstrated by measured stream-flow losses and seasonal ground-water-level fluctuations. Because of orthographic effects the Mountains on the east-side of the valley receives more precipitation and consequently more ground-water recharge than on the west-side of the valley. Ground-water flow near the valley margins is oriented perpendicular towards the river and is influenced by mounding from tributary stream infiltration. Under the main valley floor ground-water flow is directed northward, parallel with the Yellowstone River. Ground water leaves the valley by discharging to the river. Most of this discharge occurs at the Spring Creeks located in the northernmost part of the valley. The Spring Creeks occur where the valley width and aquifer thickness decrease significantly. Water quality in the Paradise valley consists of very fresh calcium-magnesium-bicarbonate water. The sum of dissolved constituent (sum of common ions) concentration in the valley ranges from 50 to 500 mg/l. Nitrate concentrations are typically less than 0.5 mg/l.
Nitrate in the Summit Valley of Southwest Montana
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ABSTRACT: The Montana Ground-Water Assessment Program is completing fieldwork in the upper Clark Fork drainage basin. Preliminary ground-water sampling results from the Summit Valley (Butte area) revealed elevated nitrate concentrations (greater than 2.0 mg/L) in the alluvial and bedrock aquifers. A review of the valley’s recent and historic ground-water analyses obtained from the Ground-Water Information Center database shows that 64 percent (96 out of 149) of the samples had nitrate concentrations greater than background (2.0 mg/L) and 15 percent (22 out of 149) of the samples exceed the 10.0 mg/L health standard. Elevated nitrate concentrations were detected below sewered urban/residential areas and unsewered residential areas as well as in shallow (less than 50 feet deep) wells and deep (greater than 200 feet deep) wells. Sampling of Blacktail and Silver Bow Creeks, the primary surface water drainages in the valley, during base flow conditions in November of 2001 showed that concentrations of nitrate exceeded 1.0 mg/L over a 5-mile stretch through the most densely populated part of the valley. The results indicate that the elevated nitrate in the ground water clearly impacts the surface water in the valley during low-flow conditions. However, nitrate was not detected in the farthest downstream surface water sample, which was obtained directly below the wastewater treatment plant outfall.

To assist with source identification, ground-water samples were collected from fourteen wells in different aquifers and land use settings for analysis of stable isotopes of nitrogen and oxygen. Different sources of nitrate (NO\textsubscript{3}) can have isotopically distinct nitrogen (δ\textsuperscript{15}N) and oxygen (δ\textsuperscript{18}O). The results showed that the nitrate in all the samples had a similar isotopic signature. The δ\textsuperscript{15}N values ranged between 4 and 12 per mill, while the δ\textsuperscript{18}O (of the NO\textsubscript{3}) values ranged between –4 and 2 per mill. The measured δ\textsuperscript{15}N and δ\textsuperscript{18}O values are not consistent with a fertilizer source for the nitrate; however they are suggestive of animal or septic waste sources.

Characterization of Impacts to Water Resources of Upper Miller Creek from Septic System Effluent, Missoula County, Montana
Tobias J. Hewitt, University of Montana, and Jon Harvala, Missoula County Water Quality District; seahawker3@juno.com

ABSTRACT: Septic systems are now the most widely used method for onsite disposal, and all can be regarded as point sources of nitrate in groundwater. One-third of all existing housing units, and 25% of new homes use septic systems. Concerns have been raised nationally that increased septic system density (>2 systems per acre) may accelerate groundwater degradation.

According to the United States Census Bureau, the population of Missoula County is currently 95,802. Assuming all county residents living outside of the Missoula city limits are unsewered, over 38,000 housing units are using septic systems. One area that has experienced recent (<10 years) residential development is the Upper Miller Creek basin, five kilometers south of Missoula, Montana. Two 20-30 tract subdivisions have been added in Upper Miller Creek, and a third subdivision is currently underway. The effects of current and future development on the quantity and quality of water resources are not well understood. The purpose of this research is to assess the sources, transport and fate of septic effluent as it is released into the vadose zone and groundwater of the Upper Miller Creek basin.

This research includes instrumentation of study site; evaluation of driller’s well logs and determination of area geology; evaluation of well log performance test for aquifer hydraulic conductivity, transmissivity, and assessing water yield for study area; occurrence of ground water; quantification of surface water flows and ground water-surface water exchange; preparation of a seasonal water balance for study area;
and an examination of the consequences of possible future development on the water resources of the study area using groundwater modeling programs. An analysis of ground water and surface water quality for major anions and cations, as well as alkalinity, pH, dissolved oxygen, specific conductance, and temperature was conducted using appropriate quality assurance and quality control procedures.

The area geology of the valley floor is mostly coarse sand, gravel and boulders with occasional lens of clay scattered throughout. The hydraulic conductivity ranges from 3 to 5 ft/day in wells that were finished in alluvial fans up to 500 ft/day for wells that are located in the central valley and closer to the confluence with the Bitterroot River. The valley is between two ridges of crystalline Precambrian Belt rocks. The aquifer thickness is approximately 30 feet thick during winter and up to 45 feet thick during spring runoff. Miller Creek flows from early spring to late summer or early fall. During the remainder of the year of investigation it was ephemeral. Water quality is generally excellent throughout the valley, although there were occasions of elevated nitrate (1.2-6.4 mg/L, background is <1 mg/L) and chloride (5.1-12.5 mg/L, background is <1 mg/L) concentrations in a few wells. One in particular had a well located down gradient from the septic flow field located on an alluvial fan. The others were located in a new subdivision (<10 years) and could result from a high hydraulic conductivity and density of septic systems located up gradient of the contaminated wells. There are approximately 130 septic systems in the study area.

**Ground-water and surface-water quality, herbicide transport, and irrigation practices: Greenfields Bench aquifer, Teton County, Montana**

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**ABSTRACT:** The Greenfields Bench, located in west-central Montana (figure 1), is a series of gravel terraces that support a shallow aquifer that serves as the sole source of drinking water for three public water supplies and more than 400 private wells. The farming practices on the Bench include irrigation of malting barley and the yearly application of herbicides for the control of weeds. The most commonly used herbicide (imazamethabenz-methyl, U.S. trade name Assert®) has been found in the ground water beneath the Bench. In addition to Assert and its acid metabolite, eight other pesticides have been detected in wells serving the Town of Fairfield, the Tri-County Water District, and in numerous private wells. The Montana Water Quality Standards have not been exceeded for any of the pesticides. However, the variety of pesticides found and the frequency of pesticide detections in area wells was indicative of aquifer vulnerability and elucidated the need for additional data collection to better understand the hydrogeological processes and to develop appropriate management strategies.

The detection of Assert in the public water supply for the Town of Fairfield prompted an expanded ground-water sampling effort across the entire Bench that consisted of quarterly sampling of 16 domestic wells from the spring of 1998 through the summer of 1999. The purpose of the expanded sampling effort was to, 1) determine whether Montana Water Quality Standards were being exceeded in private water supplies or in the other two public water supplies on the Bench, and, 2) characterize the magnitude and extent of Assert contamination in ground water and in ground-water discharge to surface-water bodies.

Across the Bench, ground-water concentrations of Assert (or its metabolite) range from 0.2 to 7.8 µg/L. The Montana Water Quality Standard for Assert is 400 µg/L.

Ground water on the Greenfields Bench discharges to surface water via drains, springs, and seeps. Water-quality samples were collected from various ground-water discharge sites to assist in the development of total maximum daily loads for the receiving streams and to assess surface-water quality for human health and ecological impacts. Data indicate that Assert concentrations remain essentially unchanged through the
flow system as ground water discharges to the streams. Concentrations of Assert in surface water ranged from 0.2 to 1.5 µg/L.

A field-scale study was conducted in 2000 and 2001 to evaluate the influence of flood- and sprinkler-irrigation on the transport (leaching) of the herbicide Assert from the organic soil zone to the saturated zone. The objective of the study was to characterize the transport of Assert and its acid metabolite to the ground water under three irrigation methods-flood, wheel-line sprinkler, and center-pivot sprinkler. Results indicate that four factors appear to control Assert concentrations in ground water: 1) hydraulic-loading characteristics of the irrigation method, 2) Assert persistence in soil, 3) hydraulic characteristics of the aquifer, and 4) adsorption/desorption of Assert onto clay particles and organic matter.

The Montana Department of Agriculture (MDA) has established its first Specific Pesticide Management Plan (SMP) on the Greenfields Bench because of the high frequency of pesticide detections in ground water, the large number of different kinds of pesticides found in ground water, and the aquifer-wide extent of pesticide occurrence. The Greenfields Bench SMP, adopted as a rule in 2001, outlines voluntary management strategies for Assert-use that are focused on protecting the water resources of the area.
POSTER SESSION

October 3, 2002

Color Infrared Low-level Digital Imagery – Applications for Riparian Management
David W. Salo, Beaverhead-Deerlodge National Forest; dsalo@fs.fed.us
Contributors: Jim McNamara, Harriet McKnight and James O’Neill, GIS Specialists on the B-D NF

ABSTRACT: Low-level resource flights on Rock Creek and the Big Hole Rivers used a color infrared camera to capture images for fishery and hydrology applications. Photos were geo-referenced and then assembled together in a mosaic for analysis in Arcview GIS software. Samples of analysis results and their application in resource management are given, along with costs and hardware needs.

Ground-Water/ Surface-Water Investigations by the Montana Department of Natural Resources and Conservation
Lawrence S. Dolan, Michael J. Roberts, William Uthman, MT-DNRC; ldolan@state.mt.us

ABSTRACT: Ground-water/surface-water interactions are complex in the irrigated intermountain basins of Montana. In these basins, excess water from flood irrigation percolates to alluvial aquifers and may eventually contribute to streamflow. Water consumption in some of these basins is increasing as new irrigation wells pump ground water from the shallow aquifers, and as inefficient, flood-irrigation systems are converted to sprinkler irrigation, with subsequent increases in irrigated acreages. The Montana Department of Natural Resources and Conservation has conducted hydrology and return-flow studies in the Beaverhead, North Fork Blackfoot, and Smith river basins in west and west-central Montana. The intent of the studies is to characterize the interactions of ground water and surface water in these basins by intensively monitoring surface-water flows and ground-water levels. The results from these studies are being provided to water managers and policy makers so that they may use the information when making water management decisions.

Current Activities of the Gallatin Local Water Quality District
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ABSTRACT: The Gallatin Local Water Quality District covers 815 square miles and is centered over the Gallatin Valley. The District’s mission is to help residents of the area protect and improve water quality. Most of the District’s activities are associated with public education, monitoring, or dissemination of water resource information. The District is currently involved in a number of special projects focused on collecting information related to local ground water and surface water resources. High-resolution color infrared aerial photography is being used to inventory wetland and riparian areas. Local ground-water studies are being conducted along the southwest flank of the Bridger Mountains and in the Mountain View subdivision area to determine causes of declining ground-water levels. A water quality assessment study is being completed in the Four Corners area to provide a baseline for monitoring future growth impacts to water quality. Surface-water monitoring data is being collected along the lower Gallatin River for the DEQ TMDL program. A potential contaminant source inventory was recently completed for the entire District to aid public water supplies with preparation of source water delineation and assessment reports. The District is also preparing source water delineation and assessment reports for several public water supplies in the Belgrade area. The surficial geology of the eastern portion of the Gallatin Valley has been mapped by the Montana Bureau of Mines and Geology (MBMG), with assistance from the District. The District is also working with the MBMG to establish a valley-wide, dedicated ground water monitoring well network for the Gallatin Valley.
Using GIS to analyze and map ground-water elements related to coalbed methane production
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ABSTRACT: The Montana Bureau of Mines and Geology (MBMG) has interpreted and compiled Geographic Information System (GIS) data for the potential coal-bed methane development area of the Powder River Basin. These data include water resources, monitoring systems, and newly interpreted coal outcrop information. The results are presented as two maps. The first is MBMG Open File Report (OFR) No. 448, entitled "Hydrologic features of the potential coalbed methane development area of the Powder River Basin, Montana," (2002). The second is MBMG Geologic Map Series (GM) No. 60, entitled "Anderson and Knobloch coal horizons and potential for methane development, Powder River Basin, Montana,” (2001). Government agencies, industry, and the public use both maps to predict long- and short-term impacts to water availability and quality from coal-bed methane extraction.

Characterization of Yellowstone River Alluvial Aquifers, Middle Yellowstone River Area, Treasure and Yellowstone Counties, Montana
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ABSTRACT: Hydrogeologic and water-quality data from the Yellowstone River alluvial aquifers in Treasure and Yellowstone counties were collected as part of Montana’s Ground-water Characterization Program. The alluvial aquifers are an important source of stock and domestic water in Yellowstone and Treasure counties, and provide water to about 5,300 wells. Most of these wells have been drilled in the vicinity of the City of Billings. These aquifers consist of water-saturated sand and gravel deposits underlying the modern floodplain and older terrace surfaces of the Yellowstone River. In many locations the saturated sand and gravel deposits are discontinuous at the terrace scarp. These discontinuities form no-flow or restricted-flow boundaries between distinct aquifers. Ground-water availability may be limited near these boundaries.

Nearly all of the recharge received by the alluvial aquifers is derived from infiltration of flood irrigation (Olson and Reiten, in press). Terraces deposits located above the irrigated valley typically are not water bearing. Ground water in the terraces is primarily discharged through baseflow to a number of small perennial surface-drainages. Ground water underlying the modern floodplain discharges as baseflow to the Yellowstone River.

Water quality in the Yellowstone River alluvial aquifers ranges from a calcium-magnesium-bicarbonate water to a sodium-sulfate water. Calcium-magnesium-bicarbonate waters are relatively fresh and have a sum of dissolved constituents (sum of common ion concentrations) of between 200 and 2,000 mg/L. Sodium-sulfate waters are highly mineralized and have a sum of dissolved constituent concentration of between 2,000 and 11,000 mg/L. Ground-water quality is primarily controlled by the thickness and type of sediments overlying the aquifer.

Hydrogeologic Characterization of AMD Production along Belt Creek Near Belt MT.
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ABSTRACT: Decades of underground coal mining have resulted in acid mine drainage (AMD), which is contaminating ground-water and surface-water resources at Belt. The Anaconda mine is the largest mine in the area and was developed in 1895. Coal was extracted from a 6-foot thick seam in the Morrison Formation. Although mining ended about 50 years ago, water with a pH of 2.94 is still issuing from mine workings near Belt. The acid mine drainage is lowering the pH of Belt Creek and adding metals to it. The creek cannot support fish below Belt and is discharging acidic, metal-laden water to the Missouri River.

The Bureau of Mines and Geology is in the process of collecting data that is needed to understand and mitigate AMD that flows out of the mine workings. Rather than treating the AMD, this project will focus
on the driving force behind the problem, reducing recharge to the mine workings. In addition, contamination of the alluvial aquifer system along Belt Creek caused by nearly 50 years of acidic discharges will be assessed. Data will be collected and compiled that can be used to establish AMD loading rates in Belt Creek.

The project includes sampling from wells, springs, and streams for field chemistry and age dating of the water. Aquifer tests will be conducted on representative wells. A monitoring plan is in the progress to track ground-water and surface water trends. We are also inventorying and monitoring the acid mine drainage discharges for sources of acidity and to track fluctuations in the discharge. Determining recharge sources, estimate recharge rates, and map land use in areas overlying mines will be the next step.

Geologic Mapping for Hydrologic Studies in Western Montana Intermontane Valleys
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ABSTRACT: Integral to hydrogeologic studies is the accessibility of good geologic data. Recent compilations of previous geologic maps and recently completed geologic maps for a number of intemontane valleys in western Montana have become available in GIS format. These geologic data are at scales between 1:48,000 and 1:100,000, and are useful for regional hydrogeologic studies. Valleys that have been recently mapped by MBMG geologists include the Helena Valley (Stickney, 1987), Bitterroot Valley (Lonn and Sears, 2001), part of the Flathead Valley (Smith, 2000), and part of the Gallatin Valley (Lonn and English, 2002). Work in a few other intemontane valleys is either ongoing or planned. Most of the remaining intemontane valleys have not been mapped in the detail needed for either regional or site-specific hydrogeologic studies. Long-term plans of the MBMG's Statemap geologic mapping project are to map the entire state at 1:100,000; however, most intemontane valleys are proposed to be mapped at 1:24,000 or 1:50,000.

One example of a recent compilation of older 1:24,000 scale geologic maps of unconsolidated surficial sediments is the series of maps that cover the valleys from Bigfork to Avon (compiled at 1:125,000 by Witkind and Weber, 1982). The original open-file reports, which had gone out-of-print, were recently digitized. The previously mapped areas are being revisited as part of the Ground-Water Characterization Program's hydrogeologic studies. The previous mapping will be evaluated and combined with additional data and new interpretation including: textural information on the unconsolidated sediments from previous work; geophysical surveys; water-well inventories; water-quality sample results; and additional field geologic mapping to be done in 2002.

References
Smith, L.N., 2000, Surficial geologic map of the upper Flathead valley (Kalispell valley) area, Flathead County, northwestern Montana: Montana Bureau of Mines and Geology Ground-Water Assessment Atlas 2, Map 6, scale 1:70,000.
Source Water Delineation and Assessment in the Yellowstone River Corridor and other Watersheds in Montana
Joe Meek, Carolyn DeMartino, Jeffery Herick, Perri Phillips May, Jim Stimson, James Swierc, Montana Department of Environmental Quality; jstimson@state.mt.us

ABSTRACT: The source water protection effort in Montana is focused on high priority public water supplies (PWS) within four major watersheds including the Yellowstone River Basin. Highest priority is placed on public water supplies that: 1) serve a population of 1,000 or more, 2) use surface water or ground water under the direct influence of surface water, 3) use ground water from shallow or unconfined aquifers, or 4) have documented exposure to contamination in the last five years. Watersheds divisions for the source water protection program are the same as the TMDL Program. Under the Source Water Protection Program each public water supply will have a completed Source Water Delineation and Assessment Report (SWDAR). Each report includes four major elements or steps:

- **Delineation** - mapping the source water protection areas.
- **Inventory** - an inventory of potential contaminant sources in the delineated area.
- **Hazard and Susceptibility Analysis** – an assessment of the threat or vulnerability of the water supply to each identified contaminant source.
- **Public Notification** – making reports available to the public.

This poster illustrates techniques and procedures used to complete source water assessments for public water supplies using surface water, springs, or ground water. Examples of GIS maps will also show how surface water buffer zones are delineated when hydraulic connection between an aquifer and a surface water body is suspected. Assessments and maps of public water supplies in each of the four basins will be used to illustrate how source water protection delineation and assessment is done in a variety of hydrogeologic settings encountered in Montana.

Riparian Habitat Dynamics and Wildlife along the Upper Yellowstone River
Dr. Andrew Hansen, Dr. Jay Rotella, Lurah P.Klaas, Danielle A. Gryskiewicz, Department of Ecology, MSU; lklaas@montana.edu

**Summary of Project:** We are one of seven research teams involved in an integrated project to collect scientific data to help understand cumulative effects of bank stabilization, natural, and other channel modification on the riparian ecosystem. This study will determine the relationships between riparian habitat dynamics and riparian avifauna, often used as indicators of habitat integrity for wildlife.

We will be addressing the distribution and abundance of individual bird species as well as avian community diversity. This study will take advantage of extensive research that the investigators have conducted on birds and vegetation in the neighboring Gallatin, Madison, and Henry’s Fork watersheds. Statistical models developed for riparian bird species from these previous studies will be used to predict bird species abundance in the entire Upper Yellowstone Study Area. Using field sampled point count data collected over two breeding seasons, we will quantify the accuracy of predictions for the models.

Working closely with the research teams for Riparian Trend and Geomorphology, we hope to understand the influences of channel change, vegetation, and land use on the riparian bird community. Using multiple regression and mixed models we will be able to evaluate the relationships between birds and predictor variables to create species specific habitat functions. Once developed, these habitat functions based on channel and vegetation characteristics will help us predict bird abundance across the study area.
The habitat functions will also serve to assess change in bird abundance using aerial photos from 1948/49 and 1999, based on the change of channel and vegetation characteristics.

Survey of the 130 bird census points as well as vegetation measurements for two field seasons were just successfully completed. Currently we are concentrating on digitizing maps for classification of the riparian areas along the river corridor using aerial photos from 1948/49 and 1999. Data analysis will begin in August 2002 and will continue into the winter of 2002/03. The baseline bird data collected will be presented in a final report to the Governor’s Upper Yellowstone River Task Force and the Army Corps of Engineers in February 2003.

The Oxygen Dependence of the Degradation Rate of Methyl Tert-Butyl Ether by a Bacterial Isolate
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ABSTRACT: Methyl tert-Butyl Ether (MTBE) is a fuel oxygenate added to gasoline to boost octane and reduce emissions of volatile organics, nitrogen oxides, and toxics such as benzene. Bacterial degradation represents a viable means of remediating MTBE that is contaminating the environment. The aerobic degradation of MTBE is catalyzed by the enzyme monooxygenase. This enzyme is dependent upon molecular oxygen. The Michaelis-Menton model is a mathematical model that describes the enzyme-mediated dependence of reaction rate on a given substrate. The Hill model further describes enzyme-mediated reaction kinetics when cooperativity among enzymes has been introduced. This study investigated the behavior of MTBE Degradation rate as a function of dissolved oxygen concentration by a bacterial isolate, PM1. Three experiments were run. In each experiment, batch microcosms containing aqueous nutrient media, MTBE, PM1, and oxygen were monitored over a period of 7 days. MTBE and oxygen concentration were determined at each sampling event. These values were used to correlate MTBE degradation rate to dissolved oxygen concentration. This data was fit to the Michaelis-Menton and Hill models using a non-linear regression algorithm.

This study shows that the biodegradation rate of MTBE by PM1 is highly dependent on dissolved oxygen concentrations, specifically at concentrations of dissolved oxygen below 2 mg/L. This sensitivity to dissolved oxygen concentration may be an important factor to consider in the design and operation of treatment and remediation systems. Furthermore, PM1 was capable of complete mineralization of up to 20 mg/L of MTBE in 7 days with sufficient oxygen present. Both the Hill model and the Michaelis-Menton model represent adequate predictors of the behavior of the data.

Coalbed Methane Potential in the Livingston Coal Field, Montana.
Bowen, D.W., Custer, S.G., Lennon, L., McTeague, M.C., Persio, A.F., Walby C., Earth Sciences, Montana State University; uessc@montana.edu.

ABSTRACT: Coalbed methane has become an important issue between Bozeman and Livingston Montana. The Cretaceous Eagle sandstone has coal and some in the industry believe there is significant potential for methane production from this formation. There is considerable community concern regarding water and methane production from the Eagle. Four students under the direction of two faculty at MSU investigated the potential for coalbed methane in the Livingston Coal Field. A series of 5 posters were prepared which summarize how coalbed methane is formed; why there is coal in the Livingston Coal Field; what the extent of the coal resource is; what structural factors control the availability of coal bed methane in the Livingston Coal Field; what the potential methane gas resource is in the Livingston Coal Field, and what water issues related to coalbed methane development are expected in this area.
A Handlens View of the Hailstone Basin  
Erin Willenburg, Rocky Mountain College

ABSTRACT: Most students pursuing a degree in Geology must complete an undergraduate thesis. As a student from Rocky Mountain College, I was presented with an opportunity to participate in a mentorship sponsored by the American Association of State Geologists with the collaboration of Montana Tech and the Montana Bureau of Mines and Geology. Under the guidance of Jon Reiten, Hydrogeologist, and David Lopez, Geologist, I am working on a small part of the Lake Basin Water Study area called Hailstone Basin.

The immediate area of the Hailstone Wildlife Refuge (approximately 12 square miles) is an area that has previously been mapped by four different individuals at small scales; E. T. Hancock (published in 1918 at a scale of 1:125,000), Edith Wilde and Karen Porter (MBMG Open File in 2001 at a scale of 1:100,000), and David Lopez (MBMG Open File in 2000 at a scale of 1:100,000). However, a more detailed map of the area was needed for further and closer study. My project on the Hailstone Basin focuses on the geologic structure and stratigraphy of that area while also including information on the present day lake level, water wells, and active springs found within my study boundary.

With the mapping complete, Mr. Reiten hopes to be able to further understand questions associated with the water availability and quality in the area. Questions such as:
- How is the geologic structure affecting the ground water?
- How effective of an aquifer is the Eagle sandstone in this highly faulted area?
- How can the variability of the water quality and quantity be explained?
- What is the geologic source of water supplies in the area?

Stream Bank Restoration Method Using Portable Concrete Blocks  
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ABSTRACT: A new stream bank restoration method is currently being tested as an alternative to the use of riprap stabilization. An eroding stream terrace is lowed by excavation to form a sub-irrigated floodplain bench that is planted with willows and sod. Portable pre-cast concrete blocks are placed along the bank to provide temporary protection for the new plantings. After the plantings develop sufficient root mass to protect the bank, the concrete blocks are removed and used at other sites. This alternative may provide a low cost, natural stream bank restoration method that can be used on small to large stream channels. Future research is anticipated to test portable bendway weirs to provide temporary stream bank protection on bioengineered stream banks.
Enhanced Wet Air Oxidation of Sediment and Soil Contaminated with Recalcitrant Organic Compounds
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ABSTRACT: The presence of sediments, soils, and sludges contaminated by recalcitrant organochlorine compounds is a major problem in Montana, across the United States, and worldwide. In Montana and other states, there exists a legacy of soil and sediment contamination resulting from the preservation of wood using creosote and pentachlorophenol. Outside of Montana, many coastal areas of the world have sediment that is contaminated with PAHs and organochlorine compounds including polychlorinated biphenyls (PCBs) and DDT. Slow release of these contaminants to surface and groundwater provides a route for animal and human exposure, and because of the hydrophobic nature of these compounds, they tend to bioaccumulate throughout the food web.

Wet air oxidation (WAO) is a commercial process used to remediate aqueous waste streams containing organic solutes and to regenerate powdered activated carbon (US Filter/Zimpro PACT Process). Fairly simple modifications to commercially available WAO systems would allow for the treatment of excavated sediment and soil with minimal initial processing. However, as determined in several studies, many organochlorine compounds are not effectively degraded by conventional wet oxidation.

The goal of this project is to explore the use of wet air oxidation for the remediation of sediments and soils contaminated with recalcitrant organochlorine compounds, and in particular, polychlorinated biphenyls or PCBs. Bench scale treatment studies are being conducted to elucidate the mechanism for wet air oxidation of PCBs in soil-water slurries. Knowledge of the mechanism will provide information necessary to devise methods to enhance wet air oxidation rates in soil-water slurries.

Assessment of MTBE Biodegradation Potential at a Gasoline Release Site near Ronan, Montana
Richard H. Veeh, Eric A. Kern, Heiko W. Langner, Richard E. Macur, Alfred B. Cunningham, Center for Biofilm Engineering, Montana State University; rick_v@erc.montana.edu

ABSTRACT: Methyl tert-butyl ether (MTBE) is an important fuel oxygenate that has been identified as a widespread point and non-point source contaminant in groundwater. MTBE has been shown to be very mobile and recalcitrant in groundwater systems, thus enhancing concern about associated health risks. Our study was undertaken to assess the potential for bacterial degradation of MTBE as part of the overall natural attenuation that may be occurring at a gasoline release site near Ronan, Montana. Initially, we employed standard batch enrichment techniques to develop an MTBE-degrading culture, using soil collected from the contaminated site as inoculum and added 14C-MTBE and 2-propanol as co-substrates. Several MTBE-degrading bacterial strains were isolated from this mixed culture in the presence of 2-propanol. Subsequently, we identified these bacterial isolates and documented changes in the mixed culture through several successive enrichments. Using molecular techniques including PCR, DGGE, and DNA sequencing, we identified most of the members of the mixed consortium. With MTBE as the sole carbon source, we determined that the isolates obtained initially were apparently declining over time relative to a more robust MTBE-degrading bacterium.
Development of microbial biobarriers for the control of acid rock drainage from mine tailings

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ABSTRACT: Acid rock drainage from hard rock mine lands is a major environmental problem that impacts both ground- and surface water throughout the Western US. Waste rock and mine tailings often contain high concentrations of metal sulfides which, when contacted by oxygen-containing water, leach metals into solution and radically lower the pH of the receiving water. This research sought to further develop an inexpensive and potentially widely applicable treatment technology to utilize indigenous microorganisms within mine tailings to abate ARD at its source. An innovative method to prevent oxygen transport into tailings is the development and maintenance of a biologically active barrier within the near-surface zone of the tailings. This barrier is made up of naturally occurring aerobic and facultative bacteria which utilize dissolved oxygen in the infiltrating water and therefore maintain the reducing conditions which are necessary for pyrite and other metal sulfides to remain bound in mineral form. In addition, the generation of anoxic conditions stimulates the activity of sulfate-reducing bacteria (SRB) within the tailings. SRB produce hydrogen sulfide as a metabolic by-product, which may further react with dissolved metals, promoting their removal as metal-sulfide precipitates. These experiments were performed in laboratory-scale columns filled with acid-producing mine tailings. Objectives for the research were to 1) confirm the ability of nutrient dosing to stimulate indigenous aerobic and facultative bacteria in mine tailings, 2) determine the extent to which effluent dissolved metals can be reduced, and 3) determine the longevity of treatment effectiveness. Bacterial populations, particularly general heterotrophic bacteria and SRB, were stimulated in molasses- and whey-treated columns compared to control columns. Column effluent pH was increased from approximately 3 to over 5 as a result of carbon addition. Effluent aluminum, zinc and copper were reduced in treated columns relative to controls. The effectiveness of whey treatment and molasses treatment was compared. Whey was found to be more effective in reducing effluent pH and stimulating favorable bacterial populations. Molasses treatment enhanced the growth of fungi in some cases, which could have an unfavorable effect on pH and metals in solution.

The Potential for Natural Wetlands to Remediate Copper-Contaminated Water

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ABSTRACT: The purpose of this research was to determine whether natural wetlands have the potential to attenuate metals from metal-rich water. Two small wetlands in Montana (Fisher Creek, near Cooke City, and Copper Gulch, near Jefferson City) were selected based on previous studies, which reported high copper concentrations within the wetland sediments. Field investigations of both wetland sites and a laboratory experiment on Copper Gulch wetland sediment were conducted. Small piezometers were installed in both wetlands for groundwater sampling and for hydrogeological characterization. Representative surface and groundwater samples and soil samples were analyzed for a complete set of water quality parameters. In addition, sequential extractions and SEM-EDX analyses were performed on soil samples to better determine the mineralogical form of metals in the wetland sediments. Field measurements (pH, specific conductivity, redox potential, temperature and alkalinity) were collected at different times throughout the year to map seasonal variations in hydrology and water chemistry.

Results of the field investigations at Fisher Creek show that influent groundwaters are weakly acidic (~pH 6), but nonetheless contain elevated copper concentrations. Although the wetland soils are extremely enriched in Cu (1-2 wt %), dissolved Cu showed no clear evidence of attenuation on the dates sampled. Based on sequential extraction results, a high percentage of this copper is in readily exchangeable or carbonate form. In addition, SEM examination revealed the presence of metallic copper and localized Cu-sulfides (covellite, chalcopyrite). In contrast to Fisher Creek, surface water in the upper part of Copper
Gulch wetland is highly acidic (~ pH 3.2), but improves to ~ pH 5 at the bottom of the wetland. Copper concentrations in the surface water leaving the wetland were reduced by about 50% of the values observed in the upper wetland. Groundwater from piezometers located up gradient of the wetland has pH ~ 5, and contains high copper concentrations (> 1 ppm), whereas groundwater within the wetland itself has much lower levels of copper (<0.01 ppm).

A laboratory experiment was conducted on Copper Gulch wetland sediment to determine if field conditions could be replicated and also to determine to what extent the wetland sediments have the capacity to sorb copper. Experimental results revealed that humic material has a very high capacity to remove and store copper from Cu-enriched water. The pH values of water in the experiment replicated very closely those values observed in the field. Even with numerous applications of 200 ppm copper solution to the wetland sediment, between 84-91% of the added copper was removed from the effluent water in each one-pass cycle.

Hydrogeochemistry of a Wetland Receiving Acid Mine Drainage, Ontario Mine, Powell County, Montana
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ABSTRACT: The Ontario Mine site, number 93 on the state priority cleanup list, is located in the Helena National Forest, south of Elliston, Montana. A large (5 acre), natural wetland down gradient from the Ontario Mine is being impacted by acid mine drainage from two adit seeps. The influent water has a low pH (3 to 3.5) and concentrations of several metals far above Montana regulatory standards. After flowing through the wetland, the affected water joins Ontario Creek, a tributary to the Little Blackfoot River. Extensive reclamation of the site is scheduled for the summer of 2002. This will mainly entail removal of tailings and waste rock from the Ontario Mine. Because a site investigation report completed in 2001 stated that the quality of surface water improved as it passes through the wetland, an effort will be made not to disturb the wetland during these activities.

Objectives of this project are to conduct pre-reclamation and post-reclamation surface water sampling, to examine the influence of groundwater on surface water quality, and to evaluate the fate and transport of metals through the Ontario wetland. Complete samplings of surface water above, within, and below the wetland were conducted in September 2001 (base flow) and May 2002 (high water). These sample sets show that the wetland is removing aluminum (Al) and iron (Fe). Most of the other metals of interest in this study (Cd, Cu, Mn, Ni, Zn) show no significant increase or decrease for both samplings. However, in both cases, dissolved lead (Pb) was shown to increase through the wetland. Soil samples are being collected from different locations within the wetland. These will be analyzed by a sequential extraction procedure to determine the speciation of lead and other metals of concern, and whether these metals are in a readily exchangeable form. A 24-hour sampling of the surface water showed a possible diurnal cycle of Fe\(^{2+}\) and total dissolved Fe, with both parameters increasing during the middle of the day due to photo-reduction.

Above the wetland, groundwater has a chemistry similar to the surface flow, with a low pH (< 4.0), high metal content, and a moderately high Eh. However, as groundwater moves through the wetland, pH increases (> 5) and Eh decreases. Some of the groundwaters sampled had a distinct odor of H\(_2\)S, indicating that bacterial sulfate reduction was occurring. With the exception of As and Fe, metal concentrations in groundwater within the wetland were much lower than above the wetland. An increase in dissolved As and Fe is explained by bacterial reduction within the organic-rich soils. Due to the very low hydraulic conductivity of the wetland soils, groundwater inputs probably play a very minor role in the chemistry of surface water draining the wetland.
Diel Variations in Dissolved Trace-Element Concentrations in Streams Draining Abandoned Mine Lands
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ABSTRACT: Substantial diel (24-hour) variations in dissolved trace-element concentrations have been measured during 20 different hourly sampling episodes at 16 sites on 13 streams draining historical mining areas in Montana and Idaho. At all sites, concentrations of dissolved (0.1-µm filtration) Cd, Mn, and Zn increased during the night, reaching maximum values shortly after sunrise; concentrations then decreased to minimum values during mid to late afternoon. Dissolved As concentrations exhibited the opposite temporal pattern, while variations in dissolved Cu concentrations were small and displayed no consistent pattern. Most sites were sampled during low-flow conditions, but two sampling episodes during snowmelt runoff at one site showed that similar diel variations occur during high flow. All sites had near-neutral to slightly alkaline pH. Diel variations did not occur in two other acidic (pH of 3.7-5.3) streams.

The magnitude of change during diel concentration cycles varied for each trace element. Zn and Mn concentrations exhibited the largest variation, with maximum concentrations ranging from 120 to 590 percent of minimum concentrations. Cd maximum concentrations were about 200 percent higher than minimum concentrations, whereas As maximum concentrations were 115 to 155 percent higher. Diel trace-element cycles appear to be independent of concentration magnitude, occurring over a wide range of concentrations: 5-44 µg/L As; 1-7 µg/L Cd, 18-1,500 µg/L Mn, and 2-4,940 µg/L Zn.

Several chemical, physical, and biological processes potentially can explain diel dissolved-trace-element cycles. Temperature- and pH-dependent sorption reactions occurring on streambed material in the channel and hyporheic zone are considered the most likely mechanisms because of the strong similarity in the symmetry and magnitude of temporal plots of concentration, temperature, and pH. In addition, sorption processes can explain the simultaneous decrease in divalent metal concentrations during the day (when pH and temperature increase) and increase in anion concentrations such as arsenate. Many sorption studies have documented the importance of pH, but the role of temperature has been largely overlooked.

Diel cycles are robust and reproducible and are sufficiently widespread and of sufficient magnitude that our understanding of trace-element mobility needs reconsideration. Consequently, diel cycles are a very important consideration when developing or interpreting trace-element studies designed to identify trace-element sources, long-term trends, or effectiveness of remediation activities.

Relative Effect of pH and Temperature on Diel Metal and Arsenic Cycling in Prickly Pear Creek
Clain A. Jones, Montana State University, David A. Nimick, and R. Blaine McCleskey, U.S. Geological Survey; clainj@montana.edu

ABSTRACT: Diel cycles in dissolved metal and arsenic concentrations have been documented in several Rocky Mountain streams. The cause(s) of the variation are unknown, yet temperature and pH-dependent sorption reactions have been cited as likely causes. A light/dark experiment was conducted to isolate temperature and pH as variables in Prickly Pear Creek, Montana. Light and dark chambers that contained a sediment layer were placed in the stream to simulate natural temperature oscillations, while photosynthesis-induced pH changes were prevented in the dark chambers. Water samples were collected simultaneously from both chambers and the stream in late July 2001. Dissolved Zn concentrations in the stream increased by 300% from late afternoon to early morning. The diel pattern for As was inverse the
pattern for Zn, but the variation was less, increasing approximately 50% from early morning to late afternoon. Concentrations of Zn and As in the light chambers showed similar variations as in the stream. Conversely, dissolved Zn and As concentrations in the dark chambers showed no obvious diel variation, indicating that light directly, or indirectly, caused the variation. As expected, pH was negatively correlated (P<0.001) with dissolved Zn concentrations in both the light and dark chambers. Temperature was not significantly correlated with dissolved Zn concentrations in the light chambers, yet was positively correlated with dissolved Zn concentrations in the dark chambers, which could not account for the minimum stream Zn concentrations occurring in the afternoon. In summary, photosynthesis-induced pH changes were determined to be the major cause of the diel dissolved Zn and As cycles in Prickly Pear Creek; yet further research is necessary in other streams to verify this finding because of large differences in both Zn and As concentrations and mineralogy of channel substrate among streams.

Diel Zinc Cycling and Groundwater-Surface Water Interactions at High Ore Creek in Basin, Montana
Christopher L. Shope, Ying Xie, Christopher H. Gammons, Montana Tech of the University of Montana; clshope@yahoo.com

ABSTRACT: In May 2002, the Montana Tech Field Hydrogeology class completed a wide variety of field experiments at High Ore Creek: a small, metal-contaminated creek located near Basin, Montana. A series of tasks were determined to fully characterize the hydrogeochemistry of surface water and groundwater in the watershed, and also to help explain observed patterns in diel (24 hour) cycling of zinc. The specific tasks included detailed synoptic sampling events in several reaches of High Ore Creek as well as a complete synoptic sampling event simultaneously initiated at the headwaters and the mouth. The field camp also installed several minipiezometers and groundwater monitoring wells and conducted a 4-hour pumping test. The students completed several metal loading mass balances, streamflow gauging throughout the length of the creek, flume installation and 24hr sampling of surface water at 2 locations.

Detailed synoptic analysis suggests that groundwater discharge in seeps near the abandoned and recently reclaimed Comet Mine site is likely the primary source of zinc loading to High Ore Creek. This is also one of two locations in which the stream appears to be gaining. Slightly downgradient of two man-made settling ponds, the creek becomes losing (or perched) for most of its length until immediately above its confluence with the Boulder River. To explain this fact despite being in a steep-sided valley, we hypothesize that the creek is underlain by a highly conductive sub-stream channel that represents the former High Ore Creek channel prior to remedial efforts. Groundwater in this sub-stream channel is also highly contaminated with zinc. However, because the buried channel is limited in depth and aerial extent, the total mass of Zn passing down the sub-stream channel is insignificant compared to the surface water Zn flux.

Although the creek is losing or perched through most of its length, 24 hour-averaged zinc loadings increase gradually in the middle and lower reaches. Algal biofilm samples collected along the creek were found to contain up to 2.6 wt% Zn, and may act a substantial sink or source for exchangeable zinc. In addition, SEM and chemical analysis of crusts from the bottoms of submerged boulders have indicated the widespread presence of poorly crystalline Zn-Mn oxides. At the same time, poorly crystalline Fe-oxyhydroxide crusts have formed on the top surface of the submerged boulders. It is postulated that desorption and/or dissolution of Zn compounds from these contaminated biological and mineralogical substrates is responsible for additional Zn loadings as water makes its way down the un-claimed portions of the creek. This process is complicated by a strong cyclic (diel) pattern in which dissolved Zn concentrations decrease during the day and increase at night. Previous studies have documented this pattern in High Ore Creek, as well as other polluted streams and rivers in Montana (Nimick et al., 2000). Recent laboratory experiments (Xie, 2002) have shown that Zn concentrations in High Ore Creek water
equilibrated with High Ore Creek bed sediment and biofilm are highly sensitive to small changes in pH and temperature. These changes are most likely due to pH- and T-sensitive sorption and/or mineral solubility reactions on organic and inorganic crusts. Present experiments are considering the effects of redox changes on dissolution of the Mn-oxide crusts and its potential for remobilization of trace metals.

References

Hydrological, Geochemical, and Biological Factors on Silica Deposition in a Hot Spring Fed Creek in Yellowstone National Park
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**ABSTRACT:** Rabbit Creek is located five miles north of Old Faithful in the Midway Geyser Basin, Yellowstone National Park. The siliceous hot spring fed creek discharges less than one cubic meter per second and contains cyanobacterial mats that grow along its edges. Mineral precipitates line the channel in Rabbit Creek. This research examines the processes controlling channel lining.

The mineral precipitates have been analyzed by x-ray diffraction and petrographic microscopy. The precipitates are mostly X-ray amorphous. Crystalline phases include quartz, cristobalite, and tridymite. Silica is observed to precipitate onto the microbial mats. Petrographic study revealed alternating microbial and silica layers. Silica precipitates abiotically only if there is an over-saturated silica solution. Silica precipitates biotically on and within the cyanobacteria mats at concentrations that are under-saturated with respect to silica.

Scanning electron microscopy revealed that silica and iron had precipitated out of solution onto an artificial substrate installed in the creek bed. The silica precipitation is attributed to the over-saturated conditions in the creek during the short period around January. The iron is thought to be a result of groundwater input from the meadow. The reduced iron oxidized quickly once discharged into the creek.

Sodium and chloride concentrations, sampled from shallow piezometers, have increased by several hundred ppm. The ferrous and total iron ratios increased during the winter season. The iron concentrations have increased by several mg/L (from not detectable to over 7 mg/L in one piezometer) throughout the winter season. Other cations also increased during the winter but not to the extent of iron. The latest sampling round in June measured iron concentrations of 1 mg/L or lower. The only detectable iron in the creek is below a meadow area. Thus, shallow groundwater is probably a secondary geochemical source to the creek channel mineral deposits.
Effects of Radio Transmitter Weight on Swimming Stamina of Telemetered Westslope Cutthroat Trout
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ABSTRACT: We empirically determined the relationship between radio transmitter weight and swimming stamina in telemetered westslope cutthroat trout in the laboratory to facilitate field studies of movements and behavior of this rare native fish. Telemetry studies of small fish are limited primarily by transmitter battery life, which is a function of battery weight. Untested dogma holds that transmitter weight should not exceed 2% of the total body weight of a telemetered fish. We found that telemetry transmitters comprising up to about 4% of total body weight do not substantially affect swimming stamina of westslope cutthroat trout. Researchers can therefore double the size of transmitters recommended by the old “2% rule-of-thumb” without significantly impairing physiological performance of telemetered fish.