Program and Abstracts for the 61st Annual Meeting of the Rocky Mountain Hydrologic Research Center

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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.

Cover: Lion Lake # 1 in Wildbasin, Rocky Mountain National Park, John Moody
Editor: John A. Moody

V-shaped, Variable-slope Flume at Rocky Mountain Hydraulic Laboratory

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During the 1950s and 1960s research was done at the Rocky Mountain Hydraulic Laboratory using rather large quantities of flowing water. This research was conducted by Chesley J. Posey, Professor of Civil Engineering at the University of New Hampshire and the creator and Director of the Rocky Mountain Hydraulic Laboratory, Ralph Powell, Professor of Civil Engineering at Ohio State University and Maurice Albertson-- together with students from various parts of the country.

Large flows were directed into a V-Shaped, variable-slope flume from a diversion dam in the North St. Vrain River. Remnants of this flume are still present on the Laboratory property. This was financed by a grant from the National Science Foundation.

Another project used a concrete flume that was built on the north edge of the river. This was used to conduct scour studies through and around various types of river structures.

Slide photos of these research systems will be presented.

Simulating Realistic Benthic Boundary Conditions in Lakes: Can Sediment-water Exchange Moderate Water-column Nutrient Concentrations?

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Nutrient mass balance studies suggest that phytoplankton production in lakes is subsidized by nutrients released from the sediments. Epilimnetic sediments, which directly underlie the lake's mixed layer, are likely to be particularly important in this regard. However, the role of turbulence in fluxes of nutrients, particularly phosphorus, across the sediment-water interface (SWI) is poorly understood. Through its influence on the diffusive boundary layer thickness at the SWI, turbulence is likely to mediate interfacial concentration gradients and facilitate nutrient release despite an oxidized microzone at the sediment surface.

To evaluate the role of epilimnetic sediments in lake nutrient dynamics, we developed a system of oscillating grids to simulate realistic diffusive boundary layers at the sediment-water interface in intact sediment cores from oligotrophic Grand Lake, Colorado. The influence of the diffusive boundary layer thickness was small, but the magnitude and net direction of dissolved N and P exchanges did appear to be strongly linked to overall concentration gradients across the SWI. These findings suggest that, rather than acting as unidirectional sinks or sources for nutrients, epilimnetic lake sediments may variably release or sequester dissolved nutrients, thereby moderating extremes in water-column nutrient concentrations.

Poster

Light and Nitrogen Fixation in Colorado Reservoirs

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The relationship between light and nitrogen fixation by cyanobacteria was determined in six reservoirs in Colorado. Phytoplankton samples collected within the top one meter were incubated *in situ* at four depths in the water column. Nitrogen fixation rates were estimated using an acetylene reduction method.

Rates of nitrogen fixation demonstrated a nonlinear relationship with light intensity. Nitrogen fixation light response curves included an initial light-limited increase, followed by light saturation and light inhibition. Also, in some communities, light conditions prior to the incubation determined the rate of nitrogen fixation measured during the incubation.

Bedload Rating and Flow Competence Curves in Mountain Gravel-bed Streams Predictable from Bed Armoring, Stream Width and Basin Area

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The prediction of bedload transport for unmeasured streams typically relies on equations that compute transport rates and critical flow from measured flow hydraulics and the bedmaterial size. However, only rarely do computed results match measured gravel bedload transport rates in coarse-bedded mountain streams with satisfactory accuracy. As an alternative, we have explored the prediction of gravel transport rates and the largest bedload particle sizes from watershed and streambed characteristics.

Data used for the analyses were obtained from extensive bedload sampling at 10 study sites in 8 mountain gravel- and cobble-bed streams. The streams have snowmelt regimes, steep gradients (1-9%), and basin area sizes of 8-105 km^2. Flows of 1.5 times bankfull are mostly contained within the channels. Samples were collected using bedload traps (4-6 installed per cross-section) and a similarly designed but 1.5 m wide netframe sampler. Both samplers have a large sampler opening, a large sampler capacity, and both permit a long sampling duration.

Power functions $Q_B = aQ^b$ were fitted to relationships of transport rates versus flow and the largest bedload particle sizes and flow ($D_{max} = fQ^g$) measured with bedload traps at eight field sites where the exponents (*b* and *g*) indicate the rating curve steepness and the coefficients (*a* and *f*) the vertical position of the curve. Bedload transport and flow competence curves were well-defined but differed between streams. Exponents and coefficients of these functions were then related to parameters describing the bedmaterial characteristics and the stream size. The *b*- and *g*-exponents decreased strongly with the degree of bed armoring (r^2 = 0.92 and 0.79), while *a*- and *f*- coefficients that are negatively related to exponents increased with armoring (r^2 = 0.84 and 0.82) and decreased strongly with stream width (r^2 = 0.91 and 0.88) and basin area size (r^2 = 0.72 and 0.67). The degree of armoring reflects gravel transport processes quite well and appears to be a good predictor of both the rating curve and flow competence curve response to increasing flows in coarse-bedded mountain streams. Coefficients were highly, but negatively, correlated to the bankfull stream width (r^2-values of 0.93 and 0.91, respectively), and are thus predictable from an easy to measure field parameter.

Our analyses to date are based on intensive field measurements at 10 study sites in eight coarse-bedded mountain streams. More field data are needed to not only to validate these findings but also to extend the analyses to different stream types. However, field data measured with different sampler types cannot be easily combined due to sampler-specific measured bedload transport rates and particle sizes.

Poster

Measured Gravel Transport Rates and Particle Sizes Difference between Helley-Smith Samplers and Bedload Traps

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Bedload transport rates were computed and compared from samples collected with bedload traps (0.3 x 0.2 m opening with a 1.5 m long net, 3.5 mm mesh width, attached) and a Helley-Smith sampler at eight sites during snowmelt highflow events (20 and 140% of bankfull) in mountain gravel and cobble-bed streams. At each site, 4-6 bedload traps were deployed 1-2 m apart and sampled simultaneously for about 1 hour. The Helley-Smith sampler was deployed at 0.5-1.0 m increments (12-18 verticals) across the stream for 2 minutes per vertical. Samples from the Helley-Smith sampler were truncated at 4 mm to compare similar particle sizes for both samplers.

Transport rates collected with the bedload traps increase rapidly with flow. Fitted power function rating curves are steep and relatively well defined with exponents of 8 to 16, while those fitted to Helley-Smith samples have exponents between 2 and 4. At flows 50% *Qbkf*, bedload traps collect transport rates 2-4 orders of magnitude smaller than the Helley-Smith sampler. Near bankfull flow, transport rates measured with both samplers become similar. D_{max} bedload particle sizes collected in bedload traps also increase strongly with flow, and fitted power function flow competence curves are likewise steeper (with exponents of 1.4 to 3.5) than for the Helley-Smith sampler (exponents of 0.3 to 1.0). At 50% of bankfull flow, the D_{max} particles collected in bedload traps are about 75% the size of those collected in the Helley Smith sampler, at bankfull flow, D_{max} particles in the bedload trap are on average 1.7 times larger.

Several factors cause different results between the two samplers: Most influential is the occasional unwanted pick up of bedmaterial particles when placing the Helley-Smith sampler onto the bed which increases measured transport rates by several orders of magnitude. Using ground plates under bedload traps eliminates this. Setting a Helley-Smith sampler onto ground plates reduced low flow transport rates and yielded results similar to those from bedload traps. Thus, much of the discrepancy between the two samplers can be avoided by using ground plates. (2) Differences in sampling time, sampling intensity, and sampler dimension explain most of the remaining difference in transport rates and particle sizes computed for bedload traps and the Helley-Smith sampler.

Different rating and flow competence curves cause differences in the computations of annual load, effective discharge and critical flow for incipient motion. These differences affect outcomes for stream restoration designs, channel maintenance flows, cumulative watershed effects, etc.Bedload traps appear to yield fairly representative samples of gravel and small cobble bedload, suggesting that they may be a suitable sampling devise for coarse-bedded streams. A Helley-Smith sampler in coarse systems may be appropriate during high transport rates, when deployed on ground plates, and for sampling fine sediment that bedload traps are unable to collect.

A Review of the 2006 Water Year in Colorado

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The 2006 water year got off to a wet start with a widespread multi-day October precipitation event soaking much of Colorado's eastern plains. A persisting winter storm track brought frequent and heavy snow to Colorado's northern mountains, but delivered very little moisture over the southern mountains and east of the Continental Divide. Near record snowpack developed in Summit County, Colorado. As spring arrived, weather patterns changed and the normal spring storms of the Front Range did not materialize. Most of Colorado experienced an exceptionally dry April-June period, and drought conditions and impacts were spreading rapidly. Then, beginning in early July, early and frequent pulses of subtropical humid air reached southern and central Colorado with frequent and widespread shower and thunderstorm activity. At the same time, the northern tier of Colorado Counties remained dry. Overall, the year was marked by warmer than average temperatures, spatially variable precipitation and below average runoff. Drought impacts abated dramatically during late summer due to higher humidity air, frequent summer rains and lowered water use over metropolitan areas.

Empirical Models to Predict Debris Flow Volumes Generated by Recently Burned Basins in the Western U.S.

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Recently burned basins frequently produce debris flows in response to moderate and heavy rainfall. Hazard assessments can benefit from the ability to predict the volume of debris flow material that may flow out of a burned basin. This study develops a set of empirically-based models that can be used to predict potential volumes of wildfire-related debris flows in different regions and geologic settings.

Debris flow volumes were estimated for 56 recently burned basins in Colorado, Utah and California by either measuring the volume of material eroded from the channels or by the amount of material removed from a debris retention basin. Independent variables thought to affect debris flow volume were determined, and include measures of basin morphology, basin areas burned at low, moderate, and high severities, soil material properties, rock type, and rainfall amounts and intensities for debris flow triggering storms. Using these data, multiple regressions were used to create separate predictive models for debris flow volumes generated by burned basins located in the western U.S., southern California, and Rocky Mountain regions, as well as for basins underlain by sedimentary, metamorphic and granitic rocks.

An evaluation of these models generated indicates that the best model explains 83% of the variability in the debris flow volumes and included variables that describe the basin area with slopes greater than or equal to 30%, the basin area burned at moderate and high severity, and total storm rainfall. This model was independently validated by comparing reported debris flow volumes to volumes estimated using the model and reported basin and rainfall data. Most of the reported volumes (77%) were within one residual standard error of the volumes predicted using the model. This model is an improvement over previous models in that it includes a measure of burn severity and estimates of modeling errors. Applying this model, in conjunction with a model for debris flow probability, will enable more complete assessments of debris flow hazards following wildfire.

Operational Implementation of a Fully-coupled Flash Flood Prediction System

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Clear hazards are presented by intense convective events occurring over complex and urban terrain regions such as that of the Rocky Mountain Front Range. Flash floods have claimed the lives of hundreds of people and accounted for hundreds of millions of dollars in time-inflated damages over the years (e.g. South Platte River, 1933; South Boulder Creek, 1969, Big Thompson River, 1976, Rapid City Flood, 1972, Fort Collins Flood, 1997, Cherry Creek 2000; and Las Vegas Flood, 1999). While early detection and warning of such events has improved over the past few decades, predictive skill of flash floods across a range of time-scales remains critically low.

We present plans for an operational implementation of a fully-coupled land data assimilation-hydrometeorological prediction system for the Colorado Front Range Region. By integrating community-based, state-of-the-art land data assimilation, nowcasting, numerical weather prediction (NWP) and hydrological modeling tools, this project seeks to advance our capability to predict and prepare for dangerous flooding events. The response of the watershed to precipitation forcing is highly non-linear in both space and time and therefore demands a physically robust and spatially-distributed framework for adequate diagnosis and prediction of potential flooding hazards. The system deployed under this project strives to improve our characterization of terrestrial hydrology during inter-storm periods and will advance our understanding of how the quality of QPE and quantitative precipitation forecasts (QPF) from radar, nowcasting and NWP systems, respectively, will impact flood predictions. Assessment of the utility the generated products is also being coordinated with collaborators at the Denver Urban Drainage and Flood Control District as well as the U.S. National Weather Service.

Poster

Climate and Wet Deposition Controls on Long-term Changes in Water Chemistry in an Alpine Catchment, Green Lakes Valley, Colorado.

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Alpine basins are sensitive indicators of climate change because of large amounts of exposed bedrock, a snowmelt dominated hydrograph, limited vegetation, and short growing seasons. Here we report on long-term trends in water chemistry at Green Lake 4 for the period 1982-2004, and evaluate the role of potential abiotic drivers causing changes in water chemistry.

Annual time-weighted mean concentrations of nitrate, sulfate, calcium, magnesium, silica and conductance from the outflow of GL4 have increased significantly over the study period, with a substantially higher rate of increase since the mid 1990's. In particular, annual minima nitrate concentrations have increased from 0.7 μeq/L in 1986 to 12.2 μeq/L in 2004. In addition, both retention rates and surface water yields of dissolved inorganic nitrogen display increasing trends. Concurrently, inorganic N in wet deposition at Niwot Ridge has increased at a rate of 0.30 (kg)/(ha*yr) and calcium has increased by 0.22 (kg)/(ha*yr). Over the last ten years where the water chemistry changes are most pronounced, air temperature has increased and annual precipitation has decreased significantly.

Climatic (temperature, precipitation), hydrologic (discharge, subsurface storage, snow water equivalence), and anthropogenic (inorganic wet deposition) variables were compared with concentrations and fluxes of both geochemical weathering products and nutrients. Initial PCA results suggest that the increasing trends in solutes, most markedly since the late 1990s, appear to be driven primarily by increases in atmospheric deposition of solutes and secondarily by climatic and hydrologic processes.

Interannual Variation in Evaporation and Vegetation Cover of a High Altitude Wetland

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From June 12, 2000 to January 15, 2005 evaporation and factors including radiation, air and soil temperature, wind speed and soil moisture were measured at High Creek fen, located in South Park, Colorado. In addition, Normalized Difference Vegetation Index (NDVI) was calculated using Terra/ MODIS data for within High Creek fen and for four sites just outside the fen in order to evaluate the relationship between vegetation cover and evaporation.

Evaporation rates were large, often exceeding the precipitation rate by three times, and demonstrated seasonal and interannual variation. For example, evaporation rates were lower during the spring and summer in 2002 when the area experienced significant drought conditions. NDVI measurements were used to quantify vegetation cover at High Creek fen and to test the idea that the observed interannual variation in evaporation was due to changes in vegetation cover. NDVI measurements inside the fen corresponded with seasonal and interannual evaporative trends, as well as with the drought response. In addition, NDVI measurements showed that vegetation cover inside the fen was significantly different than outside of the fen. In conclusion, results indicate that there is a correlation between evaporation and NDVI, and that this relationship is maintained through seasonal, interannual and disturbance event variations.

Vegetation-induced Changes to Shear Stress and Velocity on the Colorado River

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Sustained drought in the Upper Colorado River Basin has severely limited peak flows, allowing native and non-native plant species to colonize low-lying bar surfaces within the last five years. This vegetation has the potential to reduce velocity and shear stress where the vegetation is located, and locally shift flow patterns, forcing adjustments in channel morphology. The role of vegetation in influencing velocity and altering shear stress in the Colorado River was assessed in the vicinity of the USGS gauge near the Colorado-Utah state line. This reach contains a low-lying gravel bar recently colonized by predominantly native sandbar willow (*Salix exigua*), which made up 87% of the vegetation on the bar. Field measurements of vegetation characteristics, channel geometry, and water surface profiles were used to model the effects of the vegetation by combining a 2-dimensional hydraulic model (MD-SWMS) with vegetation models for rigid and flexible vegetation developed by Smith (2001; 2006). The effects of vegetation were modeled at flows that ranged from 291 m^3/s which just inundates the bar, to 796 m^3/s which covers the bar to a depth of 2 m.

Results showed that the current vegetation produced the greatest reduction in velocity and shear stress (15% and 35% reduction respectively) at flows equal to 28% of bankfull discharge when the mid-channel bar was inundated by 0.5 m of water. At the highest flow modeled the vegetation produced almost no change in velocity, but still reduced the shear stress acting on the bed by 11%. While local effects on the bar were pronounced, overall flow patterns were not greatly changed in the rest of the channel. However, additional model results based on potential future growth of vegetation on the bar, indicate significant increases in shear stress in the main channel which may lead to channel change.

Poster

The TreeFlow Project: Using Tree-ring Data to Provide Water Managers with a Multi-century Perspective on Drought

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Water resource management in the West requires knowledge of hydroclimatic variability in order to plan for adequate water supplies during periods of drought. There is now growing appreciation among water managers that the relatively short (<100 years) instrumental records of climate and streamflow do not capture the full range of natural hydroclimatic variability, particularly extreme drought events. This became especially evident during the 2002 drought in Colorado, which resulted in the lowest flow on record at many gages.

Gage records can be extended using proxy data, and tree-ring data have proven particularly useful for this purpose. Both annual tree growth and water year runoff are strongly influenced by variations in precipitation and evapotranspiration. Thus, the annual rings of moisture-sensitive trees can be used to reconstruct streamflow records back in time 300-800 years. This longer window onto past hydroclimatic conditions is more likely to capture the full range of natural variability and provide more robust information about drought occurrence. The TreeFlow Project is a collaboration with water providers to provide tree-ring data specific to the provider's needs. We have developed a network of 80 moisture-sensitive tree-ring chronologies, which since 2002 we have used to generate over 30 multi-century streamflow reconstructions for gages critical to water management in the Colorado, Rio Grande, and South Platte River basins. Our partners are using the reconstructions in a variety of ways, including incorporating them into water system models to test their system's ability to perform under a broader range of conditions (i.e., more severe and persistent droughts) than contained in the 20th century gage records. We have made these streamflow reconstruction data publicly accessible via the project website (http://www.ncdc.noaa.gov/streamflow/) which also provides guidance for interpreting the data and a tutorial explaining the reconstruction methodology. Our current efforts include expanding the geographic scope of the project to cover the western U.S., in collaboration with other tree-ring scientists and water managers in the region.

Lodgepole Pine, Bark Beetle, and Fire: Assessing Post-fire Risks before the Blaze

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Extensive bark beetle damage to forested watersheds in Grand County, Colorado has led to a growing concern about wildfire. The risk of fire increases both in the short term when needles still remain on dead standing trees and in the long term when trees fall over to become surface fuel. Water providers are expecting detrimental effects on water storage and collection reservoirs if fires burn adjacent watersheds.

The U.S. Geological Survey has organized a new multi-disciplinary project in Grand County designed to evaluate risks from fire, including post-fire effects, and other natural hazards. Several ongoing collaborations are in place with the Front Range Fuels Treatment Partnership, Northern Colorado Water Conservancy District, and Northern Colorado Bark Beetle Collaborative. The project is using: 1) remote sensing to map the extent and spread of tree mortality in stands of lodgepole pine, 2) high resolution imagery to locate individual homes and other structures, and 3) models to predict debris-flow probabilities in basins based on soil properties, basin morphology, potential burn severity and rainfall characteristics. A major product will be a multi-hazard map and associated information with values at risk identified to guide pre-fire fuel management activities, fire suppression, evacuations, and post-fire watershed rehabilitation.

Convective Rainfall Characteristics along an Elevation Gradient

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Summer convective rainfall is frequently the driver for floods in steep mountainous terrain. Along the Colorado Front Range, these storms generally form near the Continental Divide and propagate from the divide eastward toward the plains. Eight recording tipping-bucket rain gages were deployed from 26 July through 9 September 2006 along such a 35-km transect starting in the upper part of Wild Basin (3421 m) in Rocky Mountain National Park, following the east-to-west trending drainage of the North St. Vrain Creek, and ending in the town of Lyons, Colorado at an elevation of 1638 m. These gages record the time of each 0.254 mm of rainfall and these data were used to calculate the rainfall intensity and to determine the relation between the elevation and rainfall intensities associated with convective storms. Additionally, a pressure gage was used to measure the river stage in the North St. Vrain Creek 15 km downstream from the Continental Divide. River stage and data from the rain gages were used to determine the effect of convective rainfall on runoff in mountainous terrain.

The results of this study are for a short sampling period and are not enough to predict long-term trends, but do provide some initial insight into the character of convective storms in mountainous terrain. The total number of convective storms lasting longer than 5 minutes during the study period ranged from 11 to 21 for the eight rain gages but was not related to elevation. The duration of the storms increased with elevation such that the average duration was 78 minutes at the lowest elevation and 203 minutes at the highest elevation. The maximum 30-minute rainfall intensity also generally increased with elevation from 7.1 mm h^{-1} to 29.5 mm h^{-1}. However, the one exception was the site on the plains at the lowest elevation (41.2 mm h^{-1}), which also had the fewest storms. Runoff from one convective rainstorm in the upper part of Wild Basin took 6.5 hours to travel a distance of 12.4 km, for an average speed of 1.9 km h^{-1} or 0.53 m s^{-1} was faster than snowmelt runoff that covers about the same distance in about 12 hours but from a network of many small subwatersheds.