PROGRAM

75th Annual Meeting
Rocky Mountain Hydrologic Research Center
https://rmhrc.org/

Friday, 29 October, 2021: 8 am to 3:00 pm
Boulder Jewish Community Center
6007 Oreg Avenue, Boulder, CO 80303

View looking into Wild Basin with the North Saint Vrain Creek in the foreground and Mt. Copeland in the background. Taken from Colorado Route 7 bridge, 26 August 2021. Photo by John Moody.

Purpose of the Meeting

To provide researchers, practitioners, and students an opportunity to share and discuss their research in a relaxed yet scientifically stimulating atmosphere. The meeting encourages interdisciplinary communication among a variety of investigators in the fields of hydrology, engineering, environmental sciences, water resources, and other related hydrological disciplines

For the 75th Annual Meeting of the Rocky Mountain Hydrologic Research Center, we additionally encouraged abstract submissions focused on hydrologic and environmental change over multi-decade time frames and historical retrospectives of hydrologic research in the Rocky Mountain region.

The RMHRC Board meeting will follow the technical session.

75th Annual Meeting Organizing Committee: Debby Martin, Bob Milhous and Will Rense with generous help from John Moody.

Many thanks to Sara Guttman, Boulder JCC Event and Rental Director.

75th Annual Meeting of the Rocky Mountain Hydrologic Research Center October 29, 2021 Venue: Boulder Jewish Community Center, 6007 Oreg Avenue, Boulder, Colorado https://rmhrc.org/	
This is a hybrid meeting with in-person and virtual attendance conducted on the Zoom platform. Meeting link: https://us02web.zoom.us/j/86986126103?pwd=ZEZkOHJ6aXp5S3dCMHdzaW50RE5Vdz09 For questions during the meeting: Please text Debby Martin, 720-320-2113 or use Zoom chat window.	
Please note you will need to bring your own lunch.	
8:00-8:30	Registration, coffee
8:30-8:45	*Debby Martin, President, Rocky Mountain Hydrologic Research Center* **Welcome, Introductions**
	**Presenting Author*
Poster	*Sidney A. Bush*, Holly Barnard, University of Colorado Boulder; Andrew Birch, National Park Service* **Spatiotemporal patterns in hydrologic connectivity within a montane headwater catchment in central Colorado**
8:45-9:00	*Peter Ellsworth*, University of Wyoming; Michael Gillette, Professor Emeritus, School of Theatre, Film and Television, University of Arizona* ***Recollections of the Rocky Mountain Hydrologic Lab***
9:00-9:30	*T. Andrew Earles*, Wright Water Engineers* **Low Head Dam Public Safety Initiative**
9:30-10:00	*Katherine (Kate) E. Hale*, Keith Musselman, Noah Molotch, University of Colorado - Boulder/INSTAAR; Keith Jennings, Lynker Technologies* **Changes in snow water storage and hydrologic partitioning across the Western United States**
10:00-10:30 **VIRTUAL**	*Robert T. Milhous*, Hydrologist, Fort Collins, Colorado* **Should the USGS Water Year be Sacred?**
10:30-10:50	**BREAK**
10:50-11:20	*Rikki E. Held*, Colorado College* **Held v. State of Montana**
11:20-11:50	*Sharon Bywater-Reyes, Antonio Reveles- Hernandez*, Scott Franklin, University of Northern Colorado*

	Russian olive as an ecogeomorphic agent on the Powder River, Montana
11:50-12:20	*Karissa L. Courtney*, Colorado State University and NASA DEVELOP; Catherine Buczec, NASA GSFC / ADNET; D. Shahin, A. Tian, NASA DEVELOP; C. Andrews, Michigan State and NASA DEVELOP* **Mapping Russian Olive: Using Remote Sensing and Modeling to Detect and Map an Invasive Shrub along the Powder River in Montana and Wyoming**
12:20-1:00	**LUNCH**
1:00-1:30 **VIRTUAL**	*Becky A. Bolinger*, Peter Goble, Russ Schumacher, Colorado Climate Center, Colorado State University* **Colorado's Climate: Water Year 2021 in Review**
1:30-2:00	*Kate Boden*, Daniel Philippus, Anneliese Sytsma, Terri Hogue, Colorado School of Mines; Jake Kurzweil, Mountain Studies Institute* **Detecting Forest Disturbance Impacts on Hydrology in Precipitation Dominated Whiplash Watersheds**
2:00-2:30	*Garrett P. Rue*, Diane McKnight, Institute for Arctic and Alpine Research, University of Colorado-Boulder* **Enhanced rare earth element mobilization in a mountain watershed of the Colorado Mineral Belt with concomitant detection in aquatic biota: Increasing climate change-driven degradation to water quality**
2:30-3:00	*Ethan F. Burns*, Holly Barnard, Institute of Arctic and Alpine Research, Dept. of Geography, University of Colorado Boulder; Andrew Parsekian, University of Wyoming; Logan Schmidt, University of Texas Austin; Daniella Rempe, University of Texas Austin* **Deep vadose zone moisture and its role in mitigating water stress in snow dominated montane forests: preliminary results**
3:00	**ADJOURN**

Detecting Forest Disturbance Impacts on Hydrology in Precipitation Dominated Whiplash Watersheds

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Wildfires are an increasingly common occurrence in the Western United States. A disproportionate percentage of western wildfires (61%) in the past 70 years have occurred within the most recent two decades. Mitigation measures – or "forest treatments" – such as plantation thinning, mastication and controlled burning, are being utilized to adapt to new fire regimes, mitigate fire intensity, and protect valuable resources. These treatments change forest structure which can alter the partitioning of water across the landscape. It is known that high intensity wildfires or treatments can lead to changes in runoff production, but few studies have looked at local hydrologic response when forest structure is not severely altered.

This project aims to improve our understanding of the impacts of forest treatment on water availability (water yield) in the western United States. The Sagehen Watershed, located in the Sierra Nevada Mountains of California, offers a unique location to study, with different types of forest treatment occurring between 2014 and 2020. Continuous 15-min stream flow measurements at nine subcatchments within the Sagehen Watershed from 2012-2020 provide the spatial and temporal resolution needed to examine localized changes in streamflow following treatment. For each of the nine subcatchments, we used typical methods of flow duration curves, runoff ratios, and change point analysis to analyze changes in annual water yield post-treatment. <u>With these methods, we aim to answer: how do forest treatments impact annual water yield in the Sagehen watershed?</u>

Across the watershed and in each of its nine subcatchments, <u>we find no detectable change in annual water yield due to forest treatment</u>. There are two likely explanations. <u>The first is simply that the disturbance was not great enough to change the partitioning of water across the landscape</u>; meaning that more intense or extensive treatment would be required to change water yield. <u>The second is that variation in water yield is so highly correlated to precipitation, that the signal from the forest disturbance is completely overpowered</u>. This second explanation is supported by bivariate linear models which find that precipitation accounts for >90% variation in yearly runoff depth. To complicate things, the recorded annual precipitation during the period of study, 2012-2020, was historic in both lows and highs, leading to huge variability in runoff. Given these dramatic swings in precipitation, characterized here as "whiplash," <u>quantifying the impacts of forest treatment methods, even with high resolution spatial and temporal data, is extremely challenging</u>. This work puts into context the challenge of disturbance based hydrology, and opens up a larger questions of how to quantify small changes in forest structure given high variability in climate.

Colorado’s Climate: Water Year 2021 in Review

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This presentation will provide an overview of Water Year 2021 (October 2020 – September 2021) for Colorado. WY2021 was warmer and drier than average for Colorado. While there was a lot of variability throughout the seasons, the summer was significantly warmer for the entire state. There was significant improvement from the 2020 drought, although many areas remain in long-term drought, and newer short-term drought has appeared.

Several notable events will be shared, including the significant late October cold snap that ended the 2020 wildfire season, an extreme cold outbreak in February, a March blizzard for the record books, a struggling snowpack and water supplies in the spring, and the return of the monsoon in 2021, which was both good and bad (good for drought relief, bad for flooding and debris flows).

The presentation will end with a brief update on how the signal of climate change shapes these (and future) events, and what we can expect to see over Water Year 2022.

Deep vadose zone moisture and its role in mitigating water stress in snow dominated montane forests: preliminary results

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Warming and declining snowpack are projected to continue across the western United States, leading to uncertainty about water resources and forest ecosystems. Atmospheric demand is expected to increase, while snowpack may decline, leading to lower plant available moisture during the growing season. As many montane forested watersheds are characterized by thin or absent soils and extensive rooting into fractured and weathered bedrock, deep vadose zone water is thought to be a central determinant in controlling late season water availability and may mitigate water stress during a changing climate. However, a key impediment to understanding the role of the deep vadose zone as a reservoir, lies in the challenge of quantifying the plant available moisture held here and its relationship to snowmelt and rainfall timing. As a result, questions remain about what controls moisture availability to plants during the growing season and when plants will experience water stress. Here, I will discuss an ongoing study focused on direct monitoring of water storage dynamics in weathered bedrock in the snow dominated Boulder Creek watershed. Boreholes distributed across two hillslopes are used to monitor rock moisture, a term parallel to soil moisture to describe water held in bedrock pores and fractures. The study hillslopes are underlain by biotite gneiss with weathering envelopes that range from 5-15 meters thick. The overlying vegetation is dominantly Ponderosa and Lodgepole pine with lesser Douglas fir. Continuous monitoring of soil moisture, rock moisture, sap flux, pre-dawn water potential, snowpack characteristics, and local meteorology allow us to relate storage dynamics of the thin soils and extensive weathered bedrock to the timing of water delivery and plant water stress. Preliminary results indicate extensive changes in rock moisture throughout the 2021 growing season are concurrent with changes in sap flux. Such observations suggest that rock moisture may be an important source of water for montane ecosystems and that the availability of this moisture may determine the impact of warming to these forest ecosystems.

POSTER

Spatiotemporal patterns in hydrologic connectivity within a montane headwater catchment in central Colorado

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Climate projections suggest that snowfall-dominated areas will decline substantially in the coming decades. Such climate impacts are already being observed in Colorado where the dominant source of annual peak discharge is shifting from snowmelt to rainfall, altering the paths by which water flows through a landscape and is ultimately delivered to streams. Observed climate driven shifts in stream flow dynamics and permanence highlight the increasing importance of understanding the hydrologic connectivity of uplands to streams in lower elevation, montane ecoregions. We collected geochemical and hydrometric data over three years to quantify hydrologic connectivity of uplands to a montane headwater stream at the Manitou Experimental Forest in central Colorado. We use a combined approach of concentration-discharge relationships and end-member mixing analysis, paired with high resolution measurements of soil moisture, precipitation, and groundwater levels to characterize source areas to the stream in 3-dimensions: longitudinal, lateral, and vertical. Samples were collected and measurements were recorded along the stream profile (longitudinal), from groundwater wells and soil lysimeters installed with increasing distance from the stream (lateral), and from shallow versus deep groundwater wells and soil moisture measured at different depths (vertical). Results indicate distinct differences in stream chemistry along the longitudinal stream profile, with highest concentrations at the most upstream sites and lowest concentrations at the most downstream sites. Stream solute concentrations increased with decreasing stream discharge values from spring to late summer. However, the stream remained chemostatic during all recorded rain storms, suggesting a difference in flow pathways during individual summer storm pulses. End member mixing analysis suggests spatiotemporal differences in shallow and deep vertical source areas, and between riparian and upland sources to the stream. These results provide a promising step towards quantifying the expansion and contraction of runoff source areas to a montane headwater stream.

Russian olive as an ecogeomorphic agent on the Powder River, Montana

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The distribution, spread, and impacts of the exotic invasive Russian olive (Elaeagnus angustifolia) on riparian plant communities and ecogeomorphic processes have been quantified in the U.S. Southwest. However, its range and impacts remain largely unknown in more northern regions. Within this context, the Powder River (Montana, U.S.) functions as a model fluvial system for studying the potential impacts Russian olive may have on local species composition and geomorphic processes. Specifically, we measured distribution, percent cover and topographic position of Russian olive, Tamarix (another exotic invasive) and native woody species (e.g., Populus) within the Powder River riparian corridor. Although Tamarix had the widest distribution of elevations relative to the channel, Russian olive had the lowest median elevation. Despite Tamarix's wide range of elevations, it had the least cover (3 % compared to 18–19 %) within the riparian corridor and was almost entirely restricted to positions adjacent to the channel. In fact, cluster analysis found woody communities of (1) Tamarix and Russian olive near the channel, (2) small (< ~2 m height) Russian olive, Populus, and Tamarix mixed on bars, and (3) floodplain Populus with an understory of Russian olive. The lack of Tamarix communities may be related to its lower cold tolerance. Intermediate-sized Populus were notably lacking, suggesting Russian olive may be outcompeting them during or following colonization opportunities. We additionally measured plant traits known to influence flood hydraulics and associated sediment transport. The best-fit functions for plant bending force (proxy for rigidity) as a function of plant size were exponential and indicated Russian olive is more rigid than both Tamarix and Populus. Russian olive's rigidity, high densities, low channel positions, and widespread existence as a shrubby canopy likely impact flow and sediment transport more than both invasive Tamarix and native Populus. In 2021, we resurveyed published cross sections collected sporadically (1979 – 1998; 2016). These surveys indicate significant bar accretion (up to ~1 m) accompanied by channel narrowing (up to ~ 20 m) since Russian olive invasion. This suggests Russian olive is causing channel change similar to that documented by Tamarix in the U.S. Southwest. Russian olive's broad habitat suitability combined with its high rigidity, low channel positions, and existence as a shrubby canopy suggest Russian olive will be a significant agent of geomorphic change in northern regions, with implications for habitat, flood routing, and channel evolution.

Mapping Russian Olive: Using Remote Sensing and Modeling to Detect and Map an Invasive Shrub along the Powder River in Montana and Wyoming

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Since its introduction in the late 1800s, *Elaeagnus augustifolia (*Russian olive) has become a widespread invasive shrub that poses a threat to native riparian species in the United States that directly competes with native riparian plants for space and resources. To date, limited information on the distribution of Russian olive in the Powder River Basin of Montana and Wyoming have hampered management efforts and decision making. Here, we detect and model the distribution of Russian Olive using field surveys, ocular sampling, and variables from Landsat 8 Operational Land Imager (OLI), Sentinel-2 MultiSpectral Instrument (MSI), and Shuttle Radar Topography Mission (SRTM) using the Random Forest algorithm. We derived topographic, spectral, and hydrological variables from Landsat 8 Operational Land Imager (OLI), Sentinel-2 MultiSpectral Instrument (MSI), and Shuttle Radar Topography Mission (SRTM) to utilize as model inputs. The team was able to successfully create a spectral Russian olive detection map for the Powder River Basin (RMSE = 15.44, $R^2 = 0.6482$). The team also examined change in stream channel geomorphology from 1984-2020 in a time-series analysis using Landsat visible imagery and the RivMap MATLAB package and found little change. Our results will help our partners at the Powder River County Weed Board, Gay Ranch, United States Geological Survey, and University of Northern Colorado to locate and prioritize areas for riparian habitat restoration and to understand the linkages between the distribution of Russian olive and the region's hydrology and geomorphology.

Low Head Dam Public Safety Initiative

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Over the past two years, the Colorado Department of Natural Resources (DNR) developed and implemented a program to raise awareness and provide information related to the locations of low head dams in Colorado and the hazards they present to river recreationalists. Low head dams are hidden hazards on rivers that often appear as attractive water features to inexperienced river users but instead are deadly hazards that drown victims by trapping them in a recirculating hydraulic current known as a “reverse roller” below the dam. So far, the safety program has included developing mapping of potential low head dam hazards in Colorado, creation of a website and public outreach campaign, and outreach to provide training to emergency water rescue units on low head dam hazards and safety. The program was developed in cooperation with partners including the Division of Water Resources (DWR), Colorado Parks and Wildlife (CPW), Colorado Water Conservation Board (CWCB), Colorado Division of Homeland Security and Emergency Management (DHSEM), Colorado Office of Outdoor Recreation, the Mile High Flood District, the engineering consulting industry, and the general public.

This presentation will provide an overview of the program developed by DNR and ongoing efforts to improve safety around these hazardous structures. The presentation will also discuss national efforts on this topic being led by the American Society of Engineers and the United States Society on Dams, as well as educational materials that have been developed for instructors in water resources and hydraulics to include in curriculum to educated engineering students on the hazards posed by low head dams and design methods to reduce hazards to the public.

Recollections of the Rocky Mountain Hydrologic Lab

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We will briefly describe the day to day activities at the variable slope flume (1956-1959) from the perspective of teen-agers who knew nothing about engineering or hydraulics, share some memories of Ches Posey who became a good friend, and answer questions.

Changes in snow water storage and hydrologic partitioning across the Western United States

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Seasonal snowpack is an essential component in the Earth's surface hydrological cycle. About one-sixth of the global population relies on seasonal snowpack and glacier-derived runoff as a primary water resource. Snowmelt contributes to regional water supply, partially dictating the timing and amount of downstream water resources. Mountain snowpacks act as a natural 'water tower,' storing winter precipitation until spring and summer months when downstream water demand is greatest. The magnitude and duration of regional snow water storage is thus a function of precipitation phase (as rain or snow) and the subsequent timing of water release, and is unevenly distributed and is highly sensitive to climate changes. We produce a Water Tower Index in this work to quantify the magnitude and duration of snow water storage, which evaluates the magnitude and temporal differences between precipitation and surface water input seasonality. Using modeled data from the Variable Infiltration Capacity model and observational snow monitoring stations, we compare long-term trends and changes in the Water Tower Index and find that 25% of the Western United States is decreasing in Water Tower Index ($p < 0.05$), and the average regional Water Tower Index is decreasing across the entire area ($p < 0.05$). This indicates a decrease in the amount and period of regional snow water storage. Water Tower Index trends are highly sensitive to annual and seasonal temperature and precipitation variability, which are relatively consistent across different regional mountain ranges. A decrease in snow water storage will fundamentally alter hydrologic and ecologic cycles, including hydrologic partitioning, and future water resource management.

Held v. State of Montana

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Our Children's Trust is a non-profit public interest law firm that supports youth-led climate lawsuits and legal actions. They have filed several youth-led lawsuits, such as Juliana v. United States, as well as state legal actions in all 50 states.

Held v. State of Montana is a constitutional climate lawsuit where 16 youth plaintiffs have declared that Montana is violating their constitutional rights to a clean and healthful environment; to seek safety, health, and happiness; and to individual dignity and equal protection of the law. Montana supports a fossil fuel-driven energy system, which is contributing to the climate crisis as well as negatively affecting Montana Held v. State of Montana's constitutional protected public trust resources.

Should the USGS Water Year be Sacred?

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The U.S. Geological Survey defines a water year 'as the 12-month period October 1 for any given year through September 30, of the following year' and is 'designated by the calendar year in which it ends'. The objective is to have a period where the water in the watershed is reasonably the same from year to year. In much of the United States that has been the September – October period. That is especially true for the western states where part of the precipitation is in late autumn and winter and accumulates as snow and does not melt and discharge from the watershed until the following spring and early summer. The theme of this presentation is that the standard USGS Water Year should not be sacred. For instance using standard water year is illogical for an analysis of the hydrology of the Rio Tanama in Puerto Rico and for Pipestem Creek in North Dakota the year used may need to be modify because of climate change: Two floods during 1985 in Puerto Rico showed that both low pressure from the northwest and tropical cyclones from the east are important causes of high water in the Rio Tanama. One was on 18 May with a peak of 12,200 cfs and the second on 7 October with a peak of 7840 cfs. There are two observations: the storm from the the northwest had a larger discharge than the hurricane season peak and the hurricane season is split by the USGS water year. An analysis of the maximum daily discharges for three periods suggests the period 1 March - 15 June represents storms from the northwest, and 16 June - 30 November represents tropical cyclones, and 1 December – 29 February a more-or-less dry period. Northwest (frontal) storms can occur in any of the three and tropical cyclones in the northwestern storm period but are very unlikely for the dry period. The hurricane season starts on 1 June and that has been used instead of 16 June. If we assume the discharge at the end/beginning of the water year should be similar from year from year than we should look at the variation in streamflows at the end of the year. The four possible water year ends selected for the Rio Tanama are standard USGS water year of 30 September, the end of the Hurricane season (30 November and two based on a review of the Rio Tanama discharge data (28 February and 31 March). The end of February was selected 28 February because that was the day with both the smallest mean daily discharge and standard deviation in discharge .Two conclusions for the Rio Tanama are 1) use a modified water year of 1 March – 28/29 February and 2) consider using two periods for flood analysis (the frontal period in April-May and the tropical cyclone season). An out-of-season flood occurred on the Pipestem Creek in North Dakota in 2019. The discharge was 2770 cfs on 24 September followed by 2830 cfs on 22 October during a period when the discharge is usually below 10 cfs. The standard water year was split by the period of high water. It is possible the water year needs to be adjusted to account for changes in climate. The data used in the paper were collected by the US Geological Survey for Rio Tanama near Utuado, PR (USGS station number of 50028000), Pipestem Creek near Buchanan, ND (06469500) and Pipestem Creek near Pingree, ND (06469400).

Enhanced rare earth element mobilization in a mountain watershed of the Colorado Mineral Belt with concomitant detection in aquatic biota: Increasing climate change-driven degradation to water quality

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In the western USA, one legacy of historic mining is drainage of acidic, metal-rich water generated by exposure to oxygen of sulfide minerals in mine workings, referred to as acid mine drainage (AMD). Streams receiving AMD and natural acid rock drainage (ARD) have a low pH, high dissolved metal concentrations, and extensive streambed metal oxide deposits. Recently, enhanced ARD generation in the Snake River watershed in the Rocky Mountains has been shown to be associated with the effects of Climate Change. Significant regional trends in rising summer air temperatures and declining baseflow over a near 40-year record appear to be driving this degradation of water quality. More frequent drought, reduced groundwater recharge, and the resultant expansion of the vadose zone are likely promoting increased weathering; thus rendering the exponential increases in solutes such a zinc and sulfate observed over the long-term record. In mountain watersheds where complex orogeny disseminated minerals throughout the landscape, AMD/ARD weathering processes may also mobilize rare earth elements (REEs). We report that in the Snake River REEs are currently distributed in streams at concentrations ranging from 1-100 µg/L. Further, the analysis of archived samples indicates that REE concentrations are increasing over time and concomitant to zinc. Moving from the headwaters to the downstream reaches of the Snake River, which eventually discharges into Dillon Reservoir, rising pH conditions appear to influence the fate and transport of REEs as well as sorptive interactions with colloidal and particulate metal oxides. We additionally present data on the accumulation of REEs in benthic invertebrates at concentrations comparable to well-known aqueous toxicants such as cadmium and lead, suggesting a potential ecosystem impairment. Although no REE ecotoxicity standards yet exists nor are they currently monitored as a possible emerging contaminant to mountain drinking water supplies.