Program and Abstracts
for the
71st Annual Meeting
of the
Rocky Mountain Hydrologic Research Center

18 November 2016
Lory Student Center, Room 372
Colorado State University
Fort Collins, Colorado
9:00 a.m.—3:30 p.m.

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: Colorado River below Eagle, Colorado

Schedule

9:00--9:20	Registration
9:20--9:30	**Glenn Patterson**: President, Opening Remarks
9:30--9:55	**Peter Goble**: Colorado Water Year 2016 Review
10:00—10:25	**Cibi Vishnu Chinnasamy**: Analysis of free river in South Platte River for groundwater modeling in alluvial aquifer storage and recovery system
10:30—10:55	**Robert Milhous**: Effective discharges for Cache la Poudre River
11:00—11:25	**Ed Kempena**: Ice-related, winter flooding of Flat Cree, Jackson, Wyoming
11:30--11:55	POSTER, **Ben Wise**: Effects of acid mine drainage on the community composition of denitrifying bacteria
12:00--13:00	LUNCH
13:00—13:25	**Paul Schuster**: The potential release of mercury currently stored in permafrost
13:30—13:55	**Jonathan Friedman**: Climate and flow variation revealed in tree rings of riparian cottonwoods, norther Great Plains, USA
14:00—14:25	**Eleanor Griffin**: Observation of decreased runoff response to precipitation, Little Missouri River Basin, norther Great Plains, USA
14:30—14:55	**Kristin Bunte**: Estimate of gravel transport rates at bankfull flow in mountain streams
15:00—15:25	**Glenn Patterson**: Trends in snow water equivalent in Rocky Mountain National Park and the northern Front Range
15:30—17:00	Annual Meeting of Trustees

Colorado Water Year 2016 Review

Colorado Climate Center Staff: Nolan Doesken, Becky Bolinger, Zach Schwalbe, Noah Newman, and Peter Goble

Presenter: Peter Goble

Colorado's mid-latitude, high-elevation, intercontinental climate lends itself to a great deal of climate variability from year-to-year. As a result, the progression of water balance both state-wide, and as a function of river basin through the 12-month period from October-September is often fascinating. In this study, the Colorado Climate Center recaps the water year of 2016. Temperature, precipitation, snowpack, streamflow, water storage, soil and vegetation condition, and evaporative demand during 2016 were compared to climate averages for major river basins across the state of Colorado. The highlights of the 2016 water year that will be explored in this presentation are included but not limited to the following: 2016 saw a warmer but wetter than average start to the water year across the state. There was a concerning mid-season lull in snowpack across the mountains, particularly in southern Colorado. Above average moisture conditions returned in the spring of 2016, which lead to a relaxing start to the warm season from both a water supply and evaporative demand perspective. In June and July of 2016 the Front Range dried out while thunderstorms continued to bring above average moisture to the eastern plains. Monsoonal moisture was above average in southern and western Colorado through the month of August, but the eastern plains began to dry out. During September warm, persistent high pressure moved over Colorado and sparked the genesis of what is now a young, but increasingly severe state-wide drought.

Analysis of Free River in South Platte River for Groundwater Modeling in Alluvial Aquifer Storage and Recovery System

Cibi Vishnu Chinnasamy*, William C. McIntyre and David C. Mays

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Climate change is causing water managers to reassess water storage. In Colorado, the era of large above-ground dams and reservoirs is probably over, due to environmental and endangered species concerns. In this context, an alluvial aquifer storage and recovery (ASR) system presents an alternative option for water storage. A recent study estimated approximately 12 km^3 (10 million acre-feet) of storage may be possible in the South Platte River alluvium of northeast Colorado. To investigate this option, this presentation provides a brief overview presenting preliminary simulations of clogging, soil matrix stability, consolidation, and aquifer recharge times that indicate the feasibility of alluvial ASR system. An alluvial ASR site near U.S. Highway 7 at Brighton, Colorado with a storage capacity of 148,200 m^3 (110 ac-ft) was considered for this study. Analyzing data from the Colorado State Engineer's office confirms the availability of water during free river conditions to fill the proposed alluvial ASR facility in compliance with Colorado's water laws. This suggests that alluvial ASR facilities could be a viable option to meet rising water demands of Colorado, prevent water loss due to evaporation, and reduce the effect of climate change on water resources.

Effective discharges for Cache la Poudre River

Robert T Milhous
Hydrologist
Fort Collins, Colorado

There are a number unresolved problems with defining channel-forming discharges in rivers largely because fluvial systems reflect the impact of past flows on the channel. It is difficult to extract a single streamflow that defines the process. One effort to determine a single streamflow that defines the process is the use of the effective discharge and is the topic of this presentation. **T**he effective discharge is the streamflow that has the maximum long-term transport of sediment and is the increment of discharge that transports the greatest sediment load over a period of years. The effective discharge incorporates the principle suggested byWolman and Miller in a 1960 paper that the channel-forming discharge is a function of both the magnitude and frequency of sediment-transport. The movement of sediment is dependent on shear stress and can be described by the equation: $Qsl = k(\tau\text{-}\tau crt)\beta$ where Qsl is the rate of transport, k is a constant related to the characteristics of the material transported, τ the shear stress per unit area, and τcrt is a critical or threshold shear stress required to move the sediment (Wolman and Miller, 1960). Assuming the shear stress is related to the streamflow with the equation $\tau=zQ\alpha$ gives the equation $Qsl = zk(Q\alpha - Qcrt\alpha)\beta$; if the threshold discharge is zero the equation becomes the much simpler equation $Qsl = aQb$ which is the form most often used in the computation of effective discharge. Gravel and cobble rivers such as the Cache la Poudre (Poudre) River do have a threshold for movement of the bed-material. The relations with discharge used in the calculations assume of of the following: 1) suspended load is representative of the channel forming process, 2) bed load is representative, 3) suspended load plus bed load is the important process, or 4) suspended load is a surrogate for bed load which is the important channel forming process. Using the simple form of the sediment load equation calibrated to measured suspended sediment loads and Poudre River streamflow data for 1944 – 2015 yields an effective discharge of 1905 cfs. Two levels of dimensionless shear stress are reasonably representative of the threshold. For a dimensionless shear stress of 0.021 (discharge of 1756 cfs) the effective discharge is 2908 cfs, for 0.031 (2777 cfs) the effective discharge is 3593 cfs. These calculations assume either the effective discharge is related to suspended load or that suspended load is a surrogate for bed load. Data for Oak Creek in Oregon was used to compare the relations for suspended load and measured bed load. The power term, b, for suspended load is 2.36 and for bed-load 4.66. If these values are used to calculate the effective discharge the Poudre River, the suspended load effective discharge is 1905 cfs and the bed-load effective discharge is 5484 cfs. This is just one data set but it does suggest the possibility that the idea that suspended load is a surrogate for bed-load is not correct.

Reference: Wolman, M.G., and Miller, J.P., 1960. Magnitude and frequency of geomorphic processes.

Ice-Related, Winter Flooding of Flat Creek, Jackson, Wyoming

Ed Kempema[1], Brian Remlinger[2], and Rob Ettema[3]

Flat Creek through Jackson, Wyoming has a long history of ice-related, winter flooding driven by frazil and anchor ice formation. The ice-formation processes and associated flooding along the creek are fairly typical features of the winter environment in small, spring-fed streams and rivers flowing through mountain valley and meadow locations in the Rocky Mountain region. However, such flooding can pose a problem for urban development at some of these locations, such as along Flat Creek through Jackson. Similar problems have arisen elsewhere in the Rockies: notably along part of the Gunnison River, Colorado.

In our presentation we: (1) review current knowledge of ice formation in relatively small, steep streams and rivers similar to Flat Creek; (2) discuss previous ice mitigation efforts in Flat Creek; (3) present results from observations and data collected along Flat Creek during the winter of 2015-2016; and, (4) describe a conceptual model for mitigating winter flooding along Flat Creek. The insights from Flat Creek will be valuable for other locations in the Rocky Mountain region.

Efforts to mitigate ice-related flooding along Flat Creek have been ongoing since before 2000. In fall 2015, the Flat Creek Water Improvement District hired an environmental consultant to monitor flow and ice conditions in Flat Creek within the Town of Jackson. The monitoring included measurements of water temperatures, air temperatures, thaw well operations, and ice conditions along the creek. The resulting data were incorporated into a GIS geodatabase containing locations of the various measurement stations, along with ice conditions seen in the Creek. The monitoring will continue during the 2016-17 winter.

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Effects of Acid Mine Drainage on the Community Composition of Denitrifying Bacteria

Ben Wise

An estimated 23,000 abandoned mines are scattered across the State of Colorado. These abandoned mines often leak effluent that is low in pH and high in dissolved metal concentration. This acid mine drainage (AMD) adversely affects ecosystems. However, little is known about microbial community structures within these AMD-impacted systems that may otherwise be able to provide valuable ecosystem services. Additionally, far less is known about denitrifying microorganisms in these same systems, despite their critical role in mitigating nitrogen pollution. Denitrifying microorganisms are capable of limiting excess nitrogen deposition that could otherwise lead to problems such as reduced drinking water quality, toxic effects on freshwater biota, and disruption of aquatic nutrient cycling. In this study, denitrifier diversity and community structure are assessed in relation to environmental variables within an ecosystem that has been significantly altered by AMD. This study provides new insight into the biogeochemical activity of ecosystems affected by AMD and has the potential to influence future remediation and watershed management decisions. By gaining an understanding of the ecosystem services provided by denitrifying and other microorganisms and how those services are affected by ecosystem degradation, communities in the future may be able to efficiently utilize their local ecosystems in remediating polluted freshwater resources.

The potential release of mercury currently stored in permafrost

Paul F. Schuster, Kevin Schaefer, George R. Aiken, Robert G. Striegl, David P. Krabbenhoft , David A. Roth, John F. DeWild, Ronald C. Antweiler, Kim Wickland, Cuicui Mu, and Joshua Gryziec

Changing climate in northern regions is causing permafrost to thaw with major implications for the cycling of carbon, nutrients, and heavy metals, particularly mercury (Hg) in arctic and subarctic ecosystems. Permafrost occurs in nearly one quarter of the Earth's northern land mass and an estimated 13 percent of Earth's entire land surface. Large-scale permafrost thaw will release Hg currently stored in permafrost, impacting aquatic resources and posing a serious threat to human health. We measured total sediment Hg concentration in 543 samples from 13 permafrost cores from the Alaskan interior and the North Slope. We assume this Hg is atmospherically deposited natural Hg (not of anthropogenic origin) over millennia since at least the last ice age. We estimate the median mass of stored Hg in northern hemisphere permafrost to be 790+/-267 Kilotons, potentially the second largest mercury pool on the planet. Projections indicate substantial permafrost thawing leading to peak annual Hg releases exceeding current total annual anthropogenic emissions of mercury, with major implications for terrestrial and aquatic life, the world's fisheries, and ultimately human health.

Climate and flow variation revealed in tree rings of riparian cottonwoods, northern Great Plains, USA.

Jonathan M. Friedman, Derek M. Schook, Jesse R. Edmondson, David M. Meko, Ramzi Touchan and Eleanor R. Griffin.

River flow reconstructions are typically developed using tree rings from montane conifers that cannot reflect hydrologic inputs from the lower portions of a watershed. Incorporating lowland riparian trees can improve the accuracy of flow reconstructions because these trees obtain moisture directly from the alluvial water table. We used riparian plains cottonwoods (*Populus deltoides*, ssp. *monilifera*) to reconstruct discharge for three neighboring rivers in the Upper Missouri River Basin: the Little Missouri (n = 643 tree cores), Yellowstone (n = 389), and Powder (n = 408). Cottonwood growth is strongly positively correlated with flow and precipitation and weakly negatively correlated with temperature, indicating that growth is generally limited by moisture scarcity. As a result cottonwood growth rings record droughts more precisely than floods. Growth is most strongly correlated with flow and precipitation in April-July, which is consistent with dendrometer-band measurements showing growth cessation in August. The reconstructions explained at least 57% of the variance in historical discharge and extended back to 1643, 1742, and 1729. These reconstructions are the furthest downstream among Rocky Mountain rivers in the Missouri River Basin. Low-frequency flow patterns revealed wet conditions from 1870-1980, a period that includes the majority of the historical record. Flows have decreased at all sites since the 1980s. The 1816-1823 and 1861-1865 droughts were more severe than any recorded, revealing that water availability is less reliable than indicated by the historical record.

Observations of decreased runoff response to precipitation, Little Missouri River Basin, northern Great Plains, USA

Eleanor Griffin and Jonathan Friedman

The riparian cottonwood forest in Theodore Roosevelt National Park, North Dakota, is dependent on streamflow in the Little Missouri River (LMR) to supplement the highly variable but typically low annual precipitation (average 381 mm; 1935-2012) in this semi-arid region. The *Third National Climate Assessment* (http://nca2014.globalchange.gov/report/regions/great-plains) forecasts rising temperatures for the Great Plains region and changes in the timing and magnitude of precipitation that may affect the future health of this forest. However, before we can begin to assess the potential effects of future climate change on streamflow in the LMR, historical changes in the hydrologic response of this basin must be understood.

Precipitation data indicate that average annual precipitation over the basin during the period 1976 to 2012 (386 mm) was nearly the same as the average for 1939 to 1975 (384 mm). Although there was no significant difference in precipitation, data from the LMR streamflow-gaging station near Watford City, ND, indicate that the average annual runoff in this basin for 1976-2012 declined by 22% compared to 1939-1975. The average decrease in annual streamflow from this 21,500 km^2 basin was 1.25×10^8 m^3/yr (101,000 acre-ft/yr). While this is a small fraction (1.4%) of the average inflow to Lake Sakakawea from May through September (7,230,000 acre-ft, adjusted for upstream storage; National Weather Service, http://forecast.weather.gov/, 5/19/2015), it suggests a possible change in runoff response to precipitation in the northwestern Great Plains region. Water use data for the State of North Dakota (available at http://nd.water.usgs.gov/wateruse/) suggest that less than half of the average annual decrease in streamflow is caused by water withdrawals. Temperature records from U.S. Historical Climatology Network (USHCN) stations within and near the LMR basin show >1°C statistically significant increases in the monthly average maximum and minimum temperatures for February, March, April and June, and a significant 1°C decrease in average maximum temperature for October.

Increasing winter temperatures can cause intermittent snowmelt, reducing the magnitude of spring runoff from snowmelt and the potential for large ice-jam events. In addition, increasing winter temperatures can increase water losses to sublimation or evaporation. Runoff while the ground is still frozen reduces recharge of the alluvial aquifer, which may cause increased streamflow losses to the aquifer during the summer. Therefore, the observed historical changes in runoff may be linked to rising winter and summer temperatures, and the observed changes in streamflow may give an indication of a potential effect of future climate change on runoff in this region.

Estimate of gravel transport rates at bankfull flow in mountain streams

K. Bunte, K.W. Swingle, R. Ettema, S.R. Abt and D.A. Cenderelli

From stream restoration to watershed management, many studies require knowledge of the bankfull gravel transport rate. Ryan (2007) showed that for a steep watershed in central Colorado bankfull bedload transport increased with watershed area A. Expanding on her findings, our study compiled a worldwide set of 75 gravel transport relations measured predominantly in mountain streams using samplers best suited for coarse beds: bedload traps, vortex, baskets, and pit-type samplers. Power functions in the form of $Q_B = a\ Q^{\ b}$ (Eq. 1) were fitted to the sampled transport rates Q_B (g/s) and the discharge Q (m^3/s) at the time of sampling in each data set. a-coefficients and b-exponents are empirically determined. Solving Eq. 1 for bankfull flow yields the bankfull gravel transport rate $Q_{B,bf}$, and dividing by the bankfull width yields unit bankfull flow q_{bf} and the unit bankfull transport rate $q_{B,bf}$.

From a log-log scatterplot of worldwide data of $q_{B,bf}$ vs. basin area A, a positive, slightly convex trend emerges when data are limited to central Rocky Mountain streams. The trend straightens when relating $q_{B,bf}$ to a modified unit stream power expression $\omega' = \rho q_{bf} \cdot S^{0.5} \cdot \%D_{sub<8}$ that integrates the percentage of subsurface sediment < 8 mm ($\%D_{sub<8}$). For most Rocky Mountain streams, measured data of $q_{B,bf}$ vs. ω' plot within an envelope two orders of magnitude wide. A few outlier data in Colorado are explained by disturbances that caused overly large (after a log jam burst) and overly small (upstream gravel entrapment) transport rates. Most of the world-wide data fall into the extrapolated envelope of the Rocky Mountain streams, such as Alpine step-pool and plane-bed streams where large basin portions are above tree line. A regression fitted to those data yields an r^2 of 0.74. Bankfull gravel transport rates from streams in the forested Pacific Northwest fall below the envelope as well as Karakorum streams for which bankfull flow is a relatively small event. However, mountain torrents (wide gravel-cobble beds with an incised step-pool low-flow channel) and other streams draining basins with high gravel supply in the Alps, recently deglaciated Canadian Rocky Mountains, SE Himalaya, have much larger bankfull transport rates than Rocky Mountain streams.

For Rocky Mountain streams, the plotted relation of $q_{B,bf}$ vs. ω' facilitates an estimate of bankfull unit transport rates, especially if watershed sediment supply (e.g., hillslope-channel connection), active bank erosion, and downstream gravel conveyance potential (e.g., obstruction by beaver dams) are assessed from aerial photography. Stream type classification does not improve $q_{B,bf}$ estimates. Likewise, a visual assessment of watershed sediment production and channel conveyance provides an estimate of whether a stream falls inside or outside the central envelope.

Trends in snow water equivalent in Rocky Mountain National Park and the northern Front Range of Colorado

Glenn Patterson

The seasonal snowpack in Rocky Mountain National Park and the northern Front Range of Colorado, within 50 km of the park, is undergoing changes that will pose challenges for water providers, natural resource managers, and winter recreation enthusiasts. Assessing long-term temporal trends in measures of the seasonal snowpack, and in the climatic factors that influence its annual accumulation and ablation, helps to characterize those challenges. Evaluating the patterns of variation in those trends over different parts of the snow season shows that some months have increasing trends in snow water equivalent (SWE) while others have decreasing trends. Placing the current 35-year trends in the longer context of paleoclimate tree-ring reconstructions shows that the recent trends, so far, are not totally unprecedented during the previous 6 centuries. Finally, projections of future trends provided by linked climate and hydrologic models suggests that some key measures of SWE are likely to be decreasing throughout the 21st century.