Program and Abstracts for the 72nd Annual Meeting, Rocky Mountain Hydrologic Research

Center

Friday, 1 December 2017: 9 a.m. to 2:45 p.m.

Sustainability, Energy and Environment Community (SEEC), 4001 Discovery Drive

(https://seec.colorado.edu)

Sievers Conference Room, Room S228

University of Colorado, Boulder, Colorado

Registration fees: $20 for professionals, payable at the meeting, and free for students. This is also a good time to renew your RMHRC membership for $20 per year.

Rocky Mountain Hydrologic Research Center

The forerunner of the Rocky Mountain Hydrologic Research Center was the Rocky Mountain Hydraulic Laboratory organized under the laws of the State of Colorado on September 5, 1945. Chesley Posey found a site for the laboratory on the North St. Vrain Creek below Highway 7 near Allenspark, Colorado. At this 20-acre site alongside the North St. Vrain Creek, several hydraulic flumes were constructed and portions of those flumes can be seen today. Research was focused on bridge scour and open channel hydraulics. About 1960, the hydraulic research activity declined but the site has been used for more diverse research in recent years.

In 1991, the name was changed to the Rocky Mountain Hydrologic Research Center to reflect new research goals of conducting a broad range of hydrologic and environmental science investigations in this headwater area of the Rocky Mountains. The site has had little disturbance in the last 50 years. The site is still available for research and anyone interested need only contact any one of the Trustees of the Rocky Mountain Hydrologic Research Center listed below.

The purpose of the Center is to:

Maintain scientific research facilities in a natural mountain watershed.
Provide a forum for exchange of ideas.
Provide an opportunity for interaction among university faculty, students, and other researchers.
Enhance cooperative research and scientific collaboration.
Assist students and scientists in development of research and study support.

NOTE: Any interested person can become a member of the Rocky Mountain Hydrologic Research Center

Cover: Cement Creek in Silverton, Colorado, Sept. 20, 1998.

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SCHEDULE

9:00 – 9:30 am	Registration and refreshments
9:30 – 9:40 am	Welcome and address from President Glenn Patterson
9:40 – 10:05 am	**Peter Goble**, *A reflection on the Water Year of 2017*
10:05 – 10:30 am	**Katie Walton-Day**, *The August 2015 Gold King Mine release in the context of previous geologic and water-quality studies*
10:30 – 10:40 am	Break
10:40 – 11:05 am	**Rob Runkel**, *Water quality of the upper Animas River*
11:05 – 11:30 am	**Keith Musselman**, *Large projected increases in rain-on-snow potential over western North America*
11:30 – 11:55 am	**Qinghuan Zhang**, *Multi-scale streamflow simulations under future climate scenarios in the Rocky Mountains, USA*
11:55 am – 1:00 pm	Lunch
1:00 – 1:25 pm	**Kristin Bunte**, *Downstream path of gravel bedload transport in mountain streams*
1:25 – 1:50 pm	**Kate Campbell**, *Biogeochemistry of uranium in-situ recovery (ISR) mines: ore deposition, mining, and remediation*
1:50 – 2:15 pm	**Robert Milhous**, *Streamflow variation in the Poudre River*
2:15 – 2:20 pm	Closing remarks
2:20 – 3:00 pm	Board of Trustees Meeting
3:00 – 3:25 pm	Travel from SEEC (east campus) to main campus, (Guggenheim Geography, room 205; see http://www.colorado.edu/map/)
3:30 – 4:30 pm	Geography Department Colloquium – Stephanie Kampf, *Mountain hydrogeography: Streamflow patterns and processes across the Rockies*

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A Reflection on the Water Year of 2017

Peter Goble

Colorado Climate Center

Tracking deviations in Colorado's weather and water balance remains both an imperative and fascinating subject of study. In this presentation, we'll take a look back at the weather and water patterns from Water Year (WY) 2017 in Colorado. Focal points are as follows:

1. We'll dissect the WY's temperature, precipitation, snowpack, streamflow, and water supply/demand patterns.
2. Anomalous events such as the slow start to WY 2017's snowpack season, the snow onslaught of late December and early January, the high rain totals for southeast Colorado in spring and summer, and the budding drought on the west slopes will be reviewed and placed in a climate context.
3. WY 2017's place in the grand scheme of long-term climate change and climate variability will be discussed.
4. Droughts and floods are historically the costliest natural disasters in the state of Colorado. Thankfully, impacts from droughts and floods were relatively benign in WY 2017, but we did not escape the year unscathed by natural disaster. Late spring cold snaps took a toll on farming and ranching. The most costly hailstorm in Colorado history hit west Denver and Lakewood. These impacts and others on our lives and economy will be considered.

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The August 2015 Gold King Mine Release in the Context of Previous Geologic and Water-Quality Studies

Dr. Katie Walton-Day - USGS Colorado Water Science Center

In the late 1990s through early 2000s the U.S. Geological Survey (USGS) completed a watershed study in the upper Animas River watershed that provides geologic, geochemical, geophysical and biological background to interpret (1) the effects of the 2015 accidental release of 3 million gallons of metal-rich sediment and water from the Gold King Mine located on the north fork of Cement Creek, and (2) the effects of the last 15 years of remediation. The watershed comprises the headwaters of the upper Animas River, Cement Creek, and Mineral Creek, which join near the town of Silverton, Colorado. Historical mining occurred from the 1870s through the early 1990s, and left a legacy of abandoned mines and mine waste that degrade water quality. However, this mining occurred in a watershed where extensive hydrothermal alteration of the original geologic units helped create the economic mineral deposits, but also created non-highly mineralized, pyrite-rich rock that produces acid-rock drainage when weathered. Water quality in Cement Creek and lower Mineral Creek were likely degraded from acid-rock drainage prior to mining. USGS studies helped identify remediation targets, but occurred when placement of bulkheads to remediate mine drainage in the American Tunnel was ongoing. A series of bulkheads installed beginning in 1996 altered groundwater flow patterns in the area, and groundwater discharge rerouted to up-gradient abandoned mine tunnels. This change in the hydrologic regime underscores the need for re-evaluation of major sources of water-quality degradation in the upper parts of the watershed and re-evaluation and prioritization of remediation targets.

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Water Quality of the Upper Animas River

Rob Runkel – USGS Colorado Water Science Center

The August 2015 Gold King Mine release sent 3 million gallons of acidic, metal-rich water flowing down Cement Creek and the Animas River in southern Colorado, creating an orange plume of contamination that extended into the San Juan River in northern New Mexico. This unfortunate incident has refocused attention on the Silverton Colorado area, where mining activities dating back to the 1800s have adversely affected water quality in the upper Animas River, Cement Creek, and Mineral Creek. This presentation describes instream water quality in the Silverton area before, during, and after the Gold King Mine Release, with emphasis on the predominant sources of contamination, as well as the fate and transport processes that affect metals as they move downstream.

Water quality prior to the release is described using data from an October 2012 synoptic study that provides spatially detailed profiles of streamflow, concentration, and metal load. Results of the 2012 study indicate that concentrations of aluminum, cadmium, and zinc exceeded chronic aquatic life standards over the entire length of the study reach. Spatial profiles of metal load indicate specific source areas for various metals. The Red and Bonita Mine on Cement Creek, for example, accounts for nearly 20% of the zinc loading within the study reach. Further, the North Fork of Cement Creek, which includes drainage from the Gold King Mine, accounts for 40% of the copper load, and Mineral Creek accounts for over 40% of the aluminum load.

Water-quality samples collected at the mouth of Cement Creek during the second week of the release document increases in aluminum, copper, and other metal loads when compared to historical data collected under similar low-flow conditions. Metals transported from the Silverton area are subject to pH-dependent reactions (precipitation and sorption) that transform metals from the dissolved phase to colloidal particles as pH increases. These colloids aggregate and settle to the streambed, which can lead to elevated metal concentrations in the sediment. Bed sediment samples collected after the release suggest increased concentrations of arsenic, copper, and vanadium when compared to data collected prior to the release. Sediment concentrations of several other constituents were relatively unchanged or lower following the release, suggesting that the effects of the release on overall sediment quality may be minimal, relative to historic conditions. The quantity of contaminated sediments has likely increased, however, and additional monitoring may be needed to assess the effects on aquatic life, irrigation and water-supply infrastructure, and recreational resources.

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Large Projected Increases in Rain-On-Snow Flood Potential Over Western North America

Keith Musselman, Kyoko Ikeda, Mike Barlage, Flavio Lehner, Changhai Liu, Andrew Newman, Andreas Prein, Martyn Clark, and Roy Rasmussen

In the Mountain West, some of the largest annual flood events occur when warm storm systems drop substantial rainfall on extensive snow-cover. Assessing how rain-on-snow (ROS) events may respond to climate change over large, mountainous regions is challenging. It requires resolving precipitation patterns and magnitude, freezing level heights, snowpack development and the snow energy balance over large elevation gradients for both historic and future climate conditions. We present an analysis of ROS events with flood-generating potential over western North America simulated at high-resolution by the Weather Research and Forecasting (WRF) model run for both a 13-year control period and re-run with a 'business-as-usual' future climate scenario. Daily ROS with the potential to generate floods is defined as rainfall of at least 10 mm falling on snowpack of at least 10 mm, when the sum of rainfall and snowmelt contains at least 20% snowmelt. In a warmer climate, ROS is less frequent in regions where it is historically common and more frequent elsewhere. This is evidenced by large declines in total ROS volume (rainfall + snowmelt) of 20% to >50% particularly in warmer regions and at lower elevations. Conversely, ROS volume increases by 15% to 55% in the High Sierra Nevada, much of the Colorado River basin, and parts of western Canada. Despite local declines in ROS frequency and runoff volume, the intensity of extreme ROS events is projected to greatly increase across much of western North America. Increases in extreme ROS events of 30% to >300% are projected for historically flood-prone mountain river basins in the Rocky Mountains, the Sierra Nevada, the Cascades, and British Columbia. Increases in extreme ROS event intensity, coupled with a greater proportion of precipitation falling as rain, have critical implications on the climate resilience of regional flood control systems.

Multi-scale Streamflow Simulations Under Future Climate Scenarios in the Rocky Mountains, USA

Qinghuan Zhang[1,2], Ben Livneh[3,4], John F. Knowles[2,5], Andrew Badger[3], and Noah Molotch[1,2]

[1]Department of Geography, University of Colorado Boulder, Boulder, CO
[2]Institute of Arctic and Alpine Research, Boulder, CO
[3]Cooperative Institute for Research in Environmental Sciences, Boulder, CO
[4]Department of Civil and Engineering, Boulder, CO
[5]School of Geography and Development, University of Arizona, Tucson, AZ

Hydrologic models can improve our understanding of land surface water and energy budgets in mountainous watersheds that are characterized by complex geological features and climatic variability. In this study, a distributed physically-based hydrologic model was applied to the Boulder Creek Watershed (102 km^2) and to the Upper Colorado River Basin (105 km^2), USA to investigate the influence of predicted climatic change on streamflow conditions across a range of spatio-temporal scales. The hydrologic model was applied at both 1/8° and 1/16° spatial resolutions and two statistical downscaling approaches were compared. In the Boulder Creek Watershed simulations, average annual precipitation and air temperature were significantly higher in both 2050 and 2080 compared to the historical average. Annual streamflow showed different trends and magnitudes at the two spatial resolutions, with up to 15.5% decrease at 1/8° and 1% increase at 1/16°. In the Upper Colorado River Basin, streamflow generally increased during the spring and decreased during the summer seasons. Annually, streamflow was found to decrease in Dolores and San Juan basins, but to increase in all other basins at the subregion (HUC 4) scale. This work suggests that the choice of a particular climate model has the highest impact on streamflow predictions, downscaling method and spatial scale have an intermediate impact, and parameter uncertainties have the least impact on future streamflow simulations. This study provides insights for hydrologic management techniques in complex mountain terrain within the context of future climatic uncertainty.

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Downstream Path of Gravel Bedload Transport in Mountain Streams

Kristin Bunte[1] (970-491-3980; kbunte@engr.colostate.edu), Kurt W Swingle[2], Steven R Abt[1], Rob Ettema[1], and Dan Cenderelli[3]

[1]Engineering Research Center, Colorado State University, Fort Collins, CO 80523; [2]Boulder, CO.; [3]USFS, National Stream and Aquatic Ecology Center, Fort Collins.

Spatial dynamics of gravel transport in coarse-bedded mountain streams are not well known. Bedload transport measurements in sand-bedded meandering streams have shown that fine sand and pea gravel follow two distinctly different downstream paths: Fine sand takes a meandering path along the outside bend and then diagonally across the stream onto the bar tail. By contrast, pea gravel moves diagonally from the head of a point bar down into the thalweg, following the local cross-channel gradient. The path then crosses the thalweg in the pool exit and proceeds straight to the next bar head.

However, little is known about the downstream path taken by coarse gravel in coarse-bedded mountain streams. Open gravel bars are typically sparse in those streams, and the channel course is straight or sinuous rather than meandering. Nevertheless, those streams have a thalweg that meanders between faintly developed, submerged bars. To investigate gravel transport paths in those streams, the lateral distribution of gravel transport was measured by sampling gravel bedload with 4-6 bedload traps in nine individual cross-sections of various gravel/cobble-bed streams. Each of these cross-sections typified a different position along a meandering thalweg within an idealized stream reach, and taken together, the nine individual cross-sections covered two meander bends.

In asymmetrical cross-sections over the gentle slope of a bar head through the thalweg and steep bank on the other side, most gravel traveled over the bar. Across a pool exit transect, most gravel traveled near the thalweg, while transport over a riffle transect was laterally focused toward the side of the stream at which the next downstream bar appears. By joining the individual lateral transport foci in the combined results from the individual field studies, a downstream gravel transport path emerged that indicated that gravel transport in coarse-bedded mountain streams with a meandering thalweg follows the same pattern as the transport of pea gravel in sand-bedded streams.

Knowing the gravel transport path can help sampling bedload in streams that have become unwadeable at high flow: Considering that most gravel transport passes a bar head—where flow depth is relatively low—most of the cross-sectional gravel transport can still be sampled over the bar head when other parts of the channel have become unwadeable.

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Biogeochemistry of Uranium In-situ Recovery (ISR)
Mines: Ore Deposition, Mining, and Remediation

Kate Campbell – USGS Geology, Geophysics, and Geochemistry Science Center, Denver CO 80225

Sandstone-hosted roll-front uranium (U) deposits are economically important for *in situ* recovery (ISR) mining, a solution mining technique that oxidizes U(IV) ore minerals to soluble U(VI) by injecting a leach solution into the subsurface. Detailed understanding of relevant biogeochemistry before and after mining is key to site management; a more thorough characterization of the ore deposit composition and surrounding aquifer before mining can enhance the efficiency of extraction, and an effective remediation strategy depends upon aquifer chemistry and mineralogical composition after mining. Solution mining perturbs the aquifer with the addition of CO_2 and O_2 to the groundwater, creating oxidizing conditions. At some ISR sites, additional remediation is necessary to restore the aquifer to pre-mining background conditions, and *in situ* options are often considered, given the infrastructure available. Bioremediation, chemical amendments, or combined treatments are currently being evaluated for efficacy at ISR sites. Biologically-driven uranium reduction has been explored for *in situ* bioremediation of contaminated aquifers, and a similar process may naturally occur during ore deposition. Recent advances in spectroscopy, isotope chemistry, and DNA analysis have helped to resolve the forms of U(IV) in a roll-front deposit in Wyoming, with evidence for biogenic, non-crystalline U(IV) in addition to crystalline uraninite (UO_2). Characterization of the remaining aquifer materials post-mining indicated that uranium remaining in the subsurface is associated with clays, organic matter, and relict ore material, demonstrating that uranium oxidation is incomplete. This result suggests that subsurface heterogeneity may be an important factor in persistent U(VI) release to the groundwater after cessation of active mining.

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Streamflow Variation in Poudre River

Robert T Milhous

The Cache la Poudre (Poudre) River has a history of high streamflow variation sometimes caused by natural factors but mostly caused by many diversions from the river and discharges to the river. Two topics are addressed in this presentation. The first topic is to develop an understanding of the causes of the high variation and the second is to quantify the high variation indexes that allow comparison of rivers, differences between locations on the same river, and changes from year to year. This presentation mostly deals with the second topic. The variation of streamflows at a gage at the mouth of Poudre Canyon has been used as somewhat representative of 'natural' flows. This presentation shows that this assumption is useful but not quite true because of storage and releases of water from reservoirs in the basin, at least one major diversion from the river, and transfer of water from adjacent basins to the Poudre Basin. The second topic, variation indexes, is presented by using two indexes to flashiness. One is the Richards-Baker Flashiness Index – a measure of the average change in discharge between days to the average discharge. The second index is a Flashiness Index that is a measure of the average daily fractional change in discharge. As an example, the Flashiness Index variation along the river during water year 2010 was 0.13 at the canyon mouth, downstream at Fort Collins 0.23 and further downstream above Boxelder Creek 0.23. The index on a nearby river with no diversions and storage was 0.10. The limit of the index is 0.0 (no change) and 2.0 (total loss and gain between days).

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Tracking the Fate of Sediment After an Extreme Flood

(Poster)

Eidmann, Johanna S., Rathburn Sara L., and Huson, Ken

Assessing the ongoing sediment remobilization and deposition following an extreme flood is important for understanding disturbance response and recovery, and for addressing the challenges to water resource management. From September 9-15, 2013, a tropical storm generated over 350 mm of precipitation across the Colorado Front Range. The resulting 200-year flood triggered landslides and extreme channel erosion along North St. Vrain Creek that feeds Ralph Price Reservoir, an important water supply for the Cities of Lyons and Longmont, CO. The flood resulted in 10 m of aggradation upstream of the reservoir, transforming the inlet into an approach channel. Four years after the flood, downstream transport of flood sediment and deposition in the reservoir continues. This research tracks the fate of flood-derived sediment to understand the evolution and progradation of the delta as well as to inform reservoir management practices. Bathymetric DEM differencing from April 2014, April 2016, May 2017 and August 2017 (years 1, 2, 3 and 4 post-flood, respectively) demonstrates a constant rate of delta progradation of ~50 m per year since 2014. Between April 2016 and May 2017, the reservoir level was dropped approximately 10 m during reconstruction at the spillway. Despite the change in base level, year 4 pre-snowmelt runoff measurements indicate that the rate of progradation has remained comparable to the two years following the flood. Assuming that most sediment is transported during snowmelt runoff, year 4 post-snowmelt runoff bathymetry suggests a decline in progradation rate. However, an additional bathymetric survey in spring 2018 is needed to confirm this interpretation. Bathymetric differencing further indicates net deposition of 67,000 m^3 over 14,000 m^2 (an area covering 94% of the 2017 delta and common to all surveys) of the inlet between years 1 and 3. The drop in base level associated with the lower reservoir level (years 3 to 4) produced visible incision and erosion of 16,000 m^3 and deposited 6,000 m^3 of sediment over the same area. Future analysis of Structure-from-Motion differencing of the approach channel, analysis of sediment thicknesses in reservoir cores, and morphodynamic modeling using measured discharge values will further quantify the post-flood sediment budget. Grain size, loss on ignition, and XRF analyses of cores collected from the delta will additionally enhance our understanding of stratigraphic changes and delta progradation within the reservoir.

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Effects of Precipitation Type on Streamflow Efficiency at Critical Zone Observatories in the Western United States

Kate Hale – (Katherine.E.Hale@colorado.edu), MA Student, CU Geography Department and Mountain Hydrology Lab group

Advisor: Dr. Noah Molotch (noah.molotch@colorado.edu)

Annual snowpack within mountainous regions in the Western United States serves as an essential hydrologic resource for downstream communities. Acting as a reservoir throughout the year, the local snowpack of an area dictates water availability and strongly influences ecological processes. Across seasons, these areas experience shifts from rain to snow and vice versa throughout the shoulder seasons of fall and spring. Yet with changing atmospheric temperatures and increased net radiation, we expect these shoulder seasons will shift to incorporate more rain later in the fall and earlier in the spring. We know that downstream annual water availability changes as a result of precipitation amount, but the water availability changes due to precipitation form, rain to snow, is less understood. The effects of rain and snow transitions have been analyzed at a larger scale using the Budyko Curve framework and mechanistic modeling: suggesting that there is greater streamflow efficiency, the quantity of precipitation seen downstream, with greater annual snowfall. The effects of rain and snow transitions on small scale, mountainous catchments remain to be discovered. Utilizing Boulder Creek (CO) and Reynolds Creek (ID) Critical Zone Observatory catchment data to drive the Distributed Hydrology Soil and Vegetation Model (DHSVM), we assess streamflow efficiency across a range of annual snow fractions. Using observed streamflow data, local meteorological data and national soil and vegetation data at a 20-meter resolution, we manipulate the amount of annual rain and snow via model-based scenarios within a given catchment.

By changing snow fraction we explore the catchment response to precipitation type and the streamflow efficiency downstream. Any response in streamflow efficiency to precipitation type provides large implications for water resources and management on both a small and large scale across these mountainous regions.