42nd Annual

AGU Hydrology Days

April 25 – 27, 2022

COLORADO STATE UNIVERSITY

Lory Student Center – Grand Ballroom

STUDENT SHOWCASE

Tuesday April 26, 2022 | 1:30pm – 4:30pm (MST)

Lory Student Center – Grand Ballroom

Schedule: At-A-Glance

Monday April 25, 2022 – CSU Lory Student Center, Grand Ballroom

Time (MST)	Session
8:30 - 9:30 am	Registration
9:30 - 10:30 am	Agricultural Water & Economics
10:30 - 10:45 am	*Break*
10:45 - 11:45 am	Agricultural Water & Economics
12:00 - 1:00 pm	*Lunch*
1:00 - 2:00pm	**Borland Hydraulics Award Keynote Lecture: Dr. Ana Barros** *The Colors of Water - Observing, Modeling and Understanding Precipitation Processes Across the World's Mountains*
2:00 - 3:15pm	Climate, Meteorology & Snow Hydrology
3:15 - 3:30pm	*Break*
3:30 - 4:30pm	Wildfires & Watershed Protection

Tuesday April 26, 2022 – CSU Lory Student Center, Grand Ballroom

Time (MST)	Session
8:30 - 9:30 am	Registration
9:00 - 9:30 am	Poster Session
9:30 - 11:00 am	Hydraulics & Geomorphology
11:00 am - 12:00 pm	*Lunch*
12:00 - 1:00 pm	**Hydrology Days Award Keynote Lecture: Dr. Soroosh Sorooshian** *Hydroclimate Modeling and Water Resources Systems Engineering and Management: Expectations, Promises, Reality and Prospects*
1:15 - 2:45 pm	Student Showcase: Session A
2:45 - 3:00 pm	*Break*
3:00 - 4:30 pm	Student Showcase: Session B
4:45 - 6:00 pm	**Norm Evans Lecture & Reception: Dr. Jery Stedinger** *Hydrology in the Public Interest: Journey to Improve US Federal Guidelines for Flood Frequency Analysis*

Wednesday April 27, 2022 – CSU Lory Student Center, Grand Ballroom

Time (MST)	Session
8:30 - 9:30 am	Registration
9:30 - 10:30 am	Hydrologic Systems
10:30 - 10:45 am	*Break*
10:45 am - 12:00 pm	Hydrologic Systems Public Health
12:00 - 1:00 pm	*Lunch*

1:00 - 2:00pm	**Borland Hydrology Award Keynote Lecture: Dr. Ellen Wohl** *Wood in Rivers: Insights from the Headwaters*
2:00 – 3:30 pm	Integrated River Basin Planning & Management (Grand Ballroom) The Writing Water Project Workshop: Water-Focused Experiential Learning and Literacy (LSC#322)
3:45 pm	*Closing Remarks & Adjourn*

PRESENTATION SCHEDULE

Monday April 25, 2022

Session	Time	Presenter	Title
Agricultural Water & Economics	9:30 AM	Calvin Bryan	*Resource Management, Risk, and Insurance: A Decomposition of Groundwater Management Impacts in the Ogallala Region*
	9:45 AM	Zaichen Xiang	*Quantifying the Impact of Climate and Management Strategies on Groundwater Conservation in the High Plains Aquifer*
	10:00 AM	Morgan Effrein	*Colorado State University Agriculture Water Quality Program Best Management Practices to Reduce Nonpoint Source Pollution*
	10:15 AM	Sanskriti Shrestha	*Modeling the Effects of Groundwater Salinity Increases on Crop Yield in the LARV*
	10:30 AM	BREAK	
	10:45 AM	Catherine Schumak	*Goodwater Creek Experimental Watershed: Hydrology Modeling with the AgES Model*
	11:00 AM	Kendall DeJonge	*Using Infrared Thermometry to Schedule Irrigation with Limited Water*
	11:15 AM	Edson Costa Filho	*Evaluating One-Source Evapotranspiration Models When Using Multispectral Data From High-Resolution Satellites*
	11:30 AM	Zarif Rasul	*Economics of Deficit Irrigation: How Much does Production Risk Matter?*
Keynote Lecture	1:00 PM	Dr. Ana Barros	*The Colors of Water - Observing, Modeling and Understanding Precipitation Processes Across the World's Mountains*
Climate, Meteorology & Snow Hydrology	2:00 PM	Patrick Keys	*The Dry Sky: Futures for Humanity's Modification of the Atmospheric Water Cycle*
	2:15 PM	Ahmed Gharib	*Can Investment in Storage Infrastructure Reduce Water Shortages?*
	2:30 PM	Putri Komala Dara	*The Impact of Extreme Drought on Crop Abandonment in the Ogallala Aquifer Region*
	2:45 PM	Jai Hong Lee	*The Impacts of the Extreme Phases of the Southern Oscillation on Rainfall Erosivity over the United States*
	3:00 PM	Helen Flynn	*Assessment of Baseflow Characteristics in Snow-Dominated Watersheds*

Schedule continued to next page

	3:15pm	BREAK	
Wildfires & Watershed Protection	3:30 PM	Jeremy Giovando	Temperature Index Snowpack Model Parameter Adjustments for Wildfire Impacted Watersheds
	3:45 PM	Kate Boden	Impact of Forest Treatment Practices on Mountain Watersheds
	4:00 PM	Haley Canham	Post-Wildfire Rainfall-Runoff Event Response Variability Across Space and Time In Monitored Nested Watersheds In The Colorado River Headwaters
	4:15 PM	Elizabeth Motter	Quantifying the Effect of Fire on Salinity Movement in an Upper Colorado River Watershed

Tuesday April 26, 2022

Session	Time	Presenter	Title
Posters	9:00 AM	Tanner Bonham	Characterizing Nitrogen & Phosphorus Loads Delivered to Streams from Agricultural Landscapes at Various Watershed Scales
	9:00 AM	Lily Bosworth	Modeling Nitrate Removal Within the Biomat of Open-Water Engineered Wetlands to Optimize Long-Term Treatment
	9:00 AM	Thomas Heydman	Next Generation Basin-Wide Snotel Monitoring Network
	9:00 AM	Seungho Lee	The Teleconnections Between Large-scale Climate Indices and Precipitation Patterns over the United States
Hydraulics & Geomorphology	9:30 AM	Jongseok Cho	Numerical Study on Sediment Transport and Alluviation in Mixed Bedrock-Alluvial Channel
	9:45 AM	Eleanor Henson	Development Of A SWAT Hydrologic Model to Predict Salt Transport In An Upland Desert Catchment Of The Lower Arkansas River Basin
	10:00 AM	Chenchen Ma	Evaluation Of Stream Physical Habitats In Headwater Streams Under Climate Change Projections For Greenback Cutthroat Trout In The Southern Rocky Mountains, Colorado
	10:15 AM	Joseph Pugh	Addressing the Flow Measurement Conundrum
	10:30 AM	Alex Wittmershaus	Scour Failure of Bendway Weirs And Rock Vanes: Observations And Data From A Curved Flume
Keynote Lecture	12:00pm	Dr. Soroosh Sorooshian	Hydroclimate Modeling and Water Resources Systems Engineering and Management: Expectations, Promises, Reality and Prospects

Schedule continued to next page

STUDENT SHOWCASE: SESSION A			
Student Showcase (A)	1:15 PM	Julianne Liebenguth	Analyzing Security as a Source of Legitimacy across the FEW Nexus (#1A)
	1:20 PM	Azmal Hossan	Systems Level Thinking Approach to the Study of Water Dispute in South Asia (#2A)
	1:25 PM	David Woodson	How Unprecedented Is The Current Colorado River Drought? A Paleo Perspective (#3A)
	1:30 PM	Joey Blumberg	Every County Has Unique Climate Risks. What Are Yours? (#4A)
	1:35 PM	Ahmed Gharib	Can Investment in Storage Infrastructure Reduce Water Shortages? (#5A)
	1:40 PM	Kimberly LeMonde Fewless	Colorado Open Space Programs and Water Sharing: Barriers and Opportunities (#6A)
	1:45 PM	Benjamin Choat	Towards Timely Policy-Relevant Analysis Of The Return On Investment From Ecosystem Services In The South Platte River Basin (#7A)
	1:50 PM	Avery Driscoll	Irrigation Expansion As A Climate Change Adaption Strategy: Implications For Greenhouse Gas Emissions (#8A)
	1:55 PM	Caroline Dewey	Optimizing Dryland Farm Productivity Using the Relationship among Crop Water Use, Planting Density, and Yield Performance (#9A)
	2:00 PM	Tanner Bonham	Characterizing Nitrogen & Phosphorus Loads Delivered to Streams from Agricultural Landscapes at Various Watershed Scales (#10A)
	2:05 PM	Brandi Grauberger	Techno-economic and Other Stakeholder Considerations for Saline Wastewater Management: A Case Study of The Beef Processing Industry (#11A)
	2:10 PM	Christopher Toy	Is Solar Energy an Obstacle or Opportunity for Farmers? (#12A)
	2:15 PM	Liz Ross	Residential Rooftop Solar Expansion in Fort Collins, Colorado (#13A)
	2:20 PM	Christina Lilligren	Local Forecast Accuracy and the Implications to Smart Irrigation Technology (#14A)
	2:25 PM	Jorge Rico-Reyes	Rewired Anaerobic Digestion: Developing More Sustainable Chemical Factories (#15A)
	2:30 PM	Annika Weber	Arsenic Speciation In Rice Bran: Agronomic Practices, Postharvest Fermentation, And Human Health Risk Assessment Across The Lifespan (#16A)
	2:45pm		BREAK

Schedule continued to next page

STUDENT SHOWCASE SESSION B			
Student Showcase (B)	3:00 PM	Muhammad Ukasha	An Improved Rescaling Algorithm for Estimating Groundwater Depletion Rates using the GRACE Satellite (#17B)
	3:05 PM	Cavin Alderfer	Analyzing Groundwater Storage Trends in the United States from 1951 to 2020 (#18B)
	3:10 PM	Daniel White	Fluvial Response In A Meandering Reach Of A Headwater Stream One Year After Wildfire (#19B)
	3:15 PM	Andrew Schied	Habitat Mapping of the Silvery Minnow in the Middle Rio Grande, Bosque Del Apache Reach (#20B)
	3:20 PM	Anna Marshall	Characterizing Logjams from Remotely Sensed Imagery (#21B)
	3:25 PM	Julianne Scamardo	Drivers of Geomorphic Complexity In Dryland Ephemeral Streams Across The Southwestern United States (#22B)
	3:30 PM	Charles VanTilburg	Novel, Internet-of-Things-based, Solid-State pH Sensors for Soil and Groundwater (#23B)
	3:35 PM	Kate Hale	Changes in Snow Water Storage Across Western North America (#24B)
	3:40 PM	Emily Iskin	Measuring Floodplain Heterogeneity from Remote Imagery and Field Data: A Sensitivity Analysis (#25B)
	3:45 PM	Dixie Poteet	Semi-Arid Rangeland to New Houses: Behavior of a Non-Perennial Stream (#26B)
	3:50 PM	Quinn Miller	Streamflow Generation across an Elevation Gradient after the 2020 Cameron Peak Fire (#27B)
	3:55 PM	Abdullah Al Fatta	Quantifying Contributions of Water Sources to Urban Streams and Temporal Variation Using Multiyear Analysis of Water Stable Isotopes (δ18O and δ2H) (#28B)
	4:00 PM	Wyatt Reis	Where Did The Snow Go? Physical Processes Driving Accumulation And Ablation Patterns In Wildfire Burn Areas (#29B)
	4:05 PM	Erin Sherman	Expected Changes in the Snowpack of the Colorado Front Range (#30B)
	4:10 PM	Thomas Heydman	Next Generation Basin-Wide Snotel Monitoring Network (#31B)
	4:15 PM	Kate Boden	Impact of Forest Treatment Practices on Mountain Watersheds (#32B)
	4:20 PM	Jacob VanderRoest	Utilizing Ultrahigh Resolution Mass Spectrometry to Elucidate the Composition of Dissolved Organic Matter in Fire-Affected Headwaters (#33B)
Reception & Keynote Lecture	4:45pm	Dr. Jery Stedinger	Hydrology in the Public Interest: Journey to Improve US Federal Guidelines for Flood Frequency Analysis

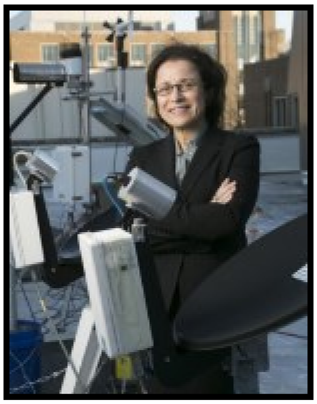
Wednesday April 27, 2022

Session	Time	Presenter	Title
Hydrologic Systems	9:30 AM	Robert Milhous	Climate Change and Seasonal Maximum Flows
	9:45 AM	Dixie Poteet	Semi-Arid Rangeland to New Houses: Behavior of a Non-Perennial Stream
	10:00 AM	Abdullah Al Fatta	Quantifying Contributions of Water Sources to Urban Streams and Temporal Variation Using Multiyear Analysis of Water Stable Isotopes (δ18O and δ2H)
	10:15 AM	Daniel Thurber	Streamflow Response to Snowmelt in a Karst Mountain System
	10:45 AM	Charles VanTilburg	Novel, Internet-of-Things-based, Solid-State pH Sensors for Soil and Groundwater
	11:00 AM	Kristen Cognac	Nested Piezometer Network Captures Spatiotemporal Variations in Streambed Fluxes Along Colorado Mountain-Front Streams
	11:15 AM	Boran Kim	Incorporating Probabilistic Variations in Soil Moisture Downscaling
Public Health	11:30 AM	Susan De Long	Monitoring and Preventing COVID-19 Outbreaks: A Comparison of Sewershed-Level and Building-Level Monitoring
Keynote Lecture	1:00 PM	Dr. Ellen Wohl	Wood in Rivers: Insights from the Headwaters
Integrated River Basin Planning & Management	2:00 PM	Richard Koehler	Using a Temporal Configuration-based Approach to Quantify Streamflow Properties
	2:15 PM	Benjamin Choat	Identifying Important Drivers Of Water Yield Across Spatial And Temporal Scales And Most Appropriate Data-Driven Methods For Prediction
	2:30 PM	Donya Dezfooli	An Introduction to Self-Assessment Framework for One Water Cities: A Roadmap to Support One Water Future and Guide Management Actions
	2:45 PM	Kira Simonson	Quantitative Assessment Of Floodplain Functionality For The Continental United States Using An Index Of Integrity
	3:00 PM	Omar Nofal	The Role of Soft and Hard Interventions to Adapt and Mitigate Flood Impacts at the Building- and Community-Level
	3:15 PM	Tyler Wible	Assessing the Effects Of Alternative Flow Scenarios On Rivers And Their Aquatic And Riparian Habitats Using the REFDSS Web Tool
Writing Water Project Workshop (#LSC 322)	2:00 – 3:30 PM	Emily Iskin	Water-Focused Experiential Learning and Literacy

KEYNOTE SPEAKERS

Borland Hydrology Award

Dr. Ana Barros – Donald Biggar Willett Chair of Engineering, Department Head and Professor University of Illinois Urbana-Champaign



Ana P. Barros is the Donald Biggar Willett Chair of Engineering, Department Head and Professor at the University of Illinois Urbana-Champaign. Ana received a Diploma in Civil Engineering with majors in Structures and Hydraulics and M.Sc. degree in Ocean Engineering from University of Porto, M.Sc. degree in Environmental Science Engineering from the OHSU/OGI School of Science and Engineering, and a Ph.D. in Civil and Environmental Engineering from the University of Washington, Seattle in 1993. Her primary research interests are in Hydrology, Hydrometeorology and Environmental Physics with a focus on water-cycle in the coupled land-atmosphere-biosphere system particularly in regions of complex terrain, remote sensing of the environment (precipitation, clouds, soil moisture, and vegetation), climate predictability, and extreme events. Over recent years her work has focused on precipitation processes including microphysics and dynamics or orographic precipitation, and land-atmosphere interactions in mountainous regions from the Himalayas to the Andes and the Southern Appalachians including land-use land-cover change impacts on regional climate

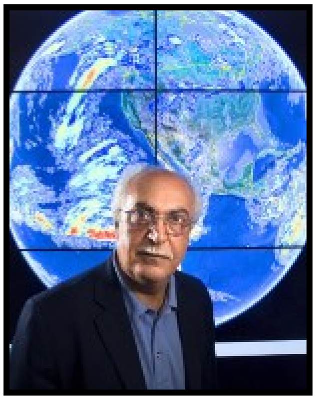
Keynote Lecture: April 25, 2022, 1pm – CSU Lory Student Center, Grand Ballroom

The Colors of Water – Observing, Modeling and Understanding Precipitation Processes Across the World's Mountains

Abstract: Water prediction at the temporal and spatial scales to make decisions that matter for resilience and prosperity of human and natural systems remains a quintessential civil and environmental engineering quest in the 21st century. For those of us among the early generation of scientists and engineers who benefitted from NASA's Mission to Planet Earth vision in the last quarter of the 20th century, the advent of ever-higher performance computing and Big Data, and met with the inevitability of interdisciplinary science, it's been the most challenging and yet optimistic of times. Over the last two decades, my research group operated monitoring networks and conducted long-term water-cycle studies in mountainous regions high and small, including some of the most biodiverse hotspots in the world, that provide water resources to nearly two billion people and counting. In this presentation, I will focus on selected research findings from our work in the Himalayas, the Andes, and the Appalachian Mountains that reveal the complex multi-scale multi-physics interactions at the interface of Ecology, Atmospheric and Hydrologic Sciences with implications for re-thinking engineering frameworks to address global water security and climate adaptation problems.

AGU Hydrology Days Award

Dr. Soroosh Sorooshian – Distinguished Professor, Dept of Civil and Environmental Engineering and Earth System Science, Director, Center for Hydrometeorology and Remote Sensing
The Henry Samueli School of Engineering, University of California, Irvine



Sorooshian is a Distinguished Professor of Civil and Environmental Engineering and Earth System Science Departments and Director of the Center for Hydrometeorology & Remote Sensing (CHRS) at University of California Irvine. His area of expertise includes the interface of global hydrologic cycle, and climate system. He is a member of the U.S. National Academy of Engineering (NAE), the International Academy of Astronautics (IAA), and the World Academy of Sciences (TWAS); Fellow, American Geophysical Union (AGU), Fellow, American Meteorological Society (AMS), and Fellow, American Association for the Advancement of Science (AAAS). He is the current Chair of the Rosenberg International Forum on Water Policy, University of California, Division of Agriculture and Natural Resources and has served as the Present and Past Member and Chair of over 30 other advisory and review committees and boards for NASA, NOAA, DOE, EPA, NSF, National Labs, UNESCO, WMO, and professional societies. National Research Council (NRC) service over the past 15 years includes member of 7 NRC committees and Chair of GEWEX Panel. He has also testified to both U.S. House of Representatives and U.S. Senate Committees on issues related to water, climate and satellite programs.

Keynote Lecture: April 26, 2022 12pm – CSU Lory Student Center, Grand Ballroom

Hydroclimate Modeling and Water Resources Systems Engineering and Management: Expectations, Promises, Reality, and Prospects

Abstract: Addressing the needs of water resources management and hydrologic hazards requires information either from predictive models or traditional statistical methods. With the recent exponential growth in the number of publications related to the use of climate models and regional downscaling studies in water resources, it begs the question of how effective and valuable the results of these studies are to the "user community". This presentation reviews the expectations, promises, reality and prospects of the applications of Hydroclimate modeling in addressing hydrologic and water resources problems. Recent advances in hydrometeorological high resolution observations of precipitation will also be discussed.

Dr. Norm Evans Lecture

Dr. Jery Stedinger – Dwight C. Baum Professor of Engineering
Dept. of Civil and Environmental Engineering – Cornell University

Jery received a B.A. in Applied Mathematics from the University of California at Berkeley in 1972, and a Ph.D. in Environmental Systems Engineering from Harvard University in 1977. Since that time he has been a professor in Cornell's School of Civil and Environmental Engineering. He spent his 1983-84 sabbatical at the U.S. Geological Survey's national headquarters in Reston, Virginia, and his 1999 sabbatical at the US Army Corps of Engineers Institute for Water Resources at Ft. Belvoir, Virginia. He spent his 2005 sabbatical at the US Army Corps of Engineers Hydrologic Engineering Center (HEC) in Davis, California, and his 2010 sabbatical again with the U.S. Geological Survey in Reston, Virginia. His Fall 2017 sabbatical was with the Technische Universität Wien in Austria. Dr. Stedinger's research has focused on statistical issues in hydrology and optimal operation of water resource systems. Research projects have addressed the value of historical and paleoflood data in flood frequency analysis, regional hydrologic regression and network analyses, risk and uncertainty analysis of flood-risk reduction projects, calibration and uncertainty analysis for rainfall-runoff models, stochastic simulation of water resource systems, and efficient multiple-reservoir and hydropower system operation considering dynamic energy markets and stochastic inflows and forecasts. Other efforts address statistical issues associated with characterization of geothermal resources as part of the planning and risk assessment for such renewable energy projects.

Keynote Lecture & Reception: April 26, 2022 4:30pm – CSU Lory Student Center, Grand Ballroom

Hydrology in the Public Interest: Journey to Improve US Federal Guidelines for Flood Frequency Analysis

Abstract: US Federal agencies agreed on uniform floodflow frequency procedures in 1976 with publication of Bulletin 17, updated to Bulletin 17B in 1982, and finally Bulletin 17C in 2018. The interagency (HFAWG) Workgroup spent a decade testing and developing new robust methods adopted in Bulletin 17C. Important differences between Bulletin 17B and 17C are use of the Expected Moment Algorithm (EMA) that allows appropriate treatment of historical data, zero flows, censored crest-stage records, and Potentially Influential Low Floods (PILFs). Correct uncertainty analysis calculations were adopted. Recommended Bayesian regional GLS skew estimators indicate regional skews are much more accurate that previously described.

Borland Hydraulics Award

Dr. Ellen Wohl – Professor of Geology and University Distinguished Professor
Dept. of Geosciences – Colorado State University

Ellen Wohl received a BS in geology from Arizona State University and a PhD in geosciences from the University of Arizona before joining the faculty at Colorado State University in 1989. Her research focuses on physical process and form in river corridors, including interactions with biotic and human communities. She has focused particularly on rivers in bedrock canyons and in mountainous regions, and she has conducted field research on every continent but Antarctica. She has written more than 200 scientific papers and book chapters, as well as 16 books, and is a Fellow of the American Geophysical Union and the Geological Society of America. Much of her current research examines how physical complexity associated with the presence of instream wood and beaver dams influences the form and function of river ecosystems. Ellen's research has followed an anabranching path through time. Her dissertation research focused on sedimentary records of ancient floods along bedrock canyons in northern Australia. Working in these canyons, she became intrigued by their channel morphology and the processes that created and maintained this morphology, so for several years she worked primarily on bedrock canyons. Many of these canyons occur in mountainous environments. Living in Colorado, the Front Range and Rocky Mountain National Park are the 'backyard' research sites, so my research focus shifted gradually toward mountain streams. The mountain streams of Colorado include a fair amount of instream wood. At some point she realized that most of the existing research on instream wood had been done in the very different environment of the Pacific Northwest, so that led her to focus on wood dynamics in Colorado and in headwater neotropical streams of Panama and Costa Rica. Wood dynamics in mountainous headwater streams are intimately connected to carbon cycling, stream metabolism, and river ecosystem productivity, and now several research projects focus on these aspects of mountain streams. In the course of mapping logjams in Rocky Mountain National Park, she kept coming across abandoned beaver dams, and began to wonder about the effects of these dams on carbon cycling and watershed-scale biogeochemistry. That's a big component of the fun of research: you start on one path, but never know exactly where it will take you

Keynote Lecture & Reception: April 27, 2022 1pm – CSU Lory Student Center, Grand Ballroom

Wood in Rivers: Insights from the Headwaters

Abstract: Drawing on three decades of field-based research in mountain streams of the Colorado Front Range, I summarize spatial and temporal patterns of large wood distribution in channels and floodplains and examine the implications with respect to fundamental river processes including hyporheic exchange, habitat, biomass, and organic carbon storage. Using the natural wood regime and wood process domains as a conceptual framework, I touch on implications for river management and restoration.

AGRICULTURAL WATER & ECONOMICS

Resource Management, Risk, and Insurance: A Decomposition of Groundwater Management Impacts in the Ogallala Region

Calvin Bryan, Christopher Goemans, Dale T. Manning, and Matthew R. Sloggy
Department of Agricultural and Resource Economics, Colorado State University

Determining the optimal regulation of commonpool resources, such as groundwater, is an area of critical research significance. Aiming to curb groundwater depletion rates, local resource managers positioned on the Ogallala Aquifer in the central US have implemented a variety of regulations (well-drilling moratoriums, allocation schemes, etc.) over the last several decades. Previous work estimating agricultural producer responses to these groundwater regulations has assumed that the impacts only occur through direct channels (Drysdale & Hendricks; 2018). In this research, we estimate the response of Federal Crop Insurance policy rates to local groundwater management policies and use our estimates to disentangle conservation policy impacts into direct effects and those that result indirectly through the impact of changing insurance prices on producer behavior. We find that the passage of an allocation scheme corresponds to an increase in the price of crop insurance for irrigated corn, both for subsidized and unsubsidized insurance rates. We also find a statistically significant increase in the total federal subsidy dollars provided to agricultural producers covered by an allocation scheme, giving us evidence that the costs of increased risk from a groundwater restriction policy are borne in part by society and in part by the federal government. Using parameter estimates from Sloggy et al. (2019) and Drysdale & Hendricks (2018), we find this indirect channel makes up a nontrivial portion of an allocation scheme's impact on total irrigation. This research adds to the body of literature on the effects of conservation policy, importantly contributing significantly to discussions of policy vs. technology as a means of sustainable resource management. We believe this work is also important as it informs the different ways in which hydrologic demand may fluctuate following the passage of a groundwater restriction while also highlighting the need to take the totality of the institutional environment into account when implementing a conservation policy prescription. Future work on our end will focus on determining what mechanism(s) could be driving this insurance market response to a groundwater restriction.

Quantifying the Impact of Climate and Management Strategies on Groundwater Conservation in the High Plains Aquifer

Zaichen Xiang and Ryan T. Bailey
Department of Civil & Environmental Engineering, Colorado State University

Groundwater in many semi-arid regions is being depleted due to over-exploitation. The objective of this study is to assess crop yield and groundwater storage under scenarios of future climate, irrigation system implementation, and planting decisions in a region of the High Plains Aquifer using a linked hydro-agronomic model, DSSAT-MODFLOW. The modeling framework is applied to Finney County, Southwest Kansas, an intensively cultivated area that has experienced severe groundwater depletion over the past 50 years due to irrigation practices. The approach of sensitivity analysis is used to determine the best set of DSSAT and MODFLOW parameters, and

then use the calibrated and tested model to quantify the impact of climate (downscaled climate data from global circulation models) and management practices (irrigation type, field planting levels) on crop yield and water table elevation during the 2021-2050 period. If only climate is considered, groundwater saturated thickness will likely be decreased by 20%-50% by 2050. Combined scenarios indicate that to maintain adequate crop yields, groundwater levels will decline no matter the type of irrigation system used (surface, drip, sprinkler) or the cultivation level implemented (quarter-plot, half-plot, and full-plot). Therefore, groundwater storage can only be conserved, not sustained. However, crop yields can be maintained with acceptable drawdown (< 0.6 m/yr.) for several combination strategies, including drip or sprinkler irrigation with quarter-plot planting. Of course, a drier future with higher carbon emission limits the number of possible strategies that meet both the crop yield and groundwater conservation criteria. Results from this study can be used to guide management strategies in regions throughout the High Plains Aquifer and other groundwaterirrigated regions worldwide.

Colorado State University Agricultural Water Quality Program Best Management Practices to Reduce Nonpoint Source Pollution

Morgan Effrein
Agricultural Water Quality Program, Colorado State University

The Agricultural Water Quality Program (AWQP) is a Colorado State University Extension program that focuses on developing and testing agricultural Best Management Practices (BMPs) to improve water quality and soil health. BMPs help agricultural producers around the state of Colorado to manage non-point source pollutants from agriculture, such as fertilizers, pesticides, E. coli, nitrogen, phosphorus, and other contaminants that are discharged into receiving waters during storms or irrigation events. BMPs come in many forms; from filter strips intended to reduce nutrient pollution to sediment fences to reduce erosion. By monitoring and testing BMPs' effect on water quality, the State of Colorado and agricultural producers can better meet total maximum daily load (TMDL) standards and protect our water quality.

Modeling the Effects of Groundwater Salinity Increases on Crop Yield in the Lower Arkansas River Valley

Sanskriti Shrestha[1], Ryan T. Bailey[1], Miguel Acevedo[2], Breana Smithers[2]
1 Department of Civil and Environmental Engineering, Colorado State University
2 Department of Electrical Engineering, University of Northern Texas Abstract

The Lower Arkansas River Valley (LARV) has been historically crucial to Colorado agriculture, particularly for corn, melons, onions, and peppers. Recent studies of the groundwater and river water have shown significant salinity increases, enough to reduce crop yield throughout the valley. In an attempt to decrease soil salinity and thereby improve soil health and long-term crop yield, this study uses on-farm desalination technology to remove salt mass from irrigation water for 16 experimental plots near Rocky Ford, Colorado. The overall goal is to observe the feasibility of the application of treated water on the improvement of the crop yield and eventually the groundwater quality over multiple seasons. Custom mixes of cover crops grown on the plots

provided data throughout the growing season. The plots were supplied direct well water and reverse osmosis (RO) permeate through drip irrigation, with varying irrigation rates according to temporally-varying water stress. This presentation provides preliminary results for soil response. Research-grade soil sensors recorded daily water content, temperature, and electrical conductivity (EC) at 6- and 12-inch depths within each of the 16 plots. The average water content increased by 0.01 m3 /m3 , and EC decreased by 1.2 mS/cm when RO permeate was used instead of direct well water for irrigation at 6 inches soil profile. However, at 12 inches depth, the average water content decreased by 0.01 m3 /m3, and EC increased by 0.02 mS/cm. This trend demonstrated the salt leaching capacity of the fields that used RO permeate irrigation water. The HYDRUS 1D numerical model is used to simulate water flow and salt transport, to investigate the long-term leaching trends for plots with and without treated irrigation water.

Goodwater Creek Experimental Watershed: Modeling Hydrology with the AgES Model

Catherine Schumak[1,2], Tim Green[2], Jim Ippolito[1], Allan Andales[1], Holm Kipka[3], Nathan Lightheart[2], Amy Ritter[4], & Clint Truman[5]
1 Department of Soil & Crop Sciences, Colorado State University
2 USDA-ARS Fort Collins
3 Department of Civil & Environmental Engineering, Colorado State University
4 Waterborne Environmental Inc.
5 Syngenta

Goodwater Creek Experimental Watershed (GCEW) is a small (72 km2), but mighty watershed located near Centralia, Missouri. GCEW is a headwaters watershed of the Salt River basin which flows to Mark Twain Lake, a major source of drinking water for the area. Thus, monitoring nutrient and pollutants is important to protect human and environmental health. The site was established in early 1970's as part of the Central Mississippi River Basin Long-Term Agroecosystem Research to study the effects of conservation practices and claypan hydrology on water quality at the watershed scale. Since then, GCEW has been studied extensively, with streamflow and climate data beginning in 1971 and water quality and socio-economic data in 1991. The watershed contains primarily agricultural land, with soybeans, corn, and wheat being the main crops. An average of 1000 mm of precipitation falls annually with the wettest seasons being winter and spring. The topography is flat with only 37 m elevation gain. The claypan soils, defined as a subsurface argillic clay layer with 50-60% clay content, have very low hydraulic conductivity when saturated, making it prone to high runoff. In contrast, cracks form during dry periods and allow for percolation. In GCEW, 85% of streamflow comes from runoff and 15% from groundwater. This makes the watershed vulnerable to surface transport of sediment, herbicides, and nutrients. Atrazine, a common herbicide, has concentrations consistently amongst the highest for a watershed in the US. This project models the hydrology of GCEW using the Agricultural Ecosystem Services (AgES) watershed model developed by the Agricultural Research Service. AgES is a fully-distributed model that can represent the spatial distribution of climate and physical watershed characteristics to route water explicitly through Hydrologic Response Units (HRUs) and stream reaches. While GCEW has been modeled before, it has not been modeled using a fully-distributed model like AgES. It is vital to realistically model the hydrology of the watershed,

as the hydrology is a major driver in the fate and transport of sediment, nutrients, and pesticides. The hydrology modeling sets the stage for future modeling efforts including nitrogen, phosphorus, and atrazine.

Using Infrared Thermometry to Schedule Irrigation with Limited Water

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2 Northern Water

As irrigated agriculture faces uncertainty and limited water resources, managing water under limited irrigation becomes increasingly important. Detecting crop water stress, both over time and space, is challenging but possible using infrared thermometry to measure canopy temperature. In this talk we discuss an ongoing experiment at the Limited Irrigation Research Farm near Greeley, CO, where canopy temperature is used as an indicator to both trigger irrigation and quantify crop consumptive use. This technology has potential to be scaled spatially to inform variable rate irrigation systems.

Evaluating One-Source Evapotranspiration Models When Using Multispectral Data From High-Resolution Satellites

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Sustainable agricultural water management is critical to conserving water and soil resources at the farm level. Furthermore, satellite images with high spatial resolution and frequent revisiting time have recently become a reliable tool for spatially monitoring actual crop evapotranspiration (ETa) and optimizing irrigation scheduling. This study evaluates the performance of three one-source surface energy balance models (Models M1, M2, M3) designed to estimate daily ETa. Data from two different satellite platforms with high spatial resolution have been used. The ETa models use different empirical aerodynamic temperature (To) equations developed to estimate sensible heat flux, a key land surface energy balance component. All three aerodynamic temperature models used micrometeorological – and remote sensing (RS) – based inputs as predictors. The analysis considered data from two sub-surface drip maize fields (20,900 m2 each) collected in August 2020 at the USDA ARS Limited Irrigation Research Farm (LIRF) near Greeley, CO. The West and East fields were the non-water stress and water deficit plot, respectively. An in-situ Eddy Covariance energy balance system provided the needed data for estimating and evaluating surface heat fluxes, To, and daily ETa products. The analysis considered each field as a point in space. Stationary nadir-looking infrared thermometers provided surface temperature data from three different locations. Fifteen Planet CubeSat (3-m spatial resolution) and twelve Sentinel-2 (10-m spatial resolution) multispectral images (bottom-of-the-atmosphere) during clear-sky days were the RS data used in the study during August 2020. Preliminary results indicate that the combination of Sentinel-2 multispectral and pointbased surface temperature data resulted in a 35% smaller root mean squared error (RMSE) compared to Planet CubeSat's daily ETa results across all evaluated models. Model M1 underestimated daily

ETa by 3% and 5% when using 10-m and 3-m spatial resolution images, respectively. Model M2 overestimated daily maize ETa by 5% and 17% when using Sentinel-2 and Planet CubeSat images, respectively. Model M3 displayed the smallest overestimation (3%) and underestimation (-1%) of daily ETa for the 3-m and 10-m image spatial resolutions, respectively. Model M1 outperformed, on average, models M2 and M3 regarding the To estimation by 37% and 59%, respectively.

Economics of Deficit Irrigation: How Much Does Production Risk Matter?

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In an era of rising water scarcity, agricultural managers face increased pressure to embrace flexible on-farm water management systems. These systems will control irrigation water use and enable the diversion of water savings to alternative uses. Typically, irrigation is utilized to achieve high yields and reduce yield fluctuations caused by water deficits. Deficit irrigation is one strategy being evaluated as a flexible water management tool. The goal is to decrease crop water use below crop water demand; however, this is paralleled by a reduction in yield and an increase in yield variance. We compare the profitability of two irrigation strategies using 'stochastic efficiency with respect to a function' – a methodology that accounts for changes in risk and allows the ranking of risky prospects. The strategies are: (i) a yield-maximizing or 'full irrigation' approach where irrigation is applied so that crops transpire at their maximum potential, and (ii) a profit-maximizing or 'deficit irrigation' approach where irrigation is applied at rates proportional to but below the paradigmatic strategy. Our approach orders alternative strategies in terms of certainty equivalent gross margins over a range of risk averse preferences. Current institutional and regulatory environments in many semi-arid regions favor the full irrigation strategy. We find that this approach maximizes expected yield and minimizes production risk (i.e., yield variance). However, when water can be transferred off farm at various water prices and variable costs, deficit irrigation offers greater expected profit and lower economic risk (i.e., profit variance). Furthermore, the deficit irrigation strategy becomes relatively more preferred as preferences become more risk averse. While concerns over production risk with deficit irrigation are valid, some level of deficit irrigation is optimal when water prices compensate for forgone yields and changes in risk. Discussion of the results will be linked to water policy issues in the semi-arid U.S. West.

CLIMATE, METEOROLOGY & SNOW HYDROLOGY

The Dry Sky: Futures for Humanity's Modification of the Atmospheric Water Cycle

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Humanity is changing the atmospheric water cycle, especially via land use change. Given the significant consequences to social and ecological systems, we conceptualize atmospheric moisture as an economic good. Historically, atmospheric moisture was considered a 'public good' since moisture was neither consumed (rival) nor controlled (exclusive). However, given anthropogenic changes, atmospheric moisture may become 'common-pool' (rival, non-excludable) or 'club' (non-rival, excludable). Moreover, advancements in fog harvesting and cloud seeding, presage the potential for moisture as a 'private' good (i.e. rival, excludable). In this research, we develop scenarios of how human modifications of the atmospheric water cycle may unfold in the future. We blend computational text analysis, with expert perspectives and story-based methods to create novel scenarios of the future. These narratives represent four unique, story-based scenarios depicting a mix of both optimistic and pessimistic futures in which atmospheric water is a 'public' 'common-pool', 'club', or 'private' good. These futures illustrate that social choices play an enormous role in how the future will unfold with regard to human interaction with the atmospheric water cycle. While climate and global systems inexorably change, human decisions modulate these changes at every turn, across scales of space, time, and power. The narrative scenarios serve three purposes. First, they provide creative artifacts for the discussion of future social and ecological changes, while being rooted in scientifically plausible futures. Second, they articulate aspects of our coupled social and hydrological world that require deeper interrogation in the present. Third, this research invites questions related to the current set of adaptation priorities for Earth system change generally, and specific development priorities related to our responses to a changing water cycle.

Can Investment in Storage Infrastructure Reduce Water Shortages?

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Population growth and climate change pressure water managers, especially in basins with high population growth rates and/or predicted fewer water supplies. The South Platte River Basin (SPRB) in Colorado is an example of these basins having dense agriculture areas and urban communities. Municipalities across the basin purchase water rights from agriculture users to secure water for growing communities, affecting overall water allocation. Additionally, they consider demand reduction strategies and new storage infrastructure. In this paper, we calibrate a water allocation model for SPRB in the Water Evaluation and Planning (WEAP) system by integrating water demand and supply models driven by climate. Then, we simulate eight future climate scenarios and alternative water adaptation strategies through sensitivity analysis of storage and demand variations on water shortage. The future baseline scenarios show that consumptive uses continuously exceed the mean water supply starting in the 2040s and

population growth outweighs the effects of climate change on water demands. Furthermore, reservoirs in the basin mitigate the consequences of the expected earlier water supplies by storing water from the high-flow season to the high-demand season. The comparison between additional storage and demands reduction strategies shows that additional storage has a modest effect on diminishing the water shortage, while demand reduction unambiguously decreases it. A sensitivity analysis of storage and demands variations identifies a threshold of 0.7 storage ratio to the expected 30-year annual mean water supply that defines the conditions in which additional storage can successfully reduce the shortage at the basin level.

The Impact of Extreme Drought on Crop Abandonment in the Ogallala Aquifer Region

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With the progression of climate change, extreme drought events are predicted to be more frequent and severe. Agriculture is particularly a vulnerable sector to the effects of drought due to its dependency on weather outcomes. Previous studies have shown evidence of the damaging effects of weather shocks on agricultural outcomes. Although they provide insight on the biophysical aspects of crop production, these studies are limited in capturing the behavioral response of growers in the wake of extreme weather events. Disregarding this important component would lead to biased estimates of the effects of extreme weather events on agricultural outcomes and economies. This paper evaluates the impact of extreme drought on the incidence of crop abandonment in the Ogallala Aquifer region of the United States. Crop abandonment is defined in this research as the difference between acres harvested and acres planted in a given year. Expanding on previous studies that measure the sensitivity of agricultural outcomes to climate variation, this research evaluates crop-specific impacts of drought on abandonment and the extent to which groundwater access in the region moderates the impact of drought. Results show that extreme drought increases the incidence of crop abandonment and that drought impacts are more pronounced in the third quarter where crops are at their prime growth stage. Further, access to groundwater moderates the effects of drought, although this ameliorating effect decreases over time. Estimates from empirical models that include controls for temperature and precipitation measures show consistent negative effects of drought on crop abandonment compared to models with only drought measures.

The Impacts of the Extreme Phases of the Southern Oscillation on Rainfall Erosivity over the United States

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Deciphering the mechanisms through which the El Niño/Southern Oscillation (ENSO) affects hydrometeorological parameters in the tropics and extratropics is of great interest. We investigated climatic teleconnections between warm and cold phases of ENSO and rainfall

erosivity index (REI) over the contiguous United States using an empirical methodology designed to detect regions showing a strong and consistent hydroclimatic signal associated with the extreme phases of ENSO episodes. To do this, we calculated not only spatial coherence values by monthly REI composite formed over 2-year ENSO cycle and the first harmonic fit to detect candidate regions but also temporal consistency rates by aggregate composite and index time series for determining core regions. Also, a machine learning technique using Gaussian Mixture Model (GMM) was employed based on magnitude and temporal phase of climate signal, and Köppen climate classification. As a result, the core regions, namely, the northwest (NW), the north central (NC), the northeast coastal (NEC), the southeast (SE), and the southwest/middle-inland (SWM) regions, were detected with a high level of response of ENSO phenomena to REI patterns. For fall through spring of the following warm (cold) event years, the ENSO composites for the core regions indicate below (above) normal in the NW and NC regions and above (below) normal in the NEC, SE, and SWM regions. The spatial coherence rates of the NW and NC regions (the NEC, SE, and SWM regions) are 0.93 to 0.98 (0.94 to 0.97) and the temporal consistency rates range from 0.62 to 0.86 (0.73 to 0.82). In addition, for the core regions identified by composite-harmonic analysis for both extreme episodes, the results of comparative analyses using cross-correlation, annual cycle, and Wilcoxon rank sum test indicate that the opposite phases-rainfall erosivity relationships have a tendency of sign reversal of the REI anomaly. Also, the positive departures during the warm event years show more coherent and strong responses than the negative anomalies in the cold event years. In conclusion, the United States experiences climatic teleconnection between ENSO forcing and midlatitude rainfall erosivity variabilities.

Assessment of Baseflow Characteristics in Snow-Dominated Watersheds

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This study seeks to find the correlation between winter snow water equivalent (SWE) values and subsequent baseflow characteristics. As climate change alters the timing of seasonal snowmelt and quantity of available snowpack, it is important to understand how the components of the hydrological cycle are related. The traditional water year (WY, in the US October 1 of the previous year through September 30) separates baseflow into two different WYs. To account for this, we propose using a melt year (MY) that begins with the onset of melt in the spring and ends prior to the onset of melt the following year. This allows us to see how water is moving through the system until the subsequent onset of melt, and, thus, how SWE and baseflow are related. We used streamflow data from several US Geological Survey stations across Colorado. All stations had a minimum elevation of 2000 meters, and at least 36 years of data within the period from 1980 to present. We developed computer code that identifies the beginning of a MY and extracts baseflow values. We used flow duration curves (FDC) to compute baseflow values as those with 50-90% probability of occurring. We examined the correlation of SWE and subsequent baseflow quantities, including any lag between the two variables. The correlation is examined over the 40+ year period of evaluation and if there are topographic and geographic variations.

WILDFIRES & WATERSHED PROTECTION

Temperature Index Snowpack Model Parameter Adjustments for Wildfire Impacted Watersheds

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Hydrologic modeling is often performed following wildfires as part of risk assessments for infrastructure and communities. Several studies have examined how soil infiltration parameters change following wildfires, but no guidance is available regarding changes to snowpack model parameters. The objectives of this study are to (1) examine the changes in two key parameters of temperature index snowpack models and (2) to develop empirical equations that can be used to estimate appropriate adjustments for those parameters. The parameters are the melt-rate function and the threshold temperature that distinguishes rainfall from snowfall (i.e., Px temperature). Snow water equivalent (SWE) data are used from 43 NRCS SNOTEL sites in the western U.S. that have been impacted by wildfire. Statistically significant increases occurred in the melt-rate for several sites north of 40° N latitude. However, statistically significant changes in the Px temperature occurred only at a limited number of sites and the direction of change was variable between sites. A generalized linear model (GLM) was developed to estimate the parameter changes following a wildfire using the observed changes at the SNOTEL sites. Separate models were developed for different periods since the wildfire occurred (i.e., ≤5 years, 5-10 years, 10-20 years, and all years). Predictor variables included topographic (elevation, northness, etc.), climatic (air temperature, winter precipitation, etc.), and pre-fire land cover (tree genus, leaf area index, etc.) characteristics. Initial results indicate the melt-rate parameters adjustments are positively correlated (i.e., higher melt-rate) with mean air temperature, while negatively correlated with lead area index change.

Impact of Forest Treatment Practices on Mountain Watersheds

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Wildfires are an increasingly common occurrence in the Western United States. In Colorado, 2020 and 2021 brought multiple catastrophic fires including the recent and tragic Marshall Fire. Wildfire mitigation measures – or "forest treatments" – such as plantation thinning, mastication and controlled burning, are increasingly utilized to reduce fire intensity and protect valuable resources. These treatments change forest structure which can alter the partitioning of water across the landscape; thus, such treatments may have critical implications for regional and state water resources. However, few studies have explicitly evaluated the impact of forest treatments on runoff and water yield. This research improves our understanding of the impacts of forest treatment on water in the western US by quantifying the change in runoff in mountainous watersheds that have undergone forest treatment. This question was investigated at the Sagehen Experimental Watershed, located in the Sierra Nevada Mountains of California. Sagehen

offers a unique and ideal location of study because multiple types of forest treatment were applied to the watershed between 2014 and 2020. Continuous 15-min stream flow measurements were recorded at nine subbasins within the Sagehen Watershed from 2012 to 2020. Results show that while annual streamflow between 2010 and 2020 was highly variable, relative to historic trends, this variability is strongly correlated to inter-annual changes in precipitation rather than forest treatment. At both the basin and sub-basin scale, therefore, any signal of change in runoff resulting from forest treatments is unidentifiable in the context of such wide variability in precipitation. The treatments appear to have minimal impact on forest structure, as far as it relates to the water budget, even at the subbasin scale. Overall, this study helps inform water resource management decisions and natural resource protection measures as we adapt to climate resilient forests and water supplies.

Post-Wildfire Rainfall-Runoff Event Response Variability Across Space and Time in Monitored Nested Watersheds in the Colorado River Headwaters

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Wildfires can contribute to flooding, debris flows, and fluvial sediment transport that can impact downstream infrastructure and aquatic habitat. With increasing wildfire risk in the western U.S., understanding watershed-scale post-wildfire impacts on paired rainfall-runoff event response and their controls is critical. Recent post-wildfire research has advanced small-scale process-based hydrologic modeling (<2 km2), but immense spatial variability in watershed and burn characteristics and temporal variability in recovery rates raises questions about the transferability of these studies to larger and more variable watersheds where management decisions are made. Existing watershed-scale field data is scarce since burned landscapes are extremely dynamic and difficult to monitor. An intensive hydrologic monitoring network was installed in the Grizzly Creek Fire (Aug 2020) in Glenwood Canyon, CO, to evaluate paired rainfall-runoff events across five burned watersheds (11 to 100 km2), two nearby unburned watersheds, and the integrated effect of the fire on the Colorado River headwaters. The monitored watersheds exhibit distinct burn (e.g. severity, network connectivity) and watershed (e.g. topography, geology) characteristics, and the dominant characteristics differ when considering the entire watershed, only the burned area, or the burned channel network. The study area experienced a strong North American summer monsoon over summer 2021, resulting in highly localized and intense storm events. Initial event-scale rainfall-runoff analysis between contiguous watersheds and through time reveals highly variable post-fire streamflow responses and underlines the importance of mindfully extrapolating observations or model simulations with respect to watershed characteristics and precipitation inputs. Our hydrologic data collection and analysis procedures were more intensive than most previous studies, but the complexity of burned mountain landscapes still resulted in challenges in analyzing rainfall-runoff paired event response. This study emphasizes the importance of intensive stratified monitoring networks to gain a better understanding of system variability and controls on post-wildfire hydrologic response.

Quantifying the Effect of Fire on Salinity Movement in an Upper Colorado River Watershed

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The Colorado River Basin provides critical water resources but is endangered by the increasing risk of wildfires and the consistent problem of salinity. Wildfire in the West is a prominent issue as seen by the fact that the four largest wildfires in Colorado history occurred in 2020 alone. Fire increases runoff by decreasing interception of the canopy and increasing repellency in the soil. Recurrently, salinity in the Colorado River Basin causes millions of dollars per year in damage to crops and water infrastructure. This is further exacerbated by the increased erosion after a wildfire. The purpose of this study is to model how the sudden loss and subsequent regrowth of vegetation due to wildfire affects the movement of salt within the Animas watershed, located in southern Colorado and northern New Mexico. The Animas watershed is a 3,543 km2 basin in the UCRB which has been affected by the Missionary Ridge fire and the 416 fire, the ninth and tenth largest wildfires in Colorado history, respectively. The numerical watershed model APEX-MODFLOW-RT3D is used to simulate hydro-chemical processes in the Animas watershed and quantify the impacts of wildfire on salt concentrations and loadings. APEX simulates the hydrologic and water quality processes for items just at or above the soil (climate, hydrology, erosionsedimentation, and more), MODFLOW simulates groundwater storage, flow, and groundwater-surface water interactions, and RT3D simulates groundwater salt ion concentrations and groundwater-surface water mass exchange. A salinity module is also added to APEX to simulate the reactive transport of salt ions in surface runoff, erosion runoff, and soil percolation and leaching. The wildfire effects will be added into the existing modeling framework by utilizing NVDI maps to reflect changes in canopy cover, which are then converted to leaf area index (LAI) and used to adjust parameters in the APEX model. The model will be calibrated using in-stream salt loading from 1992 to 2011, focusing on the Missionary Ridge fire in 2002, and then tested from 2012 to 2018 with the 416 fire. With this model, we can begin to understand how wildfires affect salinity loadings and focus remediation techniques on problem areas.

POSTERS

Characterizing Nitrogen & Phosphorus Loads Delivered to Streams from Agricultural Landscapes at Various Watershed Scales

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The Iowa Nutrient Reduction Strategy estimated the potential reductions in nitrogen and phosphorous loads that could be achieved by a wide range of in-field and edge-of-field practices. However, most work on practice performance and nutrient loads in Iowa has been done at either the plot or larger watershed scales. Nutrient loads estimated at these scales can differ substantially from loads actually delivered to surface waters from cropped lands. We evaluated nutrient transport within a central Iowa HUC12 watershed to better understand the effects of scale and stream processes on nitrogen and phosphorus transport. Nutrients and discharge were measured at five locations at various scales spaced longitudinally throughout the watershed. Automatic samplers were installed at these locations to collect high-frequency water quality samples to estimate nitrogen and phosphorus loading and concentrations during baseflow and event flow conditions. Preliminary results suggest that phosphorus loads at the HUC 12 scale can be substantially higher than loads actually delivered from agricultural landscapes (and reflected by delivery scale monitoring). In general, as watershed size increased, median nitrate-N and total nitrogen concentrations decreased. In contrast, median concentrations of total phosphorus (TP) and total reactive phosphorus (TRP) increased with watershed size. Turbidity sensors will be installed and paired with three sample sites to evaluate phosphorus fractionation and sediment transport. By utilizing turbidity as a surrogate for particulate phosphorus and sediment transport, we hope to better understand how particle-derived phosphorus moves through a central Iowa HUC12 watershed at various scales.

Modeling Nitrate Removal Within the Biomat of Open-Water Engineered Wetlands to Optimize Long-Term Treatment

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Open-water wetlands used in passive water treatment are reproducibly colonized by a benthic microbial mat ("biomat") which accumulates ~2-3 cm per year in association with geotextile lining and shallow water column design parameters. The biomat is stratified with a photosynthetic layer at the matwater interface that transitions to a more consolidated anoxic zone within the upper ~5 – 10 mm. These strata are interconnected but differ in ecological parameters such as light and oxygen availability, resulting in different microbial niches and contaminant removal capabilities as water carrying nutrients and contaminants travels through this diffuse biomat. Recently, a steady-state model for predicting nitrate diffusion profiles within the biomat was developed using

oxygen stratification and nitrate attenuation rates derived from laboratory microcosms. Field observations from the Prado Wetlands, which are fed by the wastewater effluent-impacted Santa Ana River in Corona, California, suggested modeled profiles slightly overestimated attenuation rates, but point to most nitrate attenuation occurring within ~2-3 cm of the biomat-water interface. The model makes assumptions about hydraulic biomat characteristics as a function of depth, and field observations in the delicately structured biomat are coarse, leaving contaminant transfer, attenuation, and transformation between the surface water and biomat poorly constrained. To validate modeled nitrate diffusion and removal and test the hypothesis that nitrate is predominantly attenuated in the upper 2-3 cm of the biomat, bench-scale flow through reactors simulating an open-water wetland were constructed with variable biomat depth, and influent and effluent water chemistry were monitored. Results indicate there is little difference in nitrate removal once biomat is thicker than ~2 cm, supporting the hypothesis that hydraulic exchange and biotransformation predominantly occur within the surficial strata and biomat growth beyond one year is unnecessary for optimal nitrate attenuation. Deepening our understanding of the relationship between biomat accretion through time and its influence on nitrate removal can help us balance long-term water treatment performance with resource recovery. Given the nutrient-rich and renewable nature of the biomat, there is potential to harvest and apply it as fertilizer, linking sustainable food and water systems.

Next Generation Basin-Wide Snow Monitoring Network

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Over 2 billion people in the world depend on water originating as snowpack. Monitoring of snowpack high in the alpine is essential for water forecasters, city planners, and agriculturists. Currently only a very small percentage of world's snowpack is actively monitored throughout the year. Barriers to monitoring are cost, accessibility, and lack of infrastructure to collect and process data. This uncertainty is compounded by terrain and weather conditions that cause variability that is not accurately reported. I am proposing to rethink current standards and utilize an affordable, accessible, and more in-depth monitoring network than the current standard, SNOTEL. Using "Long Range" (LoRa), a new, currently available, low power consumption, 915mHz, network interface to create and monitor a "mesh-type" network where individual sensor arrays communicate with one another, like Apple's "air tag." Currently, in the Snotel network, individual sensor arrays communicate through the way of a singular contact point known as a gateway. SNOTEL is a cost prohibitive design where only a single point is utilized to represent the spatiotemporal variability across an entire watershed, and then transfer the sensor's data to the network by telemetry. LoRa acts in a different way. Each unit is its own Arduino-based transceiver with a set of sensors that monitor climate conditions and snow information, then each unit "meshes" or connects with other units 3-10 miles away from one another. This design allows extensive monitoring across an entire basin without relying on "line of sight" or one "gateway" to connect and interface a multitude of sensors. Relative to other networks, LoRa uses far less power and is much slower in data transfer speed but is plenty capable for the metrics that snow monitoring and weather data require. The real-world implications can help us to better understand landscape wide processes and to better forecast for our water needs in the face of

climate change. Additionally, the network is adaptable for land managers, sensors can be easily added to monitor air quality, smoke, or as an emergency communication network.

The Teleconnections Between Large-scale Climate Indices and Precipitation Patterns over the United States

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Examining the physical mechanisms through which large scale climate indicators affect hydroclimatic variables in the tropics and extratropics is a scientific challenge. In this study, climatic relationships between large-scale climate indices (CIs) and United States precipitation variability were examined. Not only leading patterns of observed monthly precipitation were estimated through an empirical orthogonal teleconnection method (EOT), but also correlation and regression analyses were performed for the leading precipitation patterns and various CIs based on atmospheric-ocean circulation dataset. From the spatial structure of the leading EOT patterns for monthly total precipitation, the northwestern mode in the cold seasons and the southeastern mode for the warm seasons were detected. The temporal cycle of the leading EOT patterns indicates decreasing trends in the cold seasons and oscillations mainly on decadal timescales in the warm seasons. The findings from this study illustrate that tropical ENSO forcing has a coherent association with March and November precipitation patterns, while the Indian Ocean Dipole is identified as a driver for precipitation variability during spring and fall. The western monsoon activity has a negative (positive) correlation with March (October and December) precipitation variabilities and tropical cyclone indices also exhibit significant positive correlation with September precipitations. The leading patterns of the October and following-year March rainfall time series are predictable at up to six-month lead time from the tropical Pacific sea surface temperatures (SSTs).

HYDRAULICS & GEOMORPHOLOGY

Numerical Study on Sediment Transport and Alluviation In Mixed Bedrockalluvial Channel

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Mixed bedrock-alluvial channels are characterized by discontinuous alluvial cover patterns and exposed bedrock surface because their transport capacity exceeds their sediment supply. The pattern of alluvial cover in these channels is an important control on fluvial bedrock incision, because sediment can both protect covered bedrock from erosion while providing tools for erosion. Predictions of bedrock incision rate and landscape evolution are typically modeled as functions of the areal distribution and magnitude of sediment cover, including the relative sediment flux (sediment supply to transport capacity ratio). However, little is known about sediment transport processes in mixed bedrock-alluvial channels, or the controls and mechanisms responsible for the evolution of alluvial patterns. Numerical morphodynamic models have been unable to reproduce the evolution of alluvial cover in mixed bedrockalluvial channels, so we developed a new morphodynamic model with the aim of investigating the effects of sediment supply, channel slope, and preexisting alluvial conditions on the evolution of sediment cover in mixed bedrock-alluvial channels. Simulations of small-scale flume experiments are conducted in a straight rectangular channel with irregular non-erodible bedrock beds. In the simulations, we varied the sediment supply, initial sediment cover condition, and channel slope. A quantitative comparison is performed between the morphodynamic datasets produced by experimental observations and computational simulations. This work evaluates the model's capabilities to reproduce the experimental mixed bedrock-alluvial channels' characteristic flow and morphological features, such as alluvial processes (gradual or runaway alluviation) and degree of bedrock exposure as functions of sediment supply, channel slope, and the relative roughness of bedrock and sediment.

Development Of A SWAT Hydrologic Model to Predict Salt Transport in an Upland Desert Catchment of the Lower Arkansas River Basin

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High salinity levels act as a chemical stressor in water bodies and can lead to significant impairmentsin water quality. Salt loading threatens sustainable crop production globally and is especially prevalent in semi-arid and arid watersheds. For this reason, salt transport in irrigated semi-arid and arid regions has been intensively studied. However, little research has been conducted to evaluate the salinity contributions of dominantly non-irrigated, undeveloped basins in semi-arid regions. The objective of this study is to use the Soil and Water Assessment Tool (SWAT) to evaluate the contribution of salt to the Arkansas River from the Purgatoire River, a dominantly non-irrigated, undeveloped desert catchment in southeastern Colorado. The ArcGIS interface of the SWAT module (ArcSWAT) will be coupled with an additional comprehensive salinity module, which has not previously been tested on desert catchments. The ~3,450 mi2

Purgatoire River basin is susceptible to high salt transport due to high topographic slopes, low average annual precipitation, and sparse vegetation. Previous studies have noted that the Purgatoire River contributed ~21.7% and ~11.2% of the salt in the Arkansas River in 1990 and 2020, respectively. These results indicate that upstream undeveloped catchments can have a large effect on downstream salinity loads in productive agricultural catchments. This study uses 34 years of environmental data to model daily fluctuations in salt loading from 1990-2021 and will be calibrated using 10 years of USGS streamflow data. The validity of the salinity module will be evaluated through comparisons to electrical conductivity data loggers that were placed at two sites along the Purgatoire River. The development of this model should enable salinity best management practices to be more effectively implemented in upstream catchments by evaluating relationships such as the influence of varying precipitation, land use, and slope on salt loads. For example, one predicted outcome of this research is a forecast model for total annual salt load given total annual precipitation and/or evaporation in a region. This research will indicate whether natural, largely undeveloped basins export relevant salt loads as compared to heavily irrigated basins and how salt loads may vary with changing climatic conditions.

Evaluation of Stream Physical Habitats in Headwater Streams Under Climate Change Projections for Greenback Cutthroat Trout in the Southern Rocky Mountains, Colorado

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Headwaters are vital to sustaining aquatic biodiversity and providing ecosystem services downstream. Many studies have shown that headwater streams are especially vulnerable to changing climate that affects the hydrological cycle and alters flow regime. Coldwater fish, in particular, are especially sensitive to the fluctuations in stream flows and during summertime low flows. Though previous studies have provided insights on how changes in climate and alterations in stream discharge may affect the habitat requirements for native cutthroat trout species in the Rocky Mountains, the suitable hydraulic conditions have not been evaluated under climate change scenarios for the threatened Greenback Cutthroat Trout (GBCT) occupying the headwater regions in the Southern Rocky Mountains. Here we use field data collected in the summers of 2019 and 2020 from 12 selected headwater streams across the Front Range in the Southern Rocky Mountains to construct one-dimensional hydraulic models (HEC-RAS) to evaluate current stream hydraulic conditions. Moreover, habitat changes from projected future streamflow (mean summer and mean August) for each site were simulated and compared to the current stream habitats to assess the influence of climate change on the headwater streams. A principal component analysis (PCA) was then performed to demonstrate the importance of each morphological feature of these streams. Results from the hydraulic models show reductions in all evaluated stream physical habitats compared to the current stream hydraulic conditions. This study demonstrates that sites may experience different degrees of flow reductions under climate change, and it will be important to understand why such spatial variation exists for fuller understanding of climate change impacts on aquatic ecosystems.

Addressing the Flow Measurement Conundrum

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Estimating discharge in open channels is typically carried out in one of two ways: either in-situ direct measurement using some type of flow meter, or by using a calibrated stage-discharge rating equation. The conundrum, however, is that each method is reliant upon the other in its pursuit of achieving an accurate and reliable estimation of discharge. Hydraulic structures serving as flow measurement locations along a channel reach must be regularly calibrated through direct measurement of the flow at several stage levels. Simultaneously, the instruments used to obtain direct flow measurements suffer from their own limitations and sources of uncertainty, and it is often beneficial to ground-truth direct flow measurements with readings from a trusted streamgage. We address this issue from both sides by conducting experiments to determine measurement and calibration best practices that increase accuracy and reduce uncertainty in discharge estimation. Our focus here is on a single instrument for direct flow measurement that has become ubiquitous in its application – the acoustic Doppler current profiler (ADCP); and on a single hydraulic structure that has been widely implemented in irrigation canal systems – the pivot weir. We find that refined best practices on the average measurement duration of an ADCP discharge estimate, along the sample size of measurements and the method of transporting the device across the channel all can reduce uncertainty in estimation of mean steady discharge by a significant margin. Furthermore, our analysis of the rating equation for a pivot weir reveals new insights on the optimal operating regime, the nature of the calibration coefficient in relation to the angle of the weir, and the importance of both scaling and auxiliary design elements on the accurate calibration for this structure. These findings together will help ensure that hydrographers across a wide range of disciplines can achieve more accurate and reliable discharge estimation.

Scour Failure of Bendway Weirs and Rock Vanes: Observations and Data from a Curved Flume

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A series of flume experiments were conducted at Colorado State University (CSU) to determine how a series of six rock bendway weirs (BWs) or six rock vanes (RVs) fail when placed in a curved channel under live-bed conditions. The channel's bed, comprised of coarse sand, was subject to high shear stress values, causing it to be highly mobile. Three flow conditions were simulated with the rock structures: low flow, medium flow, and deep flow, with flow depth being about 0.75, 1.25, and 2.0 times the BW crest height or the average crest height of the RV respectively. The flow conditions simulated the passage of the rising limb of a hydrograph. BW and RV configurations followed the recommendations published by earlier studies at CSU (Siefken et al. 2021); for example, BW or RV orientation was set at 60o from the bank in the upstream direction. The length scale of the model was approximately 25, including the dimensions of the rock

structure and the rock itself. The experiments were conducted in a curved flume, 1.3 m wide and 15 m long. Observations showed that contraction scour around the end tip of the BWs or RVs caused the end (or tip) to fail. The extent of scour was approximately constant for the three flow conditions used, as the bed around the BW or RV became armored by displaced rock. This finding suggests rock stability affects scour depth. The observations were interpreted for design significance and led to the following design recommendations for such structures: BWs and RVs should be lengthened by a distance equal to 2(d50 + σg) of the rock used to build the BWs or RVs; here, d50 = the median rock size and σg = the geometric standard deviation of the rock. Also, BWs and RVs should be widened by a width distance (d50 + σg). This lengthening and widening enables the BWs or RVs to fail owing to scour, but the failed rock then armors the scour at each BW or RV, and the remaining structures are at their design crest length and width.

STUDENT SHOWCASE: SESSION A

Analyzing Security as a Source of Legitimacy across the FEW Nexus (#1A)

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The concept of environmental security is proliferating among global debates about environmental change and sustainable development. It is increasingly crucial to understand how security logics function in environmental politics and how securitization influences the architecture of global environmental governance, especially in relation to sources of legitimacy and agency. This paper explores environmental security discourses across the food-water-energy (FEW) nexus to examine the implications of securitizing complex and systemic environmental issues. The FEWs nexus is a particularly relevant political space for this project because actors working within and across the nexus frequently evoke the concept of security to articulate the risks and vulnerabilities associated with food, energy, and water issues. The frequent inclusion of businesses in proposed solutions to FEW issues also prompts important questions about the role of non-state actors in governing environmental security challenges, and how they can or should utilize such authority. In practice, discourses about agents of security have significant implications for the way complex, socio-ecological issues are governed by certain actors, for whom, and how. The purpose of this paper is to explore such discursive trends to uncover emerging agents of environmental security. More specifically, I use critical discourse analysis to analyze the authority claims of large businesses and corporations across food, energy, and water sectors to understand how they approach their position as providers of security, and to whom their authority claims are directed. Ultimately, this paper seeks to understand whether and how security is used as a source of legitimacy in environmental politics and to elucidate the broader relationship between private governance and environmental security across the FEW nexus.

Systems Level Thinking Approach to the Study of Water Dispute in South Asia (#2A)

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"Water, water, everywhere, nor any drop to drink" is the defining characteristic of water resource management in South Asia, the home of the three most densely populated river basins - the Indus, the Ganges, and the Brahmaputra. Population growth, urbanization, industrialization, and increased reliance on irrigated agriculture have created a strong demand for water in that region. Increasingly variable precipitation due to climate change generates frequent floods and droughts, making water a double-edged sword for the millions dependent on agricultural food production. The hegemonic role of regional powerful countries in controlling water in the trans-boundary rivers exacerbates the problem. Rampant distrust among the neighboring countries makes cooperative water negotiation difficult. While existing water sharing agreements have general public support, implementation is seen as poor. Using Driver, Pressure, State, Impact,

and Response (DPSIR) framework, the current study aims to examine the water dispute in South Asia with special focus on water relationship between India and Bangladesh which share fifty-four trans-boundary rivers. The water dispute between these two countries started with the construction of the Farakka Barrage by India in 1975 across the river Ganges to divert water by the Bhagirati-Hoogly system. Although both countries signed The Ganges Treaty in 1996 to share surface water, the agreement divides water flow without sharing the values and uses of the river between the two countries. The treaty favors the hydro-hegemonic India and has left downstream Bangladesh with numerous concerns and unresolved issues. Given these circumstances, Bangladesh has been implementing various water and river management projects which are highly criticized for generating water injustice because of being high modernist, following top-down approach, being controlled by local elites, failure of community engagement. Keeping Sustainable Development Goals (SDGs) by 2030 in mind, it is essential to develop a regional cooperative approach to resolve the water conflict in the region with the special consideration of potential threats from climate change. Application of a systems level thinking tool like DPSIR, which is not previously applied, would help in achieving this goal.

How Unprecedented is the Current Colorado River Drought? A Paleo Perspective (#3A)

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The on-going ~20-year long drought in the Colorado River Basin (CRB) has gained notoriety as the worst drought since modern record-keeping began over 100 years ago. Historically low reservoir levels, due to a lack of reservoir replenishing high-flow years and greater losses induced by increased temperature across the basin, the so-called “Millennium Drought” has precipitated unprecedented cutbacks to water use in the seven southwestern US states. The question on everyone’s minds is – how unprecedented is the current drought? To answer this, we seek insights from long records of paleo-flow reconstructions, which have shown that multi-decadal droughts have occurred in the CRB periodically over the last 1000 years. Some of these “mega-droughts” are estimated to be worse than the current drought in terms of both flow volume deficit and drought duration. To answer the posed question, in this study, we assess the return period of two decade long droughts in the CRB based on the paleo and modern observational record spanning over 600 years and slightly more than 100 years, respectively. We fit Hidden Markov Models (HMM) to these two data sets separately and generate long sequences of flow simulations. From these simulations, the return periods of multidecadal drought attributes – duration and magnitude - were computed and indicate that risk of a Millennium Drought type event is nearly 10 times higher when evaluating the paleo record relative to the modern record. An optimization analysis also indicates that Upper Basin ‘firm yield’ is less than 14-MAF and a yield of 15-MAF can be met with 87% reliability according to the modern record but only 77% reliability based on the paleo record. The estimates of relative frequency of drought duration and

magnitude will help place the current drought in a broader context – paleo, modern and future. This will be of great help to all stakeholders in the basin to devise efficient water management strategies.

Every County Has Unique Climate Risks. What Are Yours? (#4A)

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Recent incidents of extreme drought and heat domes in the United States highlight the potential damages of current climate trends, and the extent to which individual regions will be affected by global climate change depends on geographic location and the ability of human and environmental systems to adapt. Since weather disruptions are not uniform across space, the success of policies aimed at bolstering climate resiliency is dependent on local leaders, resource managers, and individual citizens understanding the climate risks in their own communities. This research assesses climate vulnerability at the county level by estimating historical economic responses to extreme weather and analyzing projected weather from a suite of climate models. I compile a unique dataset of hourly temperatures, daily precipitation and relative humidity, and a weekly drought severity index for every county in the United States from 1980- 2020. A two-way linear fixed effects regression model is then used to estimate the impacts of extreme drought and heat exposure on a variety of economic indicators from the Quarterly Census of Employment and Wages. I identify climate-sensitive economic sectors, their importance for total economic productivity within a county, and the potential future impacts given climate projections. The information provided in this analysis is useful for policymakers interested in tailoring programs to meet highly localized needs. *This material is based upon work supported by the National Science Foundation under Grant No. 1828902. Any opinions, findings, and conclusions or recommendations expressed in this material are those of the author(s) and do not necessarily reflect the views of the National Science Foundation.*

Can Investment in Storage Infrastructure Reduce Water Shortages? (#5A)

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Population growth and climate change pressure water managers, especially in basins with high population growth rates and/or predicted fewer water supplies. The South Platte River Basin (SPRB) in Colorado is an example of these basins having dense agriculture areas and urban communities. Municipalities across the basin purchase water rights from agriculture users to secure water for growing communities, affecting overall water allocation. Additionally, they consider demand reduction strategies and new storage infrastructure. In this paper, we calibrate a water allocation model for SPRB in the Water Evaluation and Planning (WEAP) system by integrating water demand and supply models driven by climate. Then, we simulate eight future climate scenarios and alternative water adaptation strategies through sensitivity analysis of storage and demand variations on water shortage. The future baseline scenarios show that consumptive uses continuously exceed the mean water supply starting in the 2040s and

population growth outweighs the effects of climate change on water demands. Furthermore, reservoirs in the basin mitigate the consequences of the expected earlier water supplies by storing water from the high-flow season to the high-demand season. The comparison between additional storage and demands reduction strategies shows that additional storage has a modest effect on diminishing the water shortage, while demand reduction unambiguously decreases it. A sensitivity analysis of storage and demands variations identifies a threshold of 0.7 storage ratio to the expected 30-year annual mean water supply that defines the conditions in which additional storage can successfully reduce the shortage at the basin level.

Colorado Open Space Programs and Water Sharing: Barriers and Opportunities (#6A)

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The transfer of water from working landscapes to municipal use and the subsequent dry up of those lands in Colorado ('buy and dry') has cascading impacts on rural resilience and the ecosystem services and public benefits provided by those landscapes. The situation is further complicated by other drivers, such as climate change (and drought), politics, and disconnects between market drivers and public benefits. Alternative Transfer Methods (e.g., water sharing agreements) are potential alternatives to 'buy and dry' yet aren't common despite support from the Colorado Water Conservation Board. This research thus explored barriers as well as perceived benefits of water sharing to develop policy recommendations and future research trajectories. In reviewing literature and seeking new knowledge through semi-structured qualitative interviews, focus was placed on open space programs and land conservation groups, as well as municipal or county level interdepartmental collaboration in the South Platte River Basin. Open space programs and other conservation-focused institutions are uniquely situated to participate in water sharing agreements and may broaden the realization of benefits provided by working landscapes. Interviews revealed that the rising value of water rights, differing institutional priorities and planning horizons, the complexity of water sharing agreements, lack of relevant "in house" expertise, and significant risk and trust issues are barriers. Most interviewees (regardless of institutional priorities) acknowledged the value of ecosystem services, including urban buffering, hydrologic connectivity, and wildlife habitat provided by working landscapes. Community resilience and agricultural heritage were also noted as important, sometimes equal to or greater than other benefits. This research reveals several interesting paths for future policy development and research, particularly food-energy-water system integration, policy mechanisms for agriculture sustainability in semi-arid regions, the structure and functionality of Colorado water law, and comprehensive sustainability planning at the municipal and county level.

Towards Timely Policy-Relevant Analysis of the Return on Investment from Ecosystem Services in the South Platte River Basin (#7A)

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About 15-20% of the acres of irrigated agriculture in the South Platte River Basin (SPRB) of Colorado are expected to be dried by 2050. Many of the agrarian communities in the SPRB rely on irrigated agriculture as an economic driver and are likely to be heavily impacted as water is transferred to urban uses. One option to keep financial capital in those communities is to adopt payment-for-ecosystem services policies. For good policy decisions to be made, though, timely assessment of the return on investment from various land uses is needed. Therefore, this work investigated methods that may be used for policy-relevant analysis of carbon sequestration and other ecosystem services. Generally, research efforts by academia and needs by policy makers have diverged. Academia tends to focus on expensive and long-term efforts that prioritize precision while policy makers need timely, affordable, and reasonably accurate methods that do not require an expert and provide actionable results (e.g., return on investment). Through literature review, spatially explicit benefit transfer was identified as an excellent policy-oriented method for evaluating ecosystem services. However, due to the ease with which benefit transfer can be inappropriately implemented without adequate data, it is instead presented as a method for identifying data and research needs. COMET-Planner (NRCS & CSU) was identified as an appropriate tool to valuate carbon sequestration by land that has transitioned away from irrigated agriculture. It was used to estimate annual carbon sequestration from three scenarios where irrigated agriculture was converted to more natural cover in three areas of interest in the SPRB. Monte-Carlo simulations were performed to estimate ranges of return on investment using values identified from literature review for the social cost of carbon, discount rate, and time preference. Values of ROI ranged over millions of dollars for two of the three areas of interest. An R-Shiny app was created for easy assessment in other areas of the SPRB. Overall, this work highlighted important policy-relevant considerations when valuating ecosystem services such as: 1. Identifying who pays, who gets paid, and who benefits and 2. Inclusion and honest portrayal of uncertainty when making policy decisions.

Irrigation Expansion as a Climate Change Adaption Strategy: Implications for Greenhouse Gas Emissions (#8A)

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Irrigated agriculture accounts for roughly 42% of total water withdrawals and 54% of the total annual crop value in the United States. As climate change impacts hydrological cycles, the current contraction in irrigated area across the western US and expansion across the eastern US is expected to continue. Where feasible, irrigation is a highly effective climate change adaptation strategy as it improves productivity and resiliency to adverse growing conditions. However, irrigation also produces greenhouse gas (GHG) emissions through energy use and biogenic processes. Climate change adaptation strategies that increase, rather than mitigate, emissions

can produce reinforcing feedback loops that ultimately exacerbate climate change. Therefore, understanding the net GHG impacts of adaptation strategies, such as irrigation expansion, is important for prioritizing management responses to climate change. In this project, we seek to quantify the net GHG impacts of irrigation across the US via a) increased energy use for pumping, b) altered soil biogeochemical cycling, and c) increased yields and therefore reduced demand for additional land conversion to cultivation. Energy-use emissions associated with surface and groundwater irrigation were calculated at the county scale using data on pumping expenses from the USDA Farm and Ranch Irrigation Survey, along with fuel price data, emissions factors, and USGS data on irrigation water withdrawals. Biogenic emissions are assessed using high-resolution data on soil N2O emissions and carbon storage from the DayCent biogeochemical model from comparable irrigated and non-irrigated sites. Finally, by calculating the increase in yields attributable to irrigation, we estimate the land area spared from cultivation and assess associated emissions savings. Ultimately, these data will allow us to project the net GHG impact of climate change adaptation via irrigation expansion, migration, and intensification.
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Optimizing Dryland Farm Productivity Using the Relationship among Crop Water Use, Planting Density, and Yield Performance (#9A)

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One of the most prevailing challenges to food system security is increasingly variable water availability. In order for producers to optimize crop yield and farm productivity in a changing climate, resources must reflect a better understanding of the relationship between water use, management, and yield performance in dryland conditions. However, little data exists to test optimal planting density under water limiting conditions for maize. We explored the effect of planting density on water limited crop productivity in the context of dryland maize production, conducting a field experiment in eastern Colorado. The objectives of this study were to (1) investigate the relationship between water availability and population density on grain yield response in dryland systems and (2) identify the best model of the yield-density/water response. We measured grain yield, aboveground biomass, chlorophyll fluorescence, and determined crop water use. Preliminary results suggest crop water use had a greater positive effect on grain yield than population density with no interaction between water and density. Treatments with greater water availability exhibited a yield-density response that approaches that of constant final yield, which is constant yield that cannot increase further. Lower water availability did not show a yield increase with planting density. The results of this experiment will increase the understanding of yield performance in drought-prone environments, informing efforts to increase resiliency and water use efficiency, and economic returns for dryland farmers.

Characterizing Nitrogen & Phosphorus Loads Delivered to Streams from Agricultural Landscapes at Various Watershed Scales (#10A)

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The Iowa Nutrient Reduction Strategy estimated the potential reductions in nitrogen and phosphorous loads that could be achieved by a wide range of in-field and edge-of-field practices. However, most work on practice performance and nutrient loads in Iowa has been done at either the plot or larger watershed scales. Nutrient loads estimated at these scales can differ substantially from loads actually delivered to surface waters from cropped lands. We evaluated nutrient transport within a central Iowa HUC12 watershed to better understand the effects of scale and stream processes on nitrogen and phosphorus transport. Nutrients and discharge were measured at five locations at various scales spaced longitudinally throughout the watershed. Automatic samplers were installed at these locations to collect high-frequency water quality samples to estimate nitrogen and phosphorus loading and concentrations during baseflow and event flow conditions. Preliminary results suggest that phosphorus loads at the HUC 12 scale can be substantially higher than loads actually delivered from agricultural landscapes (and reflected by delivery scale monitoring). In general, as watershed size increased, median nitrate-N and total nitrogen concentrations decreased. In contrast, median concentrations of total phosphorus (TP) and total reactive phosphorus (TRP) increased with watershed size. Turbidity sensors will be installed and paired with three sample sites to evaluate phosphorus fractionation and sediment transport. By utilizing turbidity as a surrogate for particulate phosphorus and sediment transport, we hope to better understand how particle-derived phosphorus moves through a central Iowa HUC12 watershed at various scales.

Techno-economic and Other Stakeholder Considerations for Saline Wastewater Management: A Case Study of The Beef Processing Industry (#11A)

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The meat and dairy industry are a huge part of food production in the United States. Up to 36% of the water used by the food processing industry is used for the production of beef, pork, poultry, and dairy products. Not only is this a significant amount of water consumption, but the wastewater production from meat and dairy processing is highly concentrated with an array of constituents including solids, metals, proteins, oils, and grease. This work is focused on industrial beef processing wastewater management. Comparisons were made on the economic and social barriers of incorporating sustainable wastewater management practices. Treatment of high-salinity wastewater in the beef processing industry is a complicated consideration. After a techno-economic comparison of injection, evaporation, and treatment for wastewater management methods, treatment does not seem to be a viable option. After including other considerations such as the sustainability of each method, and feeding this information into a multi-criteria decision analysis, treatment seems like a more viable option. Results show that in the industry perspective, evaporation may have the highest potential for adoption for wastewater management. However, in the consumer perspective, sustainable wastewater treatment has the

highest potential for adoption. Further and more detailed consideration of community and other stakeholder perspectives would improve this analysis greatly. This work is to be used as a framework for developing a decision tool for sustainable wastewater management methods.

Is Solar Energy an Obstacle or Opportunity for Farmers? (#12A)

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In the past decade the cost of solar photovoltaic (PV) technology has decreased substantially while the efficiency of PV has increased substantially. This has made PV appealing to energy developers, as evidenced by the exponential growth of installed PV capacity. A notable limitation of PV as a method of generating electricity is that installations require large amounts of land for harvesting sunlight. A primary method of managing this limitation has been to site new PV installations on degraded lands such as superfund sites to limit the negative consequences of development, or alternatively to locate PV installations on existing infrastructure such as roof tops. These methods are generally sound, however with increasing pressure to develop clean energy it is unlikely that they will be enough on their own to account for the volume of PV infrastructure that will be needed in order to transition away from fossil fuels. Consequently, there is increasing demand to develop PV infrastructure on agricultural land due to the desirable characteristics of agricultural land for solar electricity production. Fields get plenty of sun, are usually fairly flat to build on, and are often located fairly close to transmission lines, all qualities that are appealing to solar energy developers. Many farmers and rural communities have expressed concerns about the long-term impacts of such installations however, and there are also concerns regarding equity in partnerships between farmers and energy developers. One potential solution to help ease this dilemma is known as "agrivoltaics", or the co-location of agricultural activities and solar energy generation in a single location. With appropriate management agrivoltaics would preserve the productive capacity of the soil to ensure sustainability of land use after the lifespan of solar panels has passed. The shade provided by solar panels has also been shown to reduce evaporation and help some types of crops to use water more efficiently which is of vital importance in arid regions with limited supplies of water.

Residential Rooftop Solar Expansion in Fort Collins, Colorado (#13A)

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Electricity is traditionally created at one point along the grid and is then distributed by feeder lines. When rooftop solar panels (PV) are installed, however, the feeder lines encounter multiple electricity input points. This can pose a problem because each feeder line has a capacity limit, and if enough rooftop solar is installed, the capacity limits can be violated. PV installations are increasing in Fort Collins, Colorado. The expansion, however, is not happening uniformly—some areas of the city are seeing greater rates of installation than others. The current research involves a series of analyses to help the utility understand where rooftop PV is likely to expand in the future and whether the grid's capacity limits are likely to be violated. To accomplish this, our team

will first model which homes currently have rooftop solar in Fort Collins to determine the sociodemographic factors, such as home value and EV ownership, related to solar installation. This model will be used to estimate the likelihood that each residence will install PV in the future. We will then perform a hosting capacity analysis to determine whether the Fort Collins grid is in danger of violating its capacity limits. Traditional hosting capacity analyses assume a random distribution for future PV installations, which fails to consider differential rates of adoption as a function of sociodemographic factors. In contrast, our analyses will take this into account by incorporating each residence's likelihood of installing solar into the hosting capacity model. This will provide the utility with a more accurate estimate of whether our current electric grid can handle future rooftop solar expansion, allowing the utility to make more informed decisions about future grid upgrades.

Local Forecast Accuracy and the Implications to Smart Irrigation Technology (#14A)

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A significant amount of water is needed to take care of the average lawn in Fort Collins, CO. According to the city of Fort Collins, the average household uses an extra 10,000 gallons per month during the summer, mostly for outdoor uses. In order to combat this excessive water usage, they have offered rebates to residents who install smart irrigation controllers, which use weather predictions to assess when and how much to water a lawn. The smart controllers were intended to reduce outdoor water use, however, for already low-water users, water consumption increased after the implementation of a smart irrigation controller. As the city of Fort Collins continues to grow, the demand for water will increase, thus by making irrigation systems more efficient, residents can greatly reduce their overall water consumption. The goal of this research is to determine the accuracy of weather forecasts in Fort Collins, CO in order to determine when will be best to water a lawn in order to reduce outdoor residential water consumption. To do this, we gathered five-day forecasts from the National Weather Service for Fort Collins from November 2019 to October 2020 to compare to actual meteorological data, focusing on temperature, precipitation, wind, and cloud cover. Our analyses show that the forecasted and actual temperatures vary greatly, with forecasted temperatures tending to underestimate both minimum and maximum daily temperatures. A modified Penman-Monteith equation has been developed which uses temperature, precipitation, wind, and cloud cover in order to predict evapotranspiration and therefore, when to irrigate a lawn.

Rewired Anaerobic Digestion: Developing More Sustainable Chemical Factories (#15A)

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Colorado State University

The growing demand for food, energy, and water seems unstoppable on a crowded planet. Each year, considerable amounts of waste are added to landfills and open dumps globally. Most of the

waste generated is "organic"; in other words, it is biodegradable and comes from either plants or animals primarily associated with our food systems. Despite efforts to valorize this waste through composting or anaerobic digestion; municipalities, farmers, and food industries, currently, landfill their waste due to a lack of techno-economic incentives. One opportunity to address this challenge relies on rewiring anaerobic digestion for transforming organic waste into more profitable products like fatty acids. These molecules are petrochemicals widely used in several industries, including pharmaceuticals, food preservatives, fuels, and polymers. Using organic residues to produce these chemicals is an opportunity to transition from petrochemical systems and reduce currently landfilled waste. This presentation provides insights into the ability of microbes to convert organic waste into short and medium-chain fatty acids. We have found that we can get more or less of the fatty acids we want to produce depending on what set of microbes we use. However, rewired anaerobic digestion is still a complex and not-fully understood system. Our ongoing work uses advanced molecular biology tools to characterize genomes and fatty acid production pathways. This knowledge will be crucial in discovering and developing more sustainable chemical factories to integrate into current waste management systems.

Arsenic Speciation in Rice Bran: Agronomic Practices, Postharvest Fermentation, and Human Health Risk Assessment Across the Lifespan (#16A)

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Arsenic (As) exposure is a global public health concern affecting millions worldwide and stems from drinking water and foods. Here, we assessed how agronomic and postharvest techniques influence As concentrations in rice bran, and calculated health risks from consumption of three rice bran-As concentration scenarios. Total As and speciation were quantified in 53 rice bran samples. Inorganic As (iAs) concentrations in rice bran were used to calculate Target Hazard Quotient (THQ) and Lifetime Cancer Risk (LCR) across the lifespan. Mean iAs was highest in Thailand rice bran samples (0.619 mg/kg) and lowest in Guatemala (0.017 mg/kg) rice bran samples. When comparing monosodium-methanearsonate (MSMA) treated and Native-soil counterpart under the irrigation technique Alternate Wetting and Drying (AWD) management, the MSMA treatment had significantly higher total As ($p= 0.022$), and iAs ($p= 0.016$). No significant differences in As concentrations were found between conventional and organic production, nor between fermented and non-fermented rice bran. Health risk assessment calculations for the highest iAs-rice bran scenario for adults, children and infants exceeded THQ and LCR thresholds, and LCR was above threshold for median iAs-rice bran. This investigation provides novel information with food safety relevance as an emerging food ingredient.

STUDENT SHOWCASE: SESSION B

An Improved Rescaling Algorithm for Estimating Groundwater Depletion Rates using the GRACE Satellite (#17B)

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The Gravity Recovery And Climate Experiments (GRACE) satellite mission has been instrumental in estimating large-scale groundwater storage changes across the globe. GRACE observations include significant errors, so pre-processing is normally required before the data are used. In particular, the observations of terrestrial water storage anomalies (TWSA) are usually filtered to reduce the effects of measurement errors and then rescaled to reduce the unintended impacts of the filtering. The rescaling is typically selected to maximize the Nash-Sutcliffe Efficiency (NSE) between the outputs of large-scale hydrologic models that represent an incomplete water budget and the filtered outputs. The objectives of this study are (1) to evaluate the use of NSE in the current GRACE rescaling methodology, (2) develop an improved methodology that incorporates a complete regional water budget, and (3) examine the impacts of the rescaling methodology on regional assessments of groundwater depletion. To evaluate the use of NSE as a performance metric, we implemented the rescaling methodology when the Kling-Gupta Efficiency (KGE) is used to measure performance. Because of differences in their weighting of bias, maximization of NSE and KGE resulted in very different scale factors. However, using NSE produces more reliable estimates when comparing to TWSA estimates from global positioning systems (GPS) for the Central Valley in California. Rescaling with the complete regional water budget based on observed hydrological fluxes results in a larger scale factor (2.86) than the scale factor from the large-scale hydrologic model outputs (1.83), and the new TWSA results are more consistent with those from GPS. The larger scale factor also suggest that regional groundwater depletion is more severe than previous estimates.

Analyzing Groundwater Storage Trends in the United States from 1951-2020 (#18B)

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Groundwater is an important source of water for residents, municipalities, and irrigation in the United States. However, the change in groundwater storage through time is often difficult to quantify, particularly for large regions. Groundwater level measurements have been taken at monitoring wells across the United States for over a century, and an especially significant amount of data from the last seven decades is available through the United States Geological Survey (USGS). This study couples data retrieved from the USGS groundwater database with ArcGIS geoprocessing routines to display trends in groundwater head and groundwater storage in unconfined aquifers over the last seventy years, with a focus on groundwater in unconfined (near-surface) aquifers. Filtering data for unconfined aquifers is performed using reported well depths and national raster maps of land surface elevation and thickness of unconsolidated sediment, resulting in a total of 356,785 wells with measurement data in the past 100 years.

Groundwater head data from these wells are averaged temporally, by decade, and spatially, by watershed boundary, to quantify temporal and spatial trends in groundwater storage throughout the United States during the period 1951-2020. Watershed boundaries are designated by the 2,139 8-digit hydrologic unit code (HUC) subbasins of the conterminous United States. To provide key temporal trends in various regions of the country, subbasins are filtered according to the number of wells that have been sampled within their boundaries and the availability of measurements across the years 1951-2020. The results of the groundwater trend analysis depict the overall shifts in regional groundwater storage. These trends provide an overall status of near-surface groundwater availability in the United States, and can be used to guide local, regional, and national groundwater management in the future, particularly for regions experiencing groundwater depletion.

Fluvial Response in a Meandering Headwater Stream One Year After Wildfire (#19B)

Daniel C. White, Ryan R. Morrison, Peter A. Nelson
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In October 2020, the Cameron Peak Fire burned 845 km2 of the Cache la Poudre and Big Thompson watersheds. The impacts of large wildfires, such as the Cameron Peak Fire, on channel and floodplain landscapes in headwater streams are not well studied. Immediately after the fire we began monitoring the trajectory of responses at Little Beaver Creek, a tributary of the Cache la Poudre River draining 38.5 km2 . Specifically, we monitored channel morphology, floodplain topography, and floodplain vegetation in a wide, alluvial, meandering reach of Little Beaver Creek. We used both RTK GPS and UAV-imagery-based structure-from-motion to assess changes in topography in the floodplain and channel, and we measured flow depth using a pressure transducer at multiple locations within the reach. Following the Cameron Peak Fire, we observed overbank flow on multiple occasions in 2021, including: two late winter floods when ice occupied a significant portion of channel on 20 March and 4 April, peak snowmelt runoff on 25 May, and shortly after summer rainstorms on 2 July, and 3 September. We measured fine particulate organic matter and sediment deposition on bars and the floodplain between 17 November 2020, and 7 August 2021. Between 7 August 2021 and 17 October 2021, data shows that pools scoured and bar elevations decreased where deposition had occurred earlier in the year. Aerial imagery and visual observation validate the measured trend of widespread deposition followed by incision. This indicates that as sediment and organic material moved from hillslopes to the channel, they were temporarily stored in portions of the active channel, stored in the floodplain at a one year or longer scale, and a channel deposition-scour sequence occurred in pools. The greatest deposition and subsequent incision were observed where channel-floodplain connectivity and channel heterogeneity were high. These observations improve our understanding of flow and sediment attenuation and fluvial resilience after wildfires.

Habitat Mapping of the Silvery Minnow in the Middle Rio Grande, Bosque Del Apache Reach (#20B)

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The Bosque Del Apache reach spans 16 miles of the Middle Rio Grande River, entirely within the Bosque Del Apache National Wildlife Refuge in New Mexico. Over a century of human use and modifications have had large impacts on the river and the ecology dependent on it, especially its endemic fish species. The objective of this research is to analyze changes to the river through its hydrology, geomorphology, and hydraulics to ultimately relate these conditions to habitat requirements for the endangered fish species, the Rio Grande Silvery Minnow (RGSM). The reach was divided into five subreaches based on trends of channel depth and width. Using available flow/sediment discharge data and historical aerial imagery, several analyses were performed to understand how both flow and sediment have changed over time. Next, using 1D hydraulic modeling in HEC-RAS, the velocities and depths of the Middle Rio Grande at various discharges were calculated to find where suitable habitat conditions existed for the silvery minnow. Detailed mapping was performed by creating a plan view grid with a 10-foot resolution to illustrate where in the Bosque reach habitable areas exist for the RGSM. The reach saw an average suspended load of about 7,000 tons per day, with monsoonal summer thunderstorms generating most of the suspended sediment. It was found that the width dramatically decreased across all subreaches, stabilizing at 100 to 250 feet. The river has also undergone cycles of aggradation and degradation and is currently in a cycle of aggradation in most subreaches. The aggradation is most pronounced in the middle of the reach (up to six feet since 1949). This excess in sediment supply has led to natural levee formation, perching the main channel higher than its flood plain. Across all the years analyzed for habitat, 2012 represented the greatest amount of available silvery minnow habitat for all life stages. Larval habitat, a limiting parameter for the RGSM, was maximized in 2012 at a discharge of 2,500 cfs, generating 801 square feet of habitat per mile of river.

Characterizing Logjams from Remotely Sensed Imagery (#21B)

Anna Marshall[1], Dan Scott[2], Ellen Wohl[1]
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2 Watershed Science and Engineering (WSE)

Large wood is used in various forms and for a variety of purposes in river restoration and management. However, we lack tools and guidance required to inform process-based restoration and management using wood, particularly in the form of project monitoring. Here, we address some of the challenges and benefits associated with characterizing in-channel wood to further refine hydraulic models. We use high-resolution imagery collected along the Cedar River in King County, WA to extract specific logjam characteristics (i.e., porosity) from two-dimensional space. We use a supervised classification to identify wood throughout the Cedar River study area and then aggregate wood clusters to determine the porosity across different logjams. Utilizing these methods, we ask the questions 1) does a 2- D bird's eye view of a logjam tell us anything about logjam characteristics that is different or similar to field observations; 2) can the porosity and

aggregation of a logjam be measured from imagery; and 3) for what imagery conditions does this type of tool work best? The method we use provides details on the aggregation and porosity of logjams, information that can help to further constrain hydraulic models and successfully model wood in river restoration scenarios. Gleaning logjam characteristics from imagery provides an objective and cost-effective measure of collecting data to inform hydraulic modeling. On a broad scale, this type of methodology can inform a mechanistic understanding of how logjam characteristics and distribution alter fluvial processes and can in turn inform restoration designed to enhance river attributes such as habitat abundance, biogeochemical cycling, and carbon sequestration in forested regions and at larger river-system scales.

Drivers of Geomorphic Complexity in Dryland Ephemeral Streams Across the Southwestern United States (#22B)

Julianne Scamardo and Ellen Wohl
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The majority of river networks globally are expected to go dry for at least part of the year, and the number and frequency of ephemeral and intermittent rivers are projected to increase with a changing climate. Understanding drivers of morphology and diversity in temporary rivers is therefore crucial to managing current and future watersheds. Studies on drivers of geomorphic heterogeneity or stream complexity are emerging in perennial streams, but similar studies in ephemeral and intermittent rivers are lacking. Questions remain such as: how does river corridor complexity vary throughout ephemeral watersheds, and does complexity correlate to floodplain size or large wood abundance, as it does in perennial rivers? Measures of river corridor complexity as well as potential drivers were quantified in 31 total reaches (including the channel and floodplain) across six dryland ephemeral watersheds in the southwestern United States using field surveys and aerial imagery. River corridor complexity was quantified using braiding index, sinuosity, and metrics for the number and diversity of distinct geomorphic units or patches. Potential driving variables included average channel width, floodplain area, median grain size, large wood jam density, and jam volume within the reach. A significant binomial correlation exists between floodplain area and the diversity of geomorphic patches, where the highest diversity corresponds to intermediate sized floodplains. With decreasing distance from the channel, the likelihood of disturbance increases. Therefore, intermediate floodplain widths could correspond to intermediate disturbance potential, suggesting a link between disturbance frequency and geomorphic complexity. Additionally, a significant positive correlation exists between channel sinuosity and jam spatial density, highlighting potential positive feedbacks between jam occurrence and increased complexity, which in turn creates additional trapping mechanisms for future wood. Jam spatial densities ranged from less than 5 jams per kilometer of stream channel to approximately 150 jams per kilometer of stream channel, exceeding previous reported jam densities on temporary rivers. Results indicate the disturbance and wood are important factors influencing the morphology of ephemeral river systems, and also highlight the potential for natural and engineered jams to be used in the restoration of geomorphic processes and heterogeneity in temporary rivers globally.

Novel, Internet-of-Things-based, Solid-State pH Sensors for Soil and Groundwater (#23B)

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The Center for Contaminant Hydrology seeks to develop technology that can help to better understand the chemical environment in the subsurface associated with hazardous chemical releases. Some of the developments include a suite of low-cost, Internet of Things (IoT) based sensors that can be deployed continuously through time in the soil and water at contaminated sites to monitor the in-situ chemistry. These sensors offer the benefits of continuous monitoring in real-time from the office, home, or field, no matter how remote the site. Because of their low relative cost, they can be deployed in greater numbers that can provide large datasets to monitor sites in higher resolution than typical networks of monitoring wells or associated analytical equipment. Previous successful designs include sensors for temperature, pressure, and oxidation-reduction-potential (ORP). The goal of this work is to study and develop sensors for monitoring pH. Many sites have regulatory requirements for monitoring and operation of remedial actions but are very costly to monitor using existing methods. Often, sites are not well understood for lack of data to characterize and monitor the site effectively. Better understanding of the subsurface chemistry at a site can lead to better decisions for site managers to remediate the site and protect the public and environment. Existing pH sensing systems do not fulfill these goals because of their fragility, need for frequent maintenance and calibration, and inability to measure and report data over long periods of time. To solve this problem, we have developed a novel pH sensor and measuring system that can be placed deep in the subsurface in the vadose zone or below the groundwater table for extended periods of time (months to years) that can report data via cellular or internet connectivity at intervals as short as a few seconds with accuracy of at least one-half pH unit. Applications for this technology extend to sites with legacy contamination, active industrial sites, agricultural operations, and more.

Changes in Snow Water Storage Across Western North America (#24B)

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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.

Measuring Floodplain Heterogeneity from Remote Imagery and Field Data: A Sensitivity Analysis (#25B)

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Floodplains are characterized by spatial heterogeneity that provides many ecosystem functions, e.g. floodplain storage of water, solutes, sediment, organic matter, and contaminants. Heterogeneity results from lateral channel migration and avulsion and can be delineated as patches that are spatially contiguous and distinct. Spatial heterogeneity influences floodplain storage time of water, solutes, sediment, and organic matter; contaminant storage/remobilization; and river corridor biodiversity and productivity. Centuries of flow regulation, land drainage, and artificial levees have laterally disconnected channels and floodplains, resulting in homogenization of floodplain morphology and vegetation and loss of floodplain functions. Restoring the natural processes that create/maintain floodplain functions is of increasing scientific and practical interest. This study builds on Iskin and Wohl's (in preparation) study that calculated and compared 11 landscape heterogeneity metrics from the field of landscape ecology for three prairie streams in Colorado and Oklahoma from classified spectral and topographical rasters. This continuation incorporates publicly available high-resolution topography data, interpolated soil texture characteristics from field data collection, and vegetation and moisture spectral indices from remote imagery. Heterogeneity metrics are calculated for the more detailed classified rasters and compared to the values derived from the less detailed rasters. Preliminary results show that incorporating more detailed raster data into the classification scheme decreases the size of the patches identified, but that the heterogeneity metrics show the same patterns when compared between floodplains and between metrics. The results of the larger research of which this is a part will be applicable to many river corridors as the sites capture much of the variation in the United States. More broadly, this work can inform adaptive river management implemented by public and private practitioners by identifying processes that create and maintain floodplain heterogeneity.

Semi-Arid Rangeland to New Houses: Behavior of a Non-Perennial Stream (#26B)

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Colorado's growing population has driven an increased demand for new housing. Increased housing development in Northern Colorado has in turn resulted in the urbanization of historically semi-arid rangelands. Urbanization is known to increase peak stream flows and the frequency of high flows. However, there is little documentation detailing how hydrologic responses in semi-arid rangelands are affected from pre- to post-development. Part of this lack of documentation can be attributed to semi-arid rangelands typically having non-perennial streams. While perennial streams have flow year-round, nonperennial streams are dry for parts of the year. As a result, non-perennial streams tend to have incomplete records of streamflow presence or absence and lack documentation of other characteristics such as stream morphology or response to precipitation events. Due to the lack of pre-development baseline observations, understanding the effects of development on non-perennial streams is especially difficult. In an effort to set a pre-development baseline and record hydrologic changes throughout the stages of housing development, this research will utilize drone imagery and time-lapse photography to monitor a non-perennial stream within the West Stroh Gulch rangeland located in Parker, Colorado. In 2020, a field camera was installed in West Stroh Gulch to take photos of the non-perennial stream channel every five minutes. Observations of streamflow presence or absence were manually recorded during photo processing. In December 2021, two additional field cameras were installed to increase the number of locations monitored for stream flow along the channel. Drone flyovers will be completed in the coming months to supplement these close-up observations with aerial views and topographic data for West Stroh Gulch. With this drone data, visual changes to the stream channel and the surrounding catchment will be captured through the stages of development. Combining aerial drone data and on-the-ground time-lapse photography will create a more complete picture of changes in the hydrologic responses of a semi-arid rangeland undergoing housing development.

Streamflow Generation across an Elevation Gradient after the 2020 Cameron Peak Fire (#27B)

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The western United States is seeing an increase in catastrophic wildfire in virtually all climate types and across a broad range of elevations. Many of these fires burn in forested headwaters that communities rely on for water supply, underscoring the need for a greater understanding of how fire changes streamflow timing and magnitude. Though many studies have examined the hydrologic response to fire, the sitespecific nature of this type of research has made it difficult to generalize findings. The 2020 Cameron Peak fire in Colorado burned across a broad elevation gradient, making it an ideal case study for examining how the post-fire impact to streamflow generation varies with temperature, aridity, and seasonal snow cover. We selected three watersheds—unburned, partially burned, and severely burned—in each of two snow zones: the

high-elevation persistent snow zone, and the mid-elevation intermittent snow zone. These watersheds were instrumented to monitor snow accumulation and ablation, rainfall, and stream discharge throughout water year 2021. We compared streamflow responses to rainfall and snowmelt between watersheds to evaluate how burning affected runoff. At high elevations, snowmelt runoff began earlier in the burned watersheds, which experienced greater total flow and lower base flows compared to the unburned watershed. The results were similar for the low elevation sites, though less pronounced for snowmelt runoff. At all elevations, streamflow at the burned sites was more responsive to rainfall, with the low elevation sites exhibiting a much more rapid rise to peak discharge than the high elevation sites. The results demonstrate that the streamflow responses to fire vary between snow zones, indicating a need to account for elevation and snow persistence in post-fire risk assessments.

Quantifying Contributions of Water Sources to Urban Streams and Temporal Variation Using Multiyear Analysis of Water Stable Isotopes (δ 18O and δ 2H) (#28B)

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Urbanization and climate change are altering hydrological behavior and water availability, especially in arid and semi-arid cities. To manage and conserve water in water-scarce cities, water managers need to know the sources of streamflow such as tap water, precipitation, or lawn irrigation. Therefore, we used water stable isotopes (δ18O and δ2H) as tracers to identify the main contributors to stream baseflow. Two end-member mixing analysis techniques were used to quantify the percent contribution of the streamflow from tap and precipitation sources. We collected water samples from 13 urban and 6 grassland streams, 2 precipitation gauges, and several tap water locations in the semi-arid Denver metropolitan area, CO during 2019 and 2021. We used USGS real-time streamflow data and the 'EcoHydRology' R package to identify baseflow conditions when sampling. A Picarro L2130i Laser Water Isotope Analyzer was utilized for water stable isotope (δ18O and δ2H) analysis. Precipitation samples exhibited increasingly heavy isotopic values (‰) in late summer than in the earlier summer. The tap samples were more widely distributed in isotopic values (‰) in 2019 than in 2021. Centennial Water and Sanitation District (CWSD) water provider showed a heavier mean isotopic value than other water providers and its values decreased overtime during the summer. This matches with their use of groundwater along with surface water sources. Tap samples followed the Local Meteoric Water Line (LMWL) and Global Meteoric Water Line (GMWL) well, but precipitation samples deviated slightly from LMWL and GMWL. A similar range in isotopic values in the stream and tap water indicated that tap water was the leading contributor to urban baseflow. In our future work, we will assess the seasonal and biannual variation in tap water and precipitation contribution as well as reasons behind the dissimilar spatial pattern of isotopic values in watersheds. Moreover, we will evaluate the impacts of limiting tap water sources to streams such as the drying out of streams during summer and changes to riparian ecosystems and recreation.

Where Did the Snow Go? Physical Processes Driving Accumulation and Ablation Patterns in Wildfire Burn Areas (#29B)

Wyatt Reis, Dan McGrath
Geosciences, Colorado State University

A significant portion of the snowpack, which contributes 70% of annual runoff in mountainous areas, accumulates in high elevation forests. Since the 1980s, high elevation forests have seen a significant increase in fire activity, impacting these critical water resources. Wildfires impact the snowpack mass and energy balances in three primary ways: a reduction in canopy i) increases snow depth in burned areas during the accumulation season, however also, ii) increases the amount of shortwave radiation at the snow surface, and iii) the increase in soot/debris deposition on the snow surface decreases the albedo, increasing the energy entering the snowpack. We seek to address the significant knowledge gaps that remain regarding the ways these impacts interact, altering the physical processes of the snowpack. To quantify the impact of the fire on accumulation and ablation processes in a persistent snowpack, in-situ and remote sensing observations have been implemented in the burn zone of the 2020 Cameron Peak Fire in the Cache la Poudre watershed of North Central Colorado. Our in-situ sampling plan includes biweekly snow pit measurements, snow depth and SWE transects, along with paired automatic weather stations in burned and unburned locations. Satellite derived albedo retrievals and radiative forcing values are used to determine the ability for current operational and scientific satellites to capture the spatiotemporal variability within post-burn snowpacks. Preliminary data from November 2021 through February 2022, the second winter post-fire, shows aspect and canopy driven differences between burned and unburned areas. North aspects in the burned area had ~1.0 °C lower average snowpack temperatures and approximately twice the snow depth compared to comparable aspects in unburned areas through the end of January. However, during February, the burned area temperatures surpassed those of unburned areas. In contrast, south burned aspects have comparable snow depths while the average temperature is ~0.4 °C lower than in the unburned areas. The difference in net shortwave radiation between the sites is significant and a divergent trend is emerging. In early January the burned site received approximately similar amounts of shortwave radiation as unburned areas, by the end of February, cumulative difference approached 12,000 W/m2.

Expected Changes in the Snowpack of the Colorado Front Range (#30B)

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Water is the most important factor to sustaining life on Earth. Snow acts as a reservoir for water in the cold seasons and the melting of this snow provides large populations with water throughout warmer drier months, effectively connecting ecological, hydrological, and atmospheric systems. This is especially the case in the Colorado Front Range where the water balance in the summer heavily depends on the snowpack received during the winter and early spring. With a warming

climate, it is essential to understand changes that will occur to this vital snowpack in the future. Global Climate Models (GCMs) parameterize cloud/precipitation and land-surface processes and are incapable of resolving the highly detailed processes that can impact snowpack. In recent years, the use of high-resolution convection-permitting regional climate models have allowed for detailed understanding of physical processes related to orographic precipitation and atmospheric flows in a current and future climate as they do not use parameterized convection or orography. SnowModel is a high resolution (100-meter), snow-evolution, modeling system that can simulate processes such as blowing snow redistribution and sublimation, forest canopy interception, snow-density evolution, and snowpack melt. This project uses high-resolution atmospheric model simulations at 4-km horizontal resolution to drive SnowModel in the current and future climate for 13-years from 2000 to 2013 over the Colorado Rocky Mountains. Our results show that there will be a shorter snow season in the future. This means that on average, snow will begin later and end sooner, reducing the days that the snowpack has to accumulate. In addition, a decrease in snow water equivalent (SWE) has been observed for the future climate, meaning that the snowpack will not contain as much water content. Solid precipitation in the future climate is also expected to decrease due to the warmer temperatures during the snow season. Analyses of several physical snowpack processes from SnowModel and orographic precipitation patterns over this region will also be presented. The changes expected in the snowpack are concerning and will impact everyone living on the Front Range.

Next Generation Basin-Wide Snow Monitoring Network (#31B)

T.R. Heydman
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Over 2 billion people in the world depend on water originating as snowpack. Monitoring of snowpack high in the alpine is essential for water forecasters, city planners, and agriculturists. Currently only a very small percentage of world's snowpack is actively monitored throughout the year. Barriers to monitoring are cost, accessibility, and lack of infrastructure to collect and process data. This uncertainty is compounded by terrain and weather conditions that cause variability that is not accurately reported. I am proposing to rethink current standards and utilize an affordable, accessible, and more in-depth monitoring network than the current standard, SNOTEL. Using "Long Range" (LoRa), a new, currently available, low power consumption, 915mHz, network interface to create and monitor a "mesh-type" network where individual sensor arrays communicate with one another, like Apple's "air tag." Currently, in the Snotel network, individual sensor arrays communicate through the way of a singular contact point known as a gateway. SNOTEL is a cost prohibitive design where only a single point is utilized to represent the spatiotemporal variability across an entire watershed, and then transfer the sensor's data to the network by telemetry. LoRa acts in a different way. Each unit is its own Arduino-based transceiver with a set of sensors that monitor climate conditions and snow information, then each unit "meshes" or connects with other units 3-10 miles away from one another. This design allows extensive monitoring across an entire basin without relying on "line of sight" or one "gateway" to connect and interface a multitude of sensors. Relative to other networks, LoRa uses far less power and is much slower in data transfer speed but is plenty capable for the metrics that snow monitoring and weather data require. The real-world implications can help us to better

understand landscape wide processes and to better forecast for our water needs in the face of climate change. Additionally, the network is adaptable for land managers, sensors can be easily added to monitor air quality, smoke, or as an emergency communication network.

Impact of Forest Treatment Practices on Mountain Watersheds (#32B)

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Wildfires are an increasingly common occurrence in the Western United States. In Colorado, 2020 and 2021 brought multiple catastrophic fires including the recent and tragic Marshall Fire. Wildfire mitigation measures – or "forest treatments" – such as plantation thinning, mastication and controlled burning, are increasingly utilized to reduce fire intensity and protect valuable resources. These treatments change forest structure which can alter the partitioning of water across the landscape; thus, such treatments may have critical implications for regional and state water resources. However, few studies have explicitly evaluated the impact of forest treatments on runoff and water yield. This research improves our understanding of the impacts of forest treatment on water in the western US by quantifying the change in runoff in mountainous watersheds that have undergone forest treatment. This question was investigated at the Sagehen Experimental Watershed, located in the Sierra Nevada Mountains of California. Sagehen offers a unique and ideal location of study because multiple types of forest treatment were applied to the watershed between 2014 and 2020. Continuous 15-min stream flow measurements were recorded at nine subbasins within the Sagehen Watershed from 2012 to 2020. Results show that while annual streamflow between 2010 and 2020 was highly variable, relative to historic trends, this variability is strongly correlated to inter-annual changes in precipitation rather than forest treatment. At both the basin and sub-basin scale, therefore, any signal of change in runoff resulting from forest treatments is unidentifiable in the context of such wide variability in precipitation. The treatments appear to have minimal impact on forest structure, as far as it relates to the water budget, even at the subbasin scale. Overall, this study helps inform water resource management decisions and natural resource protection measures as we adapt to climate resilient forests and water supplies.

Utilizing Ultrahigh Resolution Mass Spectrometry to Elucidate the Composition of Dissolved Organic Matter in Fire-Affected Headwaters (#33B)

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Since 1970, the fire-season length in the western U.S. has increased from 166 to 222 days, and Colorado has been experiencing this surge in wildfire activity firsthand. The Cameron Peak Fire of 2020 was Colorado's largest wildfire in recorded history, burning over 200,000 acres of forest

land in Northern Colorado over the course of four months. This fire was located in the headwaters of multiple rivers, such as the Cache la Poudre River, which supply water to nearly half a million Front Range municipal, industrial, and agricultural users. The combustion and heating of wildfires can alter the organic content of soils and vegetation which is exported out of these burned watersheds as dissolved organic matter (DOM). Determining the chemical composition of this fire-affected DOM is imperative; for example, chlorination of some DOM compounds can potentially produce toxic disinfection byproducts during water treatment. Thus, the objective of this study is to employ ultrahigh resolution mass spectrometry to elucidate the composition of DOM in five headwater catchments affected by the Cameron Peak Fire. Throughout the first year following the fire, water samples were collected by the U.S Forest Service from streams in burned and unburned CLP sub-catchments during baseflow conditions, spring snowmelt, and monsoonal summer storm events. The DOM content was analyzed with ultrahigh resolution mass spectrometry: a powerful analytical technique that can accurately identify the composition of thousands of DOM molecules in a single sample. The results of this study will advance the evaluation of fire-affected DOM composition which may inform prudent water-treatment approaches following severe wildfires.

HYDROLOGIC SYSTEMS

Climate Change and Seasonal Maximum Flows

Robert T Milhous
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The objective of this presentation is to demonstrate that in the analysis of the frequency of high flows we need to modify our analysis from an analysis of annual peak discharges to an analysis of annual peak discharges plus an analysis of peak discharges by peak flow type and by season. Peak flows in the Cache la Poudre River (Poudre River) are usually analyzed by using a single peak discharge for each year. It is the theme of this presentation that it might be better to divide the peak discharges into classes based on the underlying mechanism causing the peak discharge. In the Poudre River watershed there are four classes: 1) snow-melt, 2) snow-melt plus rain in the lower watershed, 3) thunderstorms in late July or early August, and 4) autumn tropical storms. The first three are probably accepted by many but the fourth is almost certainly controversial. The presentation on the Poudre River considers peak discharges types that does have seasonal components. Peak flow seasons in the Rio Tanama in Puerto Rico have three seasons. These are trade wind moisture from the east (including tropical cyclones) from mid-June thru the end of November, a dry season from December thru March and a season with peak events caused by frontal storms bring moisture from the Gulf of Mexico and land to northwest.(April - mid June). A major flood occurred on the Poudre River in September 2013 is an outlier with so similar event in the long record for a hydrometric gage at the mouth of Poudre Canyon. Could this be climate change? Analysis of peak discharges on the Animas River in southwestern Colorado suggests the event could be an event from a series of major fall peaks with long time intervals between the events. That does not rule out the possibility of climate change. In environmental flow studies there is often a need to quantify the annual maximum discharges. Because there is a possibility of climate change having different impacts on the various components of the hydrological cycle the maximum annual discharge record should be divided into different classes and the impact of climate change on the different classes analyzed.

Semi-Arid Rangeland to New Houses: Behavior of a Non-Perennial Stream

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Colorado's growing population has driven an increased demand for new housing. Increased housing development in Northern Colorado has in turn resulted in the urbanization of historically semi-arid rangelands. Urbanization is known to increase peak stream flows and the frequency of high flows. However, there is little documentation detailing how hydrologic responses in semi-arid rangelands are affected from pre- to post-development. Part of this lack of documentation can be attributed to semi-arid rangelands typically having non-perennial streams. While perennial streams have flow year-round, nonperennial streams are dry for parts of the year. As a result, non-perennial streams tend to have incomplete records of streamflow presence or absence and lack documentation of other characteristics such as stream morphology or response to precipitation events. Due to the lack of pre-development baseline observations, understanding the effects of development on non-perennial streams is especially difficult. In an effort to set a

pre-development baseline and record hydrologic changes throughout the stages of housing development, this research will utilize drone imagery and time-lapse photography to monitor a non-perennial stream within the West Stroh Gulch rangeland located in Parker, Colorado. In 2020, a field camera was installed in West Stroh Gulch to take photos of the non-perennial stream channel every five minutes. Observations of streamflow presence or absence were manually recorded during photo processing. In December 2021, two additional field cameras were installed to increase the number of locations monitored for stream flow along the channel. Drone flyovers will be completed in the coming months to supplement these close-up observations with aerial views and topographic data for West Stroh Gulch. With this drone data, visual changes to the stream channel and the surrounding catchment will be captured through the stages of development. Combining aerial drone data and on-the-ground time-lapse photography will create a more complete picture of changes in the hydrologic responses of a semi-arid rangeland undergoing housing development.

Quantifying Contributions of Water Sources to Urban Streams and Temporal Variation Using Multiyear Analysis of Water Stable Isotopes (δ 18O and δ 2H)

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Urbanization and climate change are altering hydrological behavior and water availability, especially in arid and semi-arid cities. To manage and conserve water in water-scarce cities, water managers need to know the sources of streamflow such as tap water, precipitation, or lawn irrigation. Therefore, we used water stable isotopes (δ18O and δ2H) as tracers to identify the main contributors to stream baseflow. Two end-member mixing analysis techniques were used to quantify the percent contribution of the streamflow from tap and precipitation sources. We collected water samples from 13 urban and 6 grassland streams, 2 precipitation gauges, and several tap water locations in the semi-arid Denver metropolitan area, CO during 2019 and 2021. We used USGS real-time streamflow data and the 'EcoHydRology' R package to identify baseflow conditions when sampling. A Picarro L2130i Laser Water Isotope Analyzer was utilized for water stable isotope (δ18O and δ2H) analysis. Precipitation samples exhibited increasingly heavy isotopic values (‰) in late summer than in the earlier summer. The tap samples were more widely distributed in isotopic values (‰) in 2019 than in 2021. Centennial Water and Sanitation District (CWSD) water provider showed a heavier mean isotopic value than other water providers and its values decreased overtime during the summer. This matches with their use of groundwater along with surface water sources. Tap samples followed the Local Meteoric Water Line (LMWL) and Global Meteoric Water Line (GMWL) well, but precipitation samples deviated slightly from LMWL and GMWL. A similar range in isotopic values in the stream and tap water indicated that tap water was the leading contributor to urban baseflow. In our future work, we will assess the seasonal and biannual variation in tap water and precipitation contribution as well as reasons behind the dissimilar spatial pattern of isotopic values in watersheds. Moreover, we will evaluate the impacts of limiting tap water sources to streams such as the drying out of streams during summer and changes to riparian ecosystems and recreation.

Streamflow Response to Snowmelt in a Karst Mountain System

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In continental mountain regions, snow accumulation and melt are dominant controls on streamflow and water availability to downstream users and ecosystems. Subsurface flow associated with karst conduits can impact catchment response and sensitivity to climate variation. Here, we develop and evaluate a conceptual model for flow sources and pathways in karst mountain watersheds based on variability in hydrologic response throughout an intensively monitored 600 km2 watershed in Northern Utah. Streamflow patterns have been independently studied and modeled in snowmelt-dominated watersheds and in karst springs, but the combined effects of surface and subsurface flow pathways on streamflow patterns in watersheds with complex surface water - groundwater exchanges are poorly understood. Mapping and physically modeling these complex systems remains impracticable, but linked time series analysis of climate and aquatic variables can elucidate hydrogeologic characteristics and climate sensitivity. We employed established time series analysis techniques across a data set with high spatial and temporal resolution to compare the response of 10 nested catchments subjected to similar climate conditions. Patterns in snow melt, discharge, and conductance varied across catchments, water years, and response periods and were linked to geologic influences on groundwater. Our conceptual model provides a framework with which to characterize the snowmelt response and climate sensitivity of karst mountain catchments and link responses to subsurface dynamics. We also illustrate the added value of conductance time series data and gridded snow models for understanding karst aquifers.

Novel, Internet-of-Things-based, Solid-State pH Sensors for Soil and Groundwater

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The Center for Contaminant Hydrology seeks to develop technology that can help to better understand the chemical environment in the subsurface associated with hazardous chemical releases. Some of the developments include a suite of low-cost, Internet of Things (IoT) based sensors that can be deployed continuously through time in the soil and water at contaminated sites to monitor the in-situ chemistry. These sensors offer the benefits of continuous monitoring in real-time from the office, home, or field, no matter how remote the site. Because of their low relative cost, they can be deployed in greater numbers that can provide large datasets to monitor sites in higher resolution than typical networks of monitoring wells or associated analytical equipment. Previous successful designs include sensors for temperature, pressure, and oxidation-reduction-potential (ORP). The goal of this work is to study and develop sensors for monitoring pH. Many sites have regulatory requirements for monitoring and operation of remedial actions but are very costly to monitor using existing methods. Often, sites are not well understood for lack of data to characterize and monitor the site effectively. Better understanding

of the subsurface chemistry at a site can lead to better decisions for site managers to remediate the site and protect the public and environment. Existing pH sensing systems do not fulfill these goals because of their fragility, need for frequent maintenance and calibration, and inability to measure and report data over long periods of time. To solve this problem, we have developed a novel pH sensor and measuring system that can be placed deep in the subsurface in the vadose zone or below the groundwater table for extended periods of time (months to years) that can report data via cellular or internet connectivity at intervals as short as a few seconds with accuracy of at least one-half pH unit. Applications for this technology extend to sites with legacy contamination, active industrial sites, agricultural operations, and more.

Nested Piezometer Network Captures Spatiotemporal Variations in Streambed Fluxes Along Colorado Mountain-Front Streams

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Streambed fluxes are highly variable through time and space, having a range implications for stream-aquifer processes such as groundwater recharge. Since 2016, we've been developing a network of shallow (<1.5m) nested streambed piezometers along two perennial, mountain-front streams in Colorado to characterize spatiotemporal variations in streambed fluxes and to identify implications for seepage recharge. So far, twelve piezometer nests have been installed at varying distances from the mountain front. Individual piezometers are instrumented with temperature and pressure sensors set to log at 10-minute frequency. Darcy-based methods are used to estimate time-series of vertical streambed fluxes at each nest location. Flux estimates are improved through 1D numerical heat and flow modeling which is performed to calibrate hydraulic parameters. The long-term nature of the study allows for characterizations of flux variability at multiple temporal scales, including sub-daily fluctuations influenced by changes in stream stage, water temperature, and ET, as well as seasonal patterns that show stronger seepage during summer and weaker seepage during winter. We also document streambed flux responses to storm events and beaver dam formation, which significantly influence rates of seepage recharge.

Incorporating Probabilistic Variations in Soil Moisture Downscaling

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Soil moisture is a key variable for many applications including agricultural production and vehicle mobility. These applications require not only accurate estimates of soil moisture over large regions but also soil moisture patterns that exhibit realistic statistical properties, such as the range of values and the spatial correlation structure from fine spatial resolutions (~10 m grid cells) up to large spatial extents (~10 km regions). Satellites such as NASA's Soil Moisture Active Passive (SMAP) provide soil moisture data nearly globally but at resolutions that are too coarse for such applications (~9 km), so downscaling is used to estimate fine resolution soil moisture patterns from the coarse data. Downscaling methods are often based on the dependence of soil

moisture on regional topographic, vegetation, and soil characteristics. However, soil moisture patterns can also include significant random variations, which most downscaling methods neglect. The Equilibrium Moisture from Topography, Vegetation, and Soil (EMT+VS) downscaling model considers both the dependence on regional characteristics and some random variability, but the random variability was developed by considering only small spatial extents (<0.5 km). The objective of this research is to generalize the random components of the EMT+VS model to allow consideration from fine resolutions to large extents. Soil moisture measurements are considered for the 285 m by 540 m Cache la Poudre experimental watershed in Colorado and a 50 km by 75 km region in Arizona. The spatial structures of the random variations are analyzed using geostatistical methods. The EMT+VS model is then generalized and shown to produce soil moisture patterns with statistical properties similar to the observations. The improved downscaling method is expected to produce more realistic soil moisture patterns, which will improve predictions of agricultural productivity and vehicle mobility.

PUBLIC HEALTH

Monitoring and Preventing COVID-19 Outbreaks: A Comparison of Sewershed-Level and Building-Level Monitoring

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Wastewater-based epidemiology (WBE) has been established as a viable, valuable, and cost-effective means to detect and quantify SARS-CoV-2 to evaluate trends in infection levels and inform public health responses. The ability to track the virus through wastewater is more valuable than ever as the epidemiology of SARS-CoV-2 changes with vaccination, new variants, and evolving testing and infection patterns. Over the last 18 months, we have monitored wastewater from 19 treatment plants across the state of Colorado for SARS-CoV-2 and correlated the data to the clinical caseload in the population it represents through census tracts. The viral RNA load over time closely correlates with and slightly precedes increases in reported clinical cases. Additionally, we have monitored wastewater from 20 sites on and around the Colorado State University campus. Early in the pandemic, wastewater signals from building-level monitoring were used to direct the scarce supply of clinical tests to dormitories where infected individuals lived. Asymptomatic infected individuals were rapidly moved to quarantine to mitigate outbreaks. Later, when clinical tests were more accessible, wastewater became a secondary means to monitor levels of infection on campus and direct public health messaging. With mandatory masking and vaccinations, wastewater signals have been dramatically lower than in previous semesters, and continued monitoring could pinpoint outbreaks if they occur. We will present a comparison of data, conclusions, and recommended use cases for sewershed-level and building-level SARS-CoV-2 monitoring.

INTEGRATED RIVER BASIN PLANNING & MANAGEMENT

Using a Temporal Configuration-based Approach to Quantify Streamflow Properties

Richard Koehler
Visual Data Analytics

Over 170 different hydrologic metrics exist to quantify the streamflow properties of magnitude, frequency, duration, timing, and rate of change. These values are often composition-based statistics such as count, mean, median, standard deviation, or variance. However, composition metrics do not take data order into account and thus cannot address a fundamental hydrologic property – the temporal configuration of streamflow. This critical weakness can be resolved. Presented is a novel approach using the order of data to quantify streamflow properties. The resulting products are a combination of visualizations and tables providing additional streamflow information not possible with existing metrics. For example, the typical method for determining the rate of change involves finding the median or mean of all flow changes from one day to the next. Neither the mean nor median identifies which flows have changed or the degree of change that has taken place. In contrast, the techniques in this presentation use an autocorrelation lag1 discharge plot to tabulate increases, decreases or no changes across all flow levels. The techniques also generate specific rates of change for each flow level. These techniques are used in a case study of the Colorado River at Lees Ferry, Arizona to exam two 30- year periods before and after Glen Canyon Dam construction. Analysis confirms the counter-intuitive result that Glen Canyon Dam releases create a more random hydrologic regime even though this is a highly regulated system. Further, by describing all flow levels, the analysis shows specifically how the streamflow record has become more random. Streamflow characteristics and ecosystem implications of this condition are discussed.

Identifying Important Drivers of Water Yield Across Spatial and Temporal Scales and Most Appropriate Data-Driven Methods for Prediction

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Artificial neural networks are emerging as a useful tool in the field of hydrology. They show promise for enabling better predictions of water yield under various levels of land-alteration and in varying physiographic and climatic conditions. As their implementation becomes increasingly common, it will be important to know under what spatial and temporal scales they are most appropriate and when simpler, less computationally expensive, regression-based approaches will suffice. Accordingly, we will use physically-grounded data-driven methods to develop predictive models of daily, monthly, and annual water yield. By systematically investigating the model performance and results across temporal and spatial scales, we will gain insight about the importance of anthropogenic and natural watershed characteristics in driving water yield and how their importance varies across scales. Specifically, long short-term memory and gated recurrent unit artificial neural networks will be compared with regional regression approaches.

Over 5,000 basins ranging from less than 1 km2 to over 10,000 km2 from the Geospatial Attributes of Gages for Evaluating Streamflow (GAGES-II) dataset will be paired with USGS streamflow data and Daymet gridded weather data to train and test the predictive models. GAGES-II includes anthropogenic variables such as land use, population and housing density, and the presence of dams and canals. Early results from regression and principal component analysis on explanatory features have displayed the need for high-dimensional models. Of the 90 possible explanatory features initially considered (e.g., land use, historical climate, physiographic), only a handful of land use and climatic features exhibited strong collinearity. Furthermore, the first 10 principal components of the explanatory features only explained about 62% of the variance in all explanatory features. There appears to be greater redundancy in land-use variables however, with about 82% of the observed variance being described by the first 10 principal components, suggesting some land-use variables may be removed without losing information. Clustering using k-medoids revealed a lack of distinct groups of watersheds pointing towards difficulty in regionalization. Results will elucidate important drivers of water yield while providing guidance about appropriate methodologies for predicting water yield.

An Introduction to Self-Assessment Framework for One Water Cities: A Roadmap to Support One Water Future and Guide Management Actions

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Urban water systems across the world are plagued by various environmental and societal challenges. To address these pressures, a transition from traditional water management systems towards a more integrated approach is vital. This shifted approach which is known as “One Water,” is being strategically probed and implemented around the globe. Although several sustainability frameworks have been developed so far, there is not yet an established self-assessment framework to support the transition to sustainable, resilient, and equitable urban water systems. This study, therefore, presents the One Water Cities (OWC) self-assessment framework that provides opportunities for utilities to develop a coherent One Water vision, attainable goals, strategies, and monitoring plans to assess progress across collaborating organizations. The suggested framework encompasses a broad set of outcome-oriented indicators and metrics to measure progress toward implementation of the One Water approach through different levels (Onboarding, Progressing, and Advancing) by which cities can evaluate their One Water strategies, practices, and outcomes against appropriate expectations of performance. These assessment indicators and associated metrics are organized based on the OWC key elements, which represent information gleaned from a broad review of One Water literature, targeted expert interviews with progressive utilities, and a national survey of water stakeholders. Furthermore, the OWC self-assessment framework includes five categories (One Water Planning, Organizational Culture, One Water Planning, Stakeholder Engagement, Informed

Actions, and One Water Monitoring) within which clear expectations are defined. These categories enable cities to appropriately assess their level in their One Water journey and pave the transient path to the next level. The final product will help water managers and authorities to overcome barriers and enable them to benchmark and measure their progress toward the One Water paradigm shift.

Quantitative Assessment of Floodplain Functionality for the Continental United States Using an Index of Integrity

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Despite the numerous hydrological, geological, and ecological benefits produced by the floodplain ecosystem, floodplains continue to disappear and degrade at a much higher rate than other landscape types. Although this large-scale landscape modification has been widely observed, a comprehensive dataset quantifying the degree to which human development is responsible for this degradation has not previously been evaluated. Floodplain integrity can be defined as the ability of a floodplain to support essential environmental functions that sustain diversity and ecosystem services through geomorphic, hydrologic, and ecological dynamics. This research analyzes floodplain integrity at a national scale for the United States by spatially quantifying the impact of anthropogenic stressors on essential floodplain functions. The prevalence of these human modifications can be assessed through geospatial datasets, which are then quantified as indicators of floodplain health for five critical functions. The five essential floodplain functions include flood attenuation, groundwater storage, habitat provision, sediment regulation, and organics and solute regulation. Rather than just focusing on the ecological health within the floodplain, the research seeks to develop a more comprehensive integrity evaluation by assessing the health of the floodplain itself. An established methodology for quantifying floodplain integrity will be applied at a national level to better understand the impact that human development has had on floodplain health and critical floodplains functions. Integrity metrics will be evaluated for discrete floodplain units delineated along 12-digit hydrological unit codes (HUC-12) published by the USGS. Additionally, this methodology will be applied using land use change data for a 60-year period to analyze how land-use has impacted floodplain integrity over time. Quantifying the health of spatially explicit floodplain elements will allow for restoration efforts to be targeted to the areas in most desperate need of preservation.

The Role of Soft and Hard Interventions to Adapt and Mitigate Flood Impacts at the Building- and Community-Level

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Hurricanes drive multiple hazards on coastal and inland communities jeopardizing the social and economic systems within these communities. Flooding is one of the major hazards that results from a hurricane and includes fluvial and pluvial flooding for inland communities due to excessive rainfall. Flood mitigation techniques for these communities is crucial to decrease their exposure and vulnerability. Although, communities have been using different types of soft and hard

mitigation and adaptation interventions for many years, a robust quantitative approach has not been developed to identify the feasibility of these measures and how they relate to improvements in resilience. In this research, a highresolution approach was developed to account for the impact of a number of component-, building-, and community-level flood mitigation and adaptation interventions on the total community-level flood damage/loss reduction. The new approach allows propagating the uncertainty in the damage assessment from the component-level to the building- and community-level. This was done by developing a multivariate flood fragility function for each component within the building to calculate the failure probability of these components at different flood depths and durations. Then, a set of damage states was developed to account for the total building damage in terms of the exceedance probability of each damage state. For community-level analysis, a portfolio of 15 building archetypes was developed to model flood vulnerability of the different building occupancies within the community. The main advantage of this new approach is that it enables quantitative estimation of the impact of elevating water-sensitive components, and using flood barriers and water pumps on the total building- and community-level flood loss reduction. This enables better identification of the feasibility of these soft mitigation interventions with respect to other hard mitigation measures.

Assessing the Effects of Alternative Flow Scenarios on Rivers and their Aquatic and Riparian Habitats Using the REFDSS Web Tool

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The Riverine Environmental Flow Decision Support System (REFDSS) was originally developed for environmental flow assessment necessary to support aquatic habitat under multiple flow regimes. It has since been expanded to include assessment of riparian and invertebrate species in addition to aquatic species for a systemwide estimate of impacts in flow regime changes. The new REFDSS web tool integrates physical hydraulic data in the form of 2D (FaSTMECH and Nays2D) and 1D (HEC-RAS) model outputs and combines that with life-stage dependent habitat suitability criteria to assess total available habitat for a species under a flow regime. Layered onto the model is a scenario manager that allows definition and comparison of competing flow management scenarios. These evaluate the effects of instream and riparian habitat availability for the selected species of interest under the contrasting management scenarios. The side-by-side comparison of these outcomes allows environmental flow managers to make informed decisions about the future management of river segments for the protection of key environmental species.

THE WRITING WATER PROJECT WORKSHOP: Water-Focused Experiential Learning and Literacy

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Workshop Description: *The CSU Community Literacy Center, in partnership with the Colorado Water Center, has been developing an interdisciplinary curriculum that allows confined writers to engage with local, placebased Colorado water topics through virtual field trips. The Writing Water Project extends current work with incarcerated youth and adults through the SpeakOut! Program that is conducted around Northern Colorado. The primary mission of the Community Literacy Center is to create alternative literacy opportunities to educate and empower underserved populations and to support university-community literacy outreach programs. Through this session, we will present our methods for developing curriculum and conduct a short writing activity. We will also lead a discussion focused on how water literacy and outreach is relevant to academic research and science communication.*

Agenda:

- 10 min – framing of the Writing Water Project as a literacy tool
- 30 min – warm up, two writing activities, examples:
    - Respond to photos of the slot canyons in the Southwest: Think about the concept that water leaves a mark even when it isn't there (carving canyons, waterfalls, pools). Write about a time where you shaped the world around you or a time of really high energy in your life.
    - Read "Nibi," a poem from the Ojibwa oral tradition, out loud together. Think about her focus on water as sacred, as life-giving and humans as keepers of water. Write a response to these ideas in the form of a poem, story, narrative, or freewrite.
- 10 min – takeaways, discussion, questions

Nibi | Source: Ojibwe Oral Tradition
Anishinaabekwe, the Daughters,
You are the keepers of the water.
I am Nibi… water.. the sacred source, the blood of Aki, Mother Earth, the force filling dry seeds to great bursting.
I am the wombs cradle.
I purify.
Nibi, the lifegiver, forever the Circle's charge I have coursed through our Mother's veins.
Now hear my sorrow and my pain in the river's rush, the rain.
I am your grandchildren's drink. Listen, Daughters, always.
You are the keepers of the water. Hear my cry, for the springs flow darkly now through the heart of Aki.