

46th Annual

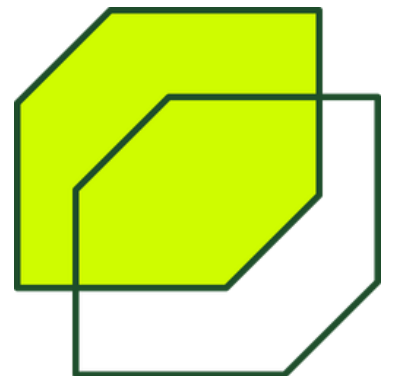
Hydrology Days

Wednesday, April 8, 2026

Colorado State University
Lory Student Center
Fort Collins, Colorado



COLORADO STATE UNIVERSITY
CIVIL AND ENVIRONMENTAL
ENGINEERING



SCHEDULE AT-A-GLANCE

Wednesday, April 8, 2026

Lory Student Center

Morning Sessions 9:00–10:30 a.m.

*Groundwater &
Hydrogeology*

Room 308

*Hydrologic Modeling,
Machine Learning &
Forecasting*

Room 310

*Water Quality, PFAS &
Urban Water
Systems*

Room 376

Break 10:30–10:45 a.m.

Late Morning Sessions 10:45 a.m.–12:00 p.m.

*Ecohydrology &
Plant Water*

Room 308

*Hydraulics,
Geomorphology &
River Processes*

Room 310

*Snow, Climate &
Mountain Hydrology*

Room 376

Lunch 12:00–1:00 p.m. Room 386

Keynote Address 1:00–2:00 p.m. Room 386

Dr. Holly Barnard, 2026 Hydrology Days Award Recipient

From Foliage to Fractures: Exploring the critical zone from multiple perspectives

Afternoon Sessions 2:00–3:00 p.m.

*Remote Sensing, ET
& Irrigation*

Room 308

*Water Systems
Engineering &
Applications*

Room 310

*Climate, Wildfire &
Broader Water
Systems*

Room 376

Parking

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Parking Permits

- **Hourly permit:** Hourly parking on campus is \$2. When you arrive in a lot with visitor parking, have your license plate number ready to enter into our hourly pay machines or you can download and use the [Park Mobile](#) app to pay by mobile phone. You can pay by credit card for the amount of time you wish to park. Your license plate number will serve as your permit. For more information visit [short-term parking](#).
- **Daily permit:** A daily permit can be purchased [online](#) or at Parking and Transportation Services, located in the Lake Street Garage at 1508 Center Avenue.

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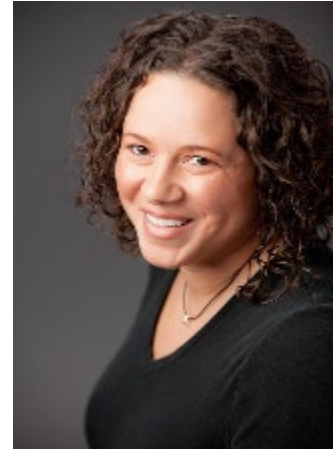
- [Moby Lot #195](#)
- [Green Hall](#)
- [Engineering #310 \(recommended\)](#)
- [Ammons Hall # 315](#)
- [Administration #349](#)
- [MAX at University Station #440](#)
- [Lake Street Garage](#)
- [Voss Veterinary Teaching Hospital](#)
- [Research Blvd #740](#)

KEYNOTE SPEAKERS

Hydrology Days Award

Dr. Holly Barnard, Professor of Geography – University of Colorado Boulder

Bio: Dr. Holly Barnard is the Co-Director of Hydrologic Sciences Graduate Program, INSTAAR Fellow, and Professor of Geography at CU Boulder. Barnard is a leading ecohydrologist whose interdisciplinary research bridges forest ecology and hydrology to understand how climate and land-use change reshape water resources. Her work integrates field experimentation, stable isotope geochemistry, and ecosystem science to advance sustainable water management in mountainous regions.



Keynote Lecture: April 8, 2026 at 1 PM – CSU Lory Student Center, Room 386

From Foliage to Fractures: exploring the critical zone from multiple perspectives

Abstract: Dr. Barnard is the lead PI of the Dynamic Water Critical Zone Cluster – a project that has focuses on the role of subsurface water storage in driving critical zone processes. Our team defines dynamic water storage is the water that remains for enough time in watersheds to influence streamflow generation, chemically weather rock and drive the release of solutes, breakdown organic carbon through microbial activity, and sustain vegetation between periods of precipitation. The amount and connectivity of dynamic water stores control critical zone processes, including evapotranspiration, forest productivity and mortality, streamflow, weathering and solute transport. Barnard will present on her research journey into critical zone science and share recent advances in the study of dynamic water storage in the critical zone.

Presentation Schedule

Wednesday, April 8, 2026

Room	Session	Time	Presenter	Title
LSC #308	Groundwater & Hydrogeology	9:00 - 10:30am	Kendra Bratzler	<i>Integrated Aquifer Characterization in the Parowan Valley with Drillers' Logs and Transient Electromagnetic (TEM) Systems</i>
			Randy Largo	<i>Hydrogeologic Controls on Groundwater Recharge Across Elevation, Northern Colorado Rockies</i>
			Rahel Pommerenke	<i>Exploring the Relationship Between Groundwater Pumping and Precipitation in the Western US</i>
			Abdullah Al Fatta	<i>Investigating Arsenic Mobilization Mechanisms Using Hydrogeochemical Approach in the Confined Aquifer of the San Luis Valley, Colorado</i>
			Dana Rastad	<i>Evaluation of Physics-Informed Neural Networks for Groundwater Flow Across Multiple Hydrogeologic Scenarios</i>
			Susmita Pant	<i>Historical and Long-Term Modeling of Groundwater-Induced Subsidence Throughout Southern San Joaquin Valley: A Combined Implicit-Explicit Framework</i>
			Reza Morovati	<i>Assessing Groundwater Depletion and Land Subsidence from Agricultural Pumping in Willcox, AZ with SWAT+MODFLOW</i>
LSC #310	Hydrologic Modeling, Machine Learning & Forecasting	9:00 - 10:30am	Owen Richardson	<i>Exploring Hydrologic Constraints on Soil Piping</i>
			Jeffrey Gonzales	<i>Integrated Surface-Subsurface Modeling of Hydrology and Nutrient Dynamics in a Heavily Tile-Drained Agricultural Watershed</i>
			Arif Asghar	<i>Implementing Machine Learning Models in SWAT+ for Reservoir Outflow Simulation</i>

			Najam us Saqib Fraz	<i>Event Scale Attribution of Precipitation Variability Using a Precipitation Decomposition Approach</i>
			Kwabena Opoku	<i>Understanding How Human Water Management Reshapes Basin Hydrology: An Enhanced Modeling Framework for a Semi-Arid River Watershed</i>
			Rafin Hasan	<i>Quantifying Groundwater Response to Low-tech Process-based Restoration (LTPBR) in a Colorado Headwater Stream Using Coupled Hydrodynamic–Groundwater Modeling Informed by Geophysical Characterization</i>
			William Doan	<i>Future Climate Impacts on the Hydrology and Water Management of Transboundary Rivers</i>
LSC #376	Water Quality, PFAS & Urban Water Systems	9:00-10:30am	Devin Snyder	<i>Engineered Media Screening for PFAS, Nutrients, & Metals Across Alternative Water Matrices</i>
			Veronika Makowski	<i>Advancing Nature-Based Solutions by Assessing Long-Term Performance of Natural and Engineered Media</i>
			Amanda Salerno	<i>Comparative Evaluation of Bioretention Media for Stormwater Runoff Reduction and Water Quality Treatment in an Urban Environment</i>
			Jui-Hsiang (Rayson) Lo	<i>Numerical Simulation of PFAS Transport in Layered Soil Systems: Implications for Secondary Groundwater Contamination</i>
			Kenneth Laffite	<i>Renewable-Powered Agricultural Desalination: A Geospatial Assessment of the Contiguous United States</i>
			A.J. Brown	<i>Fourteen Years of Edge-of-Field Monitoring: Quantifying Tillage Effects on Runoff Water Quality with Bayesian Models</i>
			Gracie Gooch	<i>Assessment of the Salinization of the South Platte River Basin: Data Collection Efforts and Uncertainty Analysis</i>
Break				

LSC #308	Ecohydrology & Plant Water	10:45am-12:00pm	Victoria Wojahn	<i>Radial Variability of Stem Water Storage in Ponderosa Pine Trees</i>
			Andrew Kellogg	<i>Slope-Aspect Governance on Ecohydrological Wildfire Recovery</i>
			Logan Seymour	<i>Comparing Methods to Quantify Groundwater Evapotranspiration by Willow in a Mountain Valley, Cache la Poudre River Watershed, Northern Colorado</i>
			Samantha Peppel	<i>A Comparative Analysis of MODIS and Eddy Covariance Daily Gross Primary Production Data in Forested Ecosystems</i>
			Manish Giri	<i>Within-Canopy Height of Aerodynamic Surface Temperature and Its Environmental Dependencies in Sub-surface Drip-Irrigated Maize</i>
			Muhammad Fawad	<i>Hyperspectral Remote Sensing of Salinity Effects on Maize: A Greenhouse Study</i>
LSC #310	Hydraulics, Geomorphology & River Processes	10:45am-12:00pm	Brooke Pennington	<i>Stationary Wave Trains in Steep Gradient Channels</i>
			Towsibur Rahman	<i>Influence of Vegetation Density and Submergence on Drag Coefficient in Vegetated Open-Channel Flow</i>
			Olivia Doehr	<i>Optimizing Freshening Flow Rates in Ponds and Reservoirs</i>
			Sam Kraus	<i>Preliminary Results for Characterizing Dispersion in Vegetated Flows with Fluorescent Dye</i>
			Dylan Davis	<i>Legacies of Beaver Extirpation in a Dynamic Eolian-Fluvial System, North Sand Creek, North Park, CO</i>
			Lesli Key	<i>Evaluating Reservoir Application of Water Injection Dredging (WID) Efficacy Using Multibeam and Sediment Core Datasets</i>

LSC #376	Snow, Climate & Mountain Hydrology	10:45am- 12:00pm	Carson Bainbridge	<i>Spatio-temporal Density Variability Across Several Study Sites in Northern Colorado</i>
			Jocelyn Cramer	<i>Snow Density Variability in Lodgepole Pine (Pinus contorta) Forests</i>
			Alex Hahnenberg	<i>Hydrologic Trends for Central Chilean Andes Watersheds – Confining the Uncertainty of Snowcourse Data</i>
			Anna Pfohl	<i>From Snow Structure to Streamflow Signal: Investigating the Effects of SWE Heterogeneity on Runoff Timing and Magnitude</i>
			Preetika Kaur	<i>L-band InSAR Coherence Controls in a Mountain Snowpack: Incidence Angle, Canopy Cover, and Liquid Water Content</i>
			Ryder Hunt	<i>Seasonal and Diel Regional Temperature- Elevation Gradients Across Northern Colorado</i>
Lunch and Keynote				
LSC #308	Remote Sensing, ET & Irrigation	2:00 – 3:00pm	Reagan Ames	<i>Customized Tools for the pyFAO56 Evapotranspiration Software Package for Field Research at the USDA-ARS Limited Irrigation Research Farm</i>
			Farhana Akter Meem	<i>Incorporating Cosmic Ray Neutron Rover Data in the Downscaling of Satellite Soil Moisture</i>
			Luke Eddington	<i>Mapping the Moisture of Unpaved Roads and Adjacent Rangeland Using a Cosmic Ray Neutron Rover</i>
			Soheil Nozari	<i>Estimating Irrigation Consumptive Use in the La Plata Basin Using Satellite-Based Observations</i>
			Md Fahim Hasan	<i>Irrigation Water Use Response to Climate Variability Across Major Aquifer Regions of the Western United States</i>

LSC #310	Water Systems Engineering & Applications	2:00 – 3:00pm	Jay Ham	<i>A Portable IoT and AI-Based Smart Irrigation Demonstration System for Education, Outreach, and Applied Research</i>
			Alexandria Rodgers	<i>Detection of Undocumented Levees Using Convolutional Neural Networks</i>
			Avital Breverman	<i>What the HEC is the Hydrologic Engineering Center?</i>
			Naomi Michael	<i>Dynamics of Desalination Across Carbon, Water, Energy, and Social Systems</i>
LSC #376	Climate, Wildfire & Broader Water Systems	2:00 – 3:00pm	Michael Talbot	<i>Process-Informed Flood Frequency Analysis for Colorado Watersheds: A Mixture Distribution Framework and Interactive Decision-Support Dashboard</i>
			Daniel Philippus	<i>Large-Scale Prediction of Post-Wildfire Stream Water Temperature for Unmonitored Sites</i>
			Jai Hong Lee	<i>Hydroclimatic Impacts of Large-scale Climatic Circulation Patterns on Middle Latitude Streamflow Variability over the United States</i>
			Phil Harrison	<i>The Evolution of Instream Flows — IFIM to Eflows</i>

Groundwater & Hydrogeology

Integrated Aquifer Characterization in the Parowan Valley with Drillers' Logs and Transient Electromagnetic (TEM) Systems

Kendra Bratzler - Colorado State University, Department of Civil and Environmental Engineering

The Parowan Valley in southwestern Utah is an agricultural region that has experienced significant land subsidence in recent years due to excessive groundwater pumping. This subsidence occurs primarily in regions with fine-grained materials such as clay deposits. Therefore, accurate characterization of subsurface lithology, especially the distribution of clay, is critical for informing groundwater management strategies aimed at mitigating further subsidence.

Previous subsurface characterizations have relied on either remotely sensed geophysical data or directly sampled lithologic data. This project integrates both datasets to improve subsurface characterization. Remotely sensed data, specifically transient electromagnetic (TEM) measurements from tTEM and WalkTEM systems, provide spatially extensive resistivity information and offer a faster, more cost-effective alternative to direct sampling. However, converting resistivity to lithology requires a rock physics transform and is influenced by subsurface saturation conditions. To account for this, groundwater levels from monitoring wells were used to estimate depth to the water table throughout the study area using a linear regression with land surface elevation. Directly sampled lithologic data were obtained from drillers' logs, which provide direct but non-standardized descriptions of subsurface materials. To address inconsistencies, a scoring system was developed to evaluate log quality based on depth interval resolution, material diversity, and geological plausibility of reported sequences.

The geophysical and lithologic datasets were integrated and interpolated using ordinary kriging. Model performance was evaluated using held-out drillers' logs to quantify classification accuracy and optimize resistivity thresholds for saturated and unsaturated clay and sand deposits. Results demonstrate the value of integrating remotely sensed geophysical data with lithologic and hydrologic datasets to enhance subsurface characterization and support groundwater management in regions prone to subsidence.

Hydrogeologic Controls on Groundwater Recharge Across Elevation, Northern Colorado Rockies

Randy Largo - Colorado State University, Department of Geosciences

This study investigates the connectivity between precipitation, surface water, and deep bedrock aquifers in Northern Colorado. How precipitation and stream water interact with deep groundwater, particularly across mountain-to-plain transitions, is not fully understood. To address this gap, we have sampled monthly precipitation, stream, and groundwater in the northern Front Range across an elevation gradient and have analyzed the oxygen ($\delta^{18}\text{O}$) and hydrogen ($\delta^2\text{H}$) values of these samples. We hypothesize that groundwater $\delta^{18}\text{O}$ exhibits reduced seasonal variability relative to precipitation and stream water due to mixing and longer residence times, and that $\delta^{18}\text{O}$ values decrease with elevation,

reflecting a tight connection between local meteoric water and deep bedrock aquifers. To address these hypotheses, we integrate new isotope data from nine volunteer residential well sites (380 – 600 ft depth). This expanded data set provides critical observations within the Front Range Mountain block. The results will be used to assess the connectivity between local precipitation and stream water and groundwater recharge as well as groundwater contributions to streamflow. Understanding these processes is increasingly important as declining snowpack, earlier snowmelt, and more frequent drought place greater pressure on groundwater resources. By improving characterization of recharge sources and groundwater-surface water interactions, we aim to better inform water resources management and climate resilience planning. This study also engages local communities through a volunteer sampling network, increasing spatial coverage while enhancing public awareness of groundwater sustainability in regions reliant on private wells.

Exploring the Relationship Between Groundwater Pumping and Precipitation in the Western US

Rahel Pommerenke - Colorado State University, Department of Civil and Environmental Engineering

Irrigated agriculture partially relies on groundwater to meet crop water demand. Increasing water demand has led to greater pumping and the overuse of aquifers in the western United States. While irrigators depend on both precipitation and irrigation to meet crop water demand, the relationship between precipitation, evapotranspiration, and groundwater pumping is complex. Factors such as crop-specific water requirements, overall water availability, water rights administration, irrigation inefficiencies, and the timing, frequency, and duration of precipitation events all influence pumping decisions. To examine this relationship, annual groundwater pumping data from 2010 to 2024 are compared with precipitation and crop evapotranspiration (ET) at the groundwater management district level across Arizona, Colorado, Kansas, Nevada, and Utah. Crop ET is derived from Daymet reference evapotranspiration and crop coefficient values. This is calculated daily and aggregated to an annual scale, representing the maximum ET for a specific crop. A partial least squares regression [Ha2.1] approach is used to analyze pumping values, normalized by irrigated areas, along with estimates of annual crop ET at the district scale. The slope and intercept of the regression provide insights into irrigation efficiency by comparison to an idealized scenario in which precipitation and pumping are inversely proportional. Pumping estimates are also compared with effective precipitation, the portion of precipitation stored in the soil and available for plant use, to assess water losses due to runoff and deep percolation. Quantifying the dynamic relationships of precipitation, effective precipitation, and groundwater pumping in stressed, groundwater-dependent systems helps link human decision-making with resource availability.

Investigating Arsenic Mobilization Mechanisms Using Hydrogeochemical Approach in the Confined Aquifer of the San Luis Valley, Colorado

Abdullah Al Fatta - Colorado State University, Department of Civil and Environmental Engineering

Elevated arsenic (As) concentrations in domestic drinking water wells pose a significant public health concern in the San Luis Valley (SLV), south-central Colorado. A multi-layered aquifer system serves as the primary drinking water source for approximately 50,000 residents. This study investigates the geochemical mechanisms controlling arsenic mobilization using an integrated approach combining water quality monitoring, stable isotopes, and groundwater age tracers. We are conducting quarterly sampling of 58 domestic wells spanning both the confined and unconfined aquifers from May 2023 to June 2025, collecting arsenic, pH, major ions, and trace elements (iron, manganese, boron, lithium, uranium), stable isotopes ($\delta^2\text{H}$, $\delta^{18}\text{O}$), and groundwater age tracers (radiocarbon and radiogenic helium-4) at selected wells. These data are being analyzed alongside regional water level and precipitation data to assess potential links between pumping activity and arsenic variability. Preliminary results indicate distinct hydrogeochemical differences between the confined and unconfined aquifers. Notably, higher arsenic in the confined system is observed exceeding the EPA maximum contaminant level (10 $\mu\text{g/L}$). Early evidence suggests that pH-dependent desorption, rather than reductive dissolution, may be the dominant mobilization mechanism. Dual groundwater age tracers show a consistent relationship between groundwater residence time and arsenic concentration, suggesting that arsenic increases with groundwater residence time (Percent Modern Carbon, $r = -0.71$; Helium-4, $r = 0.82$). Stable isotope signatures further distinguish the two aquifer systems, with the confined aquifer exhibiting a wider isotopic range consistent with multiple recharge sources and longer flow paths. Initial analysis also reveals a seasonal pattern in arsenic concentrations within the confined aquifer that appears to correspond with the irrigation pumping cycle, while no such pattern is observed in the unconfined system. Ongoing work includes groundwater age estimates, evaluating noble gas recharge temperatures to constrain recharge conditions, and assessing the role of geothermal inputs through boron analysis. This research aims to determine whether arsenic contamination in the SLV is a static geological hazard or a dynamic response to water management practices, with implications for pumping-based mitigation strategies.

Evaluation of Physics-Informed Neural Networks for Groundwater Flow Across Multiple Hydrogeologic Scenarios

Dana Rastad - Colorado State University, Department of Civil and Environmental Engineering

Physics-informed neural networks (PINNs) offer a novel framework for solving groundwater flow problems by embedding governing physical laws directly into the training process of neural networks. In this study, we evaluate the applicability of PINNs for simulating groundwater flow under a range of hydrogeologic settings. The proposed framework was tested across multiple synthetic scenarios that differ in domain geometry, pumping stresses, and recharge conditions, allowing assessment of model performance under increasingly complex physical configurations.

For each scenario, the PINN was formulated to satisfy the groundwater flow equation while honoring the corresponding boundary conditions and hydrologic forcing terms. Model predictions were compared against solutions generated by conventional numerical approaches to assess the accuracy and reliability of the PINN framework.

The results demonstrate that PINNs can effectively approximate groundwater flow solutions while offering flexibility in handling irregular geometries and heterogeneous forcing conditions. These findings suggest that physics-informed deep learning has strong potential as a complementary tool for groundwater simulation and may provide new opportunities for hydrologic modeling in settings where traditional mesh-based approaches face practical limitations.

Historical and Long-Term Modeling of Groundwater-Induced Subsidence Throughout Southern San Joaquin Valley: A Combined Implicit-Explicit Framework

Susmita Pant - Colorado State University, Department of Civil and Environmental Engineering

In California's San Joaquin Valley, extensive groundwater pumping has resulted in severe land subsidence over the past century. Existing subsidence models in the San Joaquin Valley operate either at regional scales, where spatial resolution is too coarse to capture localized deformation patterns (e.g., the Central Valley Hydrologic Model, CVHM), or are developed for only a limited number of locations. Consequently, there remains a lack of physically based subsidence estimates that resolve both spatial variability and long-term temporal evolution across the valley. To address this, our study develops a physically based subsidence model for the Southern San Joaquin Valley, that simulates more than 60 years (1960-2023) of land subsidence at a spatial resolution of 500 * 500 m. Here, we employed combined implicit- explicit finite difference method to ensure stability, computational efficiency and numerical accuracy. We then calibrated the hydrogeological parameters by fitting the physical subsidence model to monthly InSAR-observed deformation (2015-2023) at representative locations using MCMC (Markov Chain Monte Carlo). These locations were selected by first identifying the dominant spatial patterns of subsidence using Independent Component Analysis applied to the monthly cumulative subsidence data. The resulting patterns were then grouped using clustering, and the centroid of each cluster was chosen as the representative point. By scaling these calibrated parameters across corresponding clusters, this approach provides a robust framework to reconstruct regional subsidence dynamics. Future work will leverage this model to analyze long-term deformation patterns and quantify the distinct compaction contributions of the upper aquifer, lower aquifer, and the Corcoran Clay.

Assessing Groundwater Depletion and Land Subsidence from Agricultural Pumping in Willcox, AZ with SWAT+MODFLOW

Reza Morovati - Colorado State University, Department of Civil and Environmental Engineering

Sustained agricultural groundwater extraction in arid regions has led to patterns of groundwater depletion and land subsidence, posing risks to infrastructure. The Willcox Basin in southeastern Arizona is one such affected area in the southwestern United States. Long-term groundwater overdraft, linked to irrigation practices, has resulted in declining groundwater levels, land subsidence, ground fissures, infrastructure damage, and irreversible reductions in aquifer storage capacity. These trends raise serious concerns about long-term water sustainability and regional stability.

This study applies a coupled SWAT+-MODFLOW modeling framework to examine the relationships among agricultural pumping rates, groundwater head dynamics, and land subsidence in the Willcox Basin. The Soil and Water Assessment Tool (SWAT+) simulates watershed-scale hydrologic processes, crop water requirements, and irrigation demands under arid conditions, while MODFLOW represents three-dimensional groundwater flow and aquifer responses to pumping stresses. The integrated model transfers recharge, pumping demands, and groundwater–channel exchanges between surface and subsurface systems. Specifically, SWAT+ crop growth and water allocation routines determine irrigation pumping demand and withdrawals from the aquifer.

Land subsidence is quantified using established geomechanical compaction relationships within the MODFLOW SUB package, based on simulated groundwater head declines. This integrated framework explicitly captures surface–groundwater interactions and the spatial variability of agricultural water use. The model is evaluated against field-scale evapotranspiration, groundwater head changes from monitoring wells, and observed land subsidence. Multiple combinations of calibration targets are tested to assess the contribution of each dataset type in improving predictions of groundwater levels and land subsidence. The modeling results demonstrate how intensive pumping reduces groundwater levels and drives land subsidence across the basin, highlighting when and where these impacts are most pronounced. This process-based framework offers a valuable tool for evaluating aquifer sustainability and supporting science-based management strategies aimed at mitigating land subsidence in arid agricultural basins such as Willcox.

Hydrologic Modeling, Machine Learning & Forecasting

Exploring Hydrologic Constraints on Soil Piping

Owen Richardson - Colorado State University, Department of Geosciences

Soil piping is a pseudo-karst process that occurs when infiltrating water encounters a restrictive layer at depth; perched saturation atop this layer can drive lateral flow, which, at steep enough hydraulic gradients, can begin to remove material and form lateral earthen pipes. When these pipes collapse, they form amphitheater-shaped pseudo-sinkholes, or headcuts, at the surface. Although piping and piping-collapse subsidence are natural components of hillslope systems, they are frequently misinterpreted in management contexts, despite their significant implications for runoff generation and erosion. Surface-focused erosion-control structures are often ineffective because they do not address the subsurface drivers of collapse. A key uncertainty is how perched saturation develops rapidly enough at depth to initiate pipeflow on event timescales. Here, we use variably saturated flow models in Hydrus-1D to show that matrix flow alone cannot generate the requisite saturation at depth. We then implement a dual-permeability framework that partitions flow between the soil matrix and vertical fractures. This approach demonstrates that rapid infiltration through macropores (e.g., cracks, root channels, and burrows) can plausibly transmit water to depth on event timescales and generate transient perched saturation above restrictive layers, enabling soil pipe formation. These results suggest that vertical macroporosity is a first-order control on piping initiation and collapse. As a result, land use and management practices that modify vertical macropore networks may strongly influence piping susceptibility.

Integrated Surface-Subsurface Modeling of Hydrology and Nutrient Dynamics in a Heavily Tile-Drained Agricultural Watershed

Jeffrey Gonzales - Colorado State University, Department of Civil and Environmental Engineering

The Boone River Watershed (BRW) in north-central Iowa represents a tile-drained corn–soybean agroecosystems of the U.S. Midwest, where subsurface drainage enhances productivity on poorly drained soils while accelerating nitrogen (N) and phosphorus (P) export to surface waters. In such systems, tile drainage constitutes a major component of streamflow and a dominant pathway for nutrient transport, necessitating modeling frameworks that explicitly resolve coupled surface–subsurface processes. This study applies the SWAT+ gwflow model to simulate integrated hydrologic and nutrient dynamics in the BRW, incorporating explicit representation of tile drainage and groundwater–surface water interactions. A multi-objective calibration framework was implemented using PEST++IES, jointly constraining streamflow, groundwater heads, and N and P loads to improve representation of both surface and subsurface fluxes. Prior to calibration, Morris sensitivity analysis was conducted to identify influential parameters governing hydrologic and nutrient processes, enhancing parameter identifiability and computational efficiency. The calibrated model demonstrated strong performance, with Nash–Sutcliffe efficiency (NSE) and Kling–Gupta efficiency (KGE) of 0.94 for streamflow and a mean absolute error (MAE) of 0.96 m for groundwater heads. Nutrient simulations also showed good

agreement with observations, achieving NSE values of 0.78 (N) and 0.75 (P), KGE values of 0.84 (N) and 0.47 (P), and coefficients of determination (R^2) of 0.90 for both constituents.

Scenario analyses evaluating best management practices (BMPs)—including cover crops, grassed waterways, riparian buffers, and reduced fertilizer application—indicated that combined implementation can reduce total N loads by 25–35% and total P loads by 20–30%, with minimal impacts on crop productivity. These results demonstrate that coupling SWAT+ with gwflow module and advanced ensemble-based calibration provides a robust, process-based framework for representing nutrient fate and transport in tile-drained systems. The approach offers a transferable decision-support tool for designing effective nutrient reduction strategies in intensively managed agricultural watersheds across the U.S. Midwest and similar agroecosystems globally.

Implementing Machine Learning Models in SWAT+ for Reservoir Outflow Simulation

Arif Asghar - Colorado State University, Department of Civil and Environmental Engineering

Surface reservoirs serve as key components of river basins to store and regulate water resources. They play various important roles such as hydroelectric power generation, flood control, irrigation, and domestic water supply. The correct estimation of reservoir outflow is crucial for water management in a watershed. However, estimating daily outflow volumes is challenging due to influencing factors such as climate, upstream hydrological processes, reservoir rules, and water rights. The hydrological model, SWAT+, uses a decision table approach to estimate reservoir outflow, which can reasonably simulate the reservoir release in a watershed under certain conditions. However, this approach becomes challenging for multipurpose reservoirs, which have complex operations rules. In recent years, machine learning models such as multivariate linear regression (MLR) and LSTM (Long Short-Term Memory) have been found to be very effective for the simulation of reservoir release. In this study, we trained machine learning models such as MLR, and LSTM using a suite of input data (inflow, storage, release, precipitation, seasonality parameter such as day of the week, day of the year and month of the year) and integrated the machine learning models into the SWAT+ modeling code to forecast reservoir outflow for the next day during a model simulation. The method is applied to four reservoirs located in the Central Valley, California: Shasta, Don Pedro and New Melones and Whiskeytown. The results indicate that the proposed models can be used to accurately estimate the reservoir release. The proposed approach demonstrates that the Nash–Sutcliffe efficiency (NSE) values during both training and testing period for Don Pedro, Shasta, Whiskeytown and New Melones, using the MLR and LSTM models were very good. These results demonstrate that the LSTM model performed slightly better than MLR model for Don Pedro, Shasta and New Melones reservoirs, while the MLR model slightly outperformed the LSTM model for Whiskeytown reservoir during both training and validation periods. This study shows that coupling machine learning models with a hydrological model such as SWAT+ is an effective technique for accurate simulation of reservoir release at a daily time scale.

Event Scale Attribution of Precipitation Variability Using a Precipitation Decomposition Approach

Najam us Saqib Fraz - Colorado State University, Department of Civil and Environmental Engineering

Precipitation changes are often measured at the annual scale (e.g. mean annual), but this does not reveal how rainfall components are changing over time. This study uses a precipitation decomposition framework that divides precipitation into components such as event frequency, depth, duration, intensity, and covariance terms relating to these components. This framework helps determine whether changes in precipitation arise from shifts in storm occurrence, magnitude, persistence, or intensity. Such distinctions are important because similar annual totals or trends may mask variability in the underlying components. Based on the component signatures of variability, similarities among catchments are examined, and spatial variability in these components across catchments are assessed. Catchments are further classified into depth driven, frequency driven, or magnitude driven change regimes. This classification is important because it can influence water resources, floods, land-atmosphere interactions, crop yields, and wildfires.

Understanding How Human Water Management Reshapes Basin Hydrology: An Enhanced Modeling Framework for a Semi-Arid River Watershed

Kwabena Opoku - Colorado State University, Department of Civil and Environmental Engineering

Water resources in semi-arid river basins are increasingly influenced by human water management, yet the mechanisms by which infrastructure and operations redistribute water among surface flow, groundwater, evapotranspiration (ET), and storage remain poorly quantified. Existing watershed models often represent only a subset of these processes, limiting their ability to diagnose system behavior in highly regulated basins. This study enhances the modeling framework of the coupled SWAT+gwflow model to represent the full range of natural and anthropogenic processes governing basin hydrology. New model components simulate irrigation diversions, canal routing and seepage, artificial recharge pond infiltration, groundwater pumping for irrigation, riparian evapotranspiration, and groundwater-channel exchange. Together, these features enable a physically consistent representation of how managed water systems alter hydrologic flux partitioning. The model is applied to the 7,440 km² Middle South Platte-Cherry Creek watershed in Colorado, USA, a highly engineered basin that includes urban water supply infrastructure for the Denver metropolitan area and extensive downstream agriculture. Preliminary simulations and sensitivity analyses explore how key management features influence groundwater recharge, stream-aquifer interactions, evapotranspiration, and basin water storage. Results indicate that human-controlled processes can dominate basin-scale water redistribution, emphasizing the need for integrated modeling approaches to understand and manage coupled surface-groundwater systems. The developed framework provides a foundation for future calibration, scenario evaluation, and decision support in semi-arid regions facing increasing water stress.

To enable this improvement, we developed the first CONUS-scale, km-resolution, forecasting-capable, daily SWT model for ungaged watersheds, titled “temperature estimation: near-term expected temperatures” (TempEst-NEXT), using data-driven techniques. TempEst-NEXT is capable of hindcasting and near-term (1-16 day) forecasting, and is compatible with NOAA’s NextGen National Water Model

framework for operational applications. Historical tests with forecasted forcing data (2-day lead) for mean daily SWT show a median R2 of 0.92, RMSE of 2.4 C, and bias of 1.7% for ungaged watersheds, with similar performance in preliminary real-time forecast runs (1-16 day lead). For watersheds with training data across the CONUS, TempEst-NEXT has a median validation-period R2 of 0.95, RMSE of 1.4 C, and bias of 0.0073%. An advantage of TempEst-NEXT over comparable SWT models is that its forecasting capabilities can support real-time decision-making without local calibration for water-resource management, such as reservoir releases. Broadly, TempEst-NEXT stands ready to support efficient, flexible, large-scale prediction of stream thermal regimes, especially in watersheds where SWT observations are infrequent or unavailable.

Quantifying Groundwater Response to Low-tech Process-based Restoration (LTPBR) in a Colorado Headwater Stream Using Coupled Hydrodynamic–Groundwater Modeling Informed by Geophysical Characterization

Rafin Hasan - Colorado State University, Department of Civil and Environmental Engineering

Beaver dam analogues (BDAs) and post-assisted log structures (PALS) serve multiple ecosystem functions in degraded headwater streams: raising floodplain water tables, enhancing hyporheic exchange and associated biogeochemical processing, reconnecting relic channels, improving water quality through increased denitrification, and supporting riparian vegetation and biodiversity. All these outcomes are fundamentally mediated by how water moves through the shallow subsurface yet the subsurface flow response to BDAs varies a lot between sites. Some studies report groundwater rises extending 30–50 m from the channel, while others observe minimal response even in near-stream wells. This inconsistency strongly suggests that three-dimensional subsurface heterogeneity exerts first-order control on restoration outcomes, but very little study has characterized the subsurface at a BDA site well enough to test this hypothesis or to predict groundwater responses using coupled groundwater surface water modeling. This project addresses two linked goals. The first is to understand how and how much subsurface heterogeneity specifically the three-dimensional distribution of hydraulic conductivity across alluvium, saprolite, fractured bedrock, and fresh bedrock controls the spatial pattern and magnitude of groundwater response to BDA/PALS installation. The second one is to develop a transferable, coupled modeling framework that practitioners can apply at new sites to predict restoration outcomes from measurable site characteristics. The framework integrates: (1) seismic refraction tomography (SRT) and electrical resistivity tomography (ERT) for subsurface characterization; (2) SRH-2D for physics-based estimation of post-restoration stream stage; and (3) MODFLOW-6 for simulation groundwater flow and distribution, calibrated via PEST++ IES. The framework is applied to South Fork Creek in Roosevelt National Forest, Colorado, using about 15 months of pre- and post-restoration monitoring data. Expected outcomes include identification of subsurface controls on BDA/PALS effectiveness, spatially distributed maps of water level change and stream–groundwater exchange, and a reusable predictive modeling workflow for BDA/PALS site assessment.

Future Climate Impacts on the Hydrology and Water Management of Transboundary Rivers

William Doan - Colorado State University, Department of Civil and Environmental Engineering

There are two-hundred and sixty-three transboundary river basins which cross political boundaries of two or more countries. These basins account for approximately 60 percent of the global freshwater flows. Transboundary river basins frequently have water agreements in place between countries that seek to effectively manage and protect these shared waters resources. These agreements are critical for ensuring cooperation, sustainable use and addressing potential conflicts that may arise due to water scarcity and competing demands among the countries involved. It is critical to quantify and account for the uncertainties and risks associated with changing climate scenarios when managing transboundary rivers.

This paper focuses on the first of three proposed steps to evaluate potential climate impacts on managing transboundary rivers:

Applying the latest deterministic rainfall-snowmelt-runoff methodologies to calibrate existing conditions of transboundary watersheds, particularly with an eye to accurately applying future climate scenarios involve:

- Use of climate reanalysis climate data as the main model for drivers of climate change.
- Potential use of 2D finite-volume diffusion wave methodology to transform rainfall excess to basin runoff.
- Use of GIS gridded discretization techniques to accurately reflect basin conditions involving soil infiltration and land-use, as well as climatic forcing functions involving precipitation, air temperature, long and short wave radiation, air pressure, and wind velocities.
- Use of snowmelt energy budget methodology to more accurately simulate snowmelt runoff.

Preliminary case-study using the above technologies involve the Jhelum River Basin in India and Pakistan. This basin involves monsoonal flooding, snowmelt-driven flooding, and complex water management issues involving operational impacts of Pakistan's Neelum-Jhelum and India's Kishenganga hydropower dams in the Kashmir Valley Region, an area anticipated to be heavily impacted by future climate scenarios.

Water Quality, PFAS & Urban Water Systems

Engineered Media Screening for PFAS, Nutrients, & Metals Across Alternative Water Matrices

Devin Snyder - Colorado State University, Department of Civil and Environmental Engineering

Engineered media are widely used for adsorption-based treatment of PFAS and co-occurring constituents in reuse-relevant waters, yet amendment selection is often guided by simplified testing that does not capture matrix effects. Dissolved organic matter, particulates, and competitive solutes can reduce uptake, increase variability, and alter relative ranking among candidate media. Such translation gaps limit confidence in media choices for nature-based treatment systems designed to operate under variable influent chemistry. Here we evaluate a batch-scale screening dataset spanning deionized water and three alternative matrices including graywater, recycled wastewater, and stormwater to identify media candidates, that remain effective across water types while targeting PFAS, nutrients, and metals. Across matrices, removal outcomes varied systematically with water chemistry, and media rankings shifted between clean and real waters. Organic matter dynamics, reflected through TOC trends, were frequently aligned with reduced removal, consistent with competition for sorption capacity and transport constraints. However, TOC alone did not fully explain PFAS behavior, indicating that robustness screening must consider multiple interacting matrix features. Decision-support summaries that prioritize cross-matrix consistency highlighted a limited subset of media that maintained strong and reproducible performance across matrices, in contrast to materials that performed well only under complex matrix chemistry conditions. These findings show that defensible down-selection for reuse applications should emphasize robustness across representative waters rather than single-matrix performance. The screening outcomes provide candidates and selection criteria that can guide subsequent flow-through validation and support reliable implementation of amended nature-based systems.

Advancing Nature-Based Solutions by Assessing Long-Term Performance of Natural and Engineered Media

Veronika Makowski - Colorado State University, Department of Civil and Environmental Engineering

Urban water systems face increasing pressure from population growth, densification, and the presence of emerging contaminants. Nature-based solutions (NbS), including bioretention systems, offer a promising approach to improve water quality while providing ecosystem and urban livability benefits. However, limited guidance exists on media selection for NbS capable of simultaneously removing nutrients, metals, and per- and polyfluoroalkyl substances (PFAS), creating uncertainty for utilities and designers. Column experiments are being conducted to assess the performance of engineered adsorbent material blends for removal of PFAS (i.e., PFOA and PFOS), nutrients (NO_3^- , NH_4^+ , PO_4^{3-}), and metals (i.e., Cu, Pb, Zn) across alternative water matrices (i.e., gray water (GW), recycled wastewater (RW), and stormwater (SW)) under conditions that mimic NbS. Nine columns will be operated in triplicate using three media configurations: a bioretention soil media control, a layered media configuration, and a blended media configuration incorporating targeted sorbents. These columns have been operated for RW and currently being operated for GW and then SW. They are being

operated under intermittent and continuous flow regimes to simulate field-relevant Nbs conditions. Performance will be evaluated by studying mass balances and desorption testing to assess removal efficiency, longevity, and operational tradeoffs. During the RW column experiment it was seen that PFAs were absorbed in both layered and mixed media columns, showing lower levels than in the influent and bioretention soil media control. Nutrient and metals levels were also lower in the mixed and layered media columns. However, there were no breakthroughs between the layered and mixed media in terms of PFAs levels. The next steps in the research experimental process will be to continue the GW experiment and then move on to the SW experiment. Throughout these column experiments, PFAs spiking levels in the influent will be adjusted to potentially to more breakthroughs between layered and mixed media configurations. Results from the column experiments will support further research in field-based bioretention Nbs systems.

Comparative Evaluation of Bioretention Media for Stormwater Runoff Reduction and Water Quality Treatment in an Urban Environment

Amanda Salerno - Colorado State University, Department of Civil and Environmental Engineering

To protect surface and underground watersheds from serious harm, it is necessary to implement intentional infrastructure that allows interception and treatment of water in urban areas. This research aims to evaluate bioretention systems, a type of green infrastructure, as an alternative to reduce stormwater runoff, volume and time, while also improving water quality. The bioretention facilities for this research are located in the Hydro Building backyard, SPUR Campus, with two selected media: MHFD media + 5% compost (SSC) and Amended Fort Collins Mix (SBZ), both with the same plant selection. Each bioretention facility receives stormwater runoff from the surrounding area, and the effluent is analyzed to evaluate heavy metals and nutrients, such as phosphorus and nitrogen, COD, TSS, and E. coli, for water quality purposes. Using ISCO Samplers, the drain time of runoff from the bioretention facilities is analyzed to evaluate runoff peak reduction and detention time from the systems. The different bioretention media present different water quality treatments and detention times. SSC has a shorter runoff time (4 hours) than SBZ (4 hours and 45 minutes). TSS levels decreased by around 70% in the effluent from both bioretention facilities. There is an increase in total nitrogen (14% for SBZ and 42% for SSC) and total phosphorus concentrations (73% for SBZ and 235 % for SSC) in the effluent runoff. COD decreased in the effluent from all analyses (68% for SBZ and 49% for SSC), indicating the removal of organic matter by the bioretention cell media. Finally, E. coli levels also reduce in the effluent runoff by around 80%. In both systems, the reactions involving N (nitrogen) are complex. Overall, the NO_x-N/TN ratio is higher in the effluent than in the influent. More TKN is present in the influent than NO_x-N, and more NO_x-N than TKN in the effluent, indicating nitrification in the systems. This ongoing study shows results that help Denver better understand the appropriate substrate for improved stormwater management around bioretention facilities. Further data collection is needed to understand the fate of contaminants in those bioretention facilities.

Numerical Simulation of PFAS Transport in Layered Soil Systems: Implications for Secondary Groundwater Contamination

Jui-Hsiang (Rayson) Lo - Colorado State University, Department of Civil and Environmental Engineering

Per- and polyfluoroalkyl substances (PFAS) are contaminants of emerging concern due to their persistence, widespread environmental occurrence, and potential human health impacts. This study uses COMSOL Multiphysics to simulate PFAS transport in groundwater under heterogeneous layered soil conditions. The objectives are to investigate PFAS transport behavior in layered subsurface systems, analyze PFAS storage in low-permeability layers, and quantify the contribution of back diffusion from these layers to plume tailing and sustained secondary groundwater contamination. The model simulates PFAS transport in domains comprising both high-permeability and low-permeability soil layers. Simulation results are used to evaluate temporal changes in PFAS concentrations at monitoring locations, plume geometry, PFAS storage in low-permeability layers, and long-term tailing behavior caused by diffusion from low-permeability zones back into flowing groundwater. This study advances understanding of how subsurface heterogeneity controls PFAS transport and long-term release in groundwater systems. In particular, results indicate that low-permeability layers can serve as PFAS storage zones and prolonged secondary sources of contamination, even after the primary source has been removed. These findings can inform site characterization, long-term monitoring, risk assessment, and remediation design for PFAS-contaminated groundwater systems.

Renewable-Powered Agricultural Desalination: A Geospatial Assessment of the Contiguous United States

Kenneth Laffite - Colorado State University, Department of Civil and Environmental Engineering

Increasing salinization of irrigation water threatens agricultural productivity and exacerbates the pressure on limited freshwater supplies. To mitigate this, integrating renewable energy with brackish or saline water desalination presents a promising alternative water supply. In this study, we developed a geospatial methodology to identify locations suitable for renewable-powered agricultural desalination across the contiguous United States (CONUS). We utilized a multi-criteria spatial analysis integrating national datasets on watershed boundaries, surface and groundwater salinity, irrigated cropland cover, solar photovoltaic potential, and wind capacity factors. Watersheds were evaluated against established literature thresholds to determine operational viability. Our results identify extensive suitable regions, predominantly in the water-scarce western United States, including the High Plains, the Rocky Mountain region, and the Southwest, alongside localized areas in California, Florida, and the lower Mississippi River basin. Quantitatively, we identified approximately 33,925 km² of irrigated land suitable for surface water and 79,445 km² for groundwater for this intervention. These findings highlight the widespread scale of agricultural salinization in the CONUS and demonstrate the geographic feasibility of deploying renewable-powered desalination to secure sustainable water resources for irrigated agricultural systems.

Fourteen Years of Edge-of-Field Monitoring: Quantifying Tillage Effects on Runoff Water Quality with Bayesian Models

A.J. Brown- Colorado State University, Agricultural Water Quality

Understanding how tillage practices influence runoff water quality is critical for evaluating agricultural management impacts on the environment. Tillage alters soil properties that affect edge-of-field (EoF) runoff volume, sediment transport, and nutrient losses from cropped fields. While many plot-scale studies have examined short-term responses to tillage, few have quantified these effects using long-term, edge-of-field monitoring data collected under production field conditions. This study analyzed a 14-year EoF monitoring dataset from field-scale replicated conventional, strip-till, and minimum-till systems under furrow-irrigated conditions in Fort Collins, CO. Runoff volume and water-quality samples were collected during individual irrigation events using field and laboratory methods that evolved over time. Water quality consisted of sediment, nutrient, and salt parameters (10 total). Tillage disturbance was quantified using the NRCS Soil Tillage Intensity Rating (STIR), a continuous metric integrating the depth, speed, and surface disturbance of field operations, enabling consistent comparison of management intensity across years. A Bayesian causal modeling framework was applied that accounts for measurement uncertainty and shared temporal structure to estimate the effects of STIR on runoff water quality and quantity. Results show that STIR is strongly associated with particulate constituents, with higher concentrations and loads observed under more intense tillage. These effects extended one to two years following disturbance, indicating legacy impacts of tillage management. Overall, less intensive tillage systems provided both immediate and lasting benefits for reducing sediment and nutrient losses, with average mass loading reductions for all analytes ranging from 6 – 28% over the 14-year study.

Assessment of the Salinization of the South Platte River Basin: Data Collection Efforts and Uncertainty Analysis

Gracie Gooch - Colorado State University, Department of Civil and Environmental Engineering

The combined pressures of increasing water scarcity and rising soil-water salt concentrations in the Western United States pose a growing threat to the sustainability of irrigated agriculture. The South Platte River Basin in northeastern Colorado, irrigated for more than 150 years and responsible for roughly 75% of the state's agricultural sales, is particularly vulnerable. This study characterizes current salinity conditions across the basin using remote sensing, groundwater sampling, and surface-water sampling integrated within a river-mass-balance framework. A spatial model of the river system is being developed to integrate Monte Carlo uncertainty analysis that accounts for measurement error, variability in flow and concentration, and spatiotemporal trends. These results provide baseline information to irrigators and water-management agencies, and will establish the foundation for a forthcoming SWAT+ model to evaluate future management scenarios.

Ecohydrology & Plant Water

Radial Variability of Stem Water Storage in Ponderosa Pine Trees

Victoria Wojahn - Colorado State University, Department of Civil and Environmental Engineering

Understanding how trees store and use water is essential for predicting ecosystem responses to climate variability, particularly in semi-arid forests where vegetation strongly influences water availability. Internal stem water storage helps buffer mismatches between transpiration and water uptake, but its spatial organization and functional role remain poorly understood. This study investigates how water storage is distributed within tree stems and how different radial regions contribute to water use in ponderosa pine forests in Colorado. Motivated by field observations indicating radial variation in tissue capacitance, we test the hypothesis that internal water storage is partitioned into compartments with distinct response times. We use four months of time-lapse Electrical Resistivity Tomography (ERT) data collected from a ponderosa pine during a dry period followed by significant precipitation events. ERT is used to image spatial and temporal variations in stem water content at three heights along the trunk, and measurements are analyzed in relation to environmental conditions, including precipitation, vapor pressure deficit (VPD) and soil moisture. By quantifying diel and seasonal dynamics of internal water storage, this work aims to improve our understanding of how trees regulate water use under changing environmental conditions. These insights will help advance predictions of forest responses to drought and climate variability.

Slope-Aspect Governance on Ecohydrological Wildfire Recovery

Andrew Kellogg - University of Wyoming, Department of Civil Engineering – Hydrology

Amid climate change and increasingly frequent and severe wildfires within the Southern Rocky Mountains, diverse spatiotemporal understanding of ecohydrological wildfire recovery is growingly increasingly important. Short-term impacts and recovery windows within these forests are well quantified; however, the coupling between plant available water storage (PAWS) and long-term biomass recovery—mediated by aridity and topographical northness—is far less understood. In this study, an existing conceptual wildfire-recovery model was iteratively practiced at an upper montane burned forest in southeastern Wyoming to address this uncertainty. Statistical analysis of the topographical controls on the spatiotemporal variability of PAWS and normalized difference vegetation indices recovery ($\Delta NDVI$) was conducted at both a north facing and south facing hillslope, and basin-level scale. Data was collected via onsite observations, near surface soil moisture, stream-discharge, and medium to high resolution geospatial imagery. Evidence is presented of divergent snowmelt dynamics across gradients of northness, providing advantageously higher PAWS on north facing hillslopes in late summer months. Despite favorable runoff partitioning on north facing hillslopes, $\Delta NDVI$ lacked substantial predictability across gradients of northness at a hillslope or basin-level scale. Results speak to this burned forest operating with a hydroclimate with dominant annual timescales of energy-limitation and seasonal late summer water limitation. This study diverged from existing conceptual models, prompting a revised conceptual framework where seasonal transitions in aridity may gradually govern long-term vegetation recovery across hillslopes. Continued research across diverse spatiotemporal wildfire environments is essential to further our understanding and management skills amid a changing climate.

Comparing Methods to Quantify Groundwater Evapotranspiration by Willow in a Mountain Valley, Cache la Poudre River Watershed, Northern Colorado

Logan Seymour - Colorado State University, Department of Geosciences

Mountain watersheds often contain wide valley segments where floodplains store groundwater that supports stream baseflow and riparian ecosystems. Phreatophytes (plants that root to the water table) in these ecosystems can transpire directly from groundwater, reducing groundwater contributions to streamflow or inducing stream losses. This groundwater evapotranspiration flux (ET_g) is poorly understood despite its importance in mountain stream-aquifer water budgets. This study investigates the ET_g flux in a representative wide valley at the CSU Mountain Campus, which includes a 36-hectare riparian zone dominated by willows (*Salix geyeriana*). Two ground-based methods are used to characterize groundwater-vegetation interactions: (i) analysis of diurnal water table fluctuations (DWTs) in monitoring wells to quantify ET_g; and (ii) measurements of water flux through plant stems using sap flow sensors to quantify total transpiration (T). The water sources of sap flow T (groundwater and soil moisture) may vary with time of year and recent weather events. DWTs provide a theoretical total ET_g, of which the groundwater-sourced portion of sap flow T (T_g) is expected to be a seasonally variable fraction. Comparison of water stable isotopes of soil moisture and groundwater to the isotopic signature of plant xylem water will help isolate T_g. Preliminary 2025 isotope data show xylem water plotting on a mixing line with groundwater and soil moisture end members, suggesting phreatophytes draw from both sources. Methods are in good agreement with respect to timing of peak fluxes. However, cumulative flux magnitudes differ as ET_g includes evaporation, and methods indicate different daily flux durations.

A Comparative Analysis of MODIS and Eddy Covariance Daily Gross Primary Production Data in Forested Ecosystems

Samantha Peppel - South Dakota School of Mines, Department of Civil and Environmental Engineering

Gross Primary Production (GPP) is a key factor to quantify the amount of carbon converted into energy through photosynthesis by vegetation. Remotely sensed GPP products provide spatially continuous coverage but require validation at local scale to support adequate data interpretation. NASA's MODIS (Moderate Resolution Imaging Spectroradiometer) GPP product provides an 8-day cumulative GPP prediction. Other satellites, such as NASA's ECOSTRESS (ECOSystem Spaceborne Thermal Radiometer Experiment on Space Station), require GPP estimates on a daily scale for daily water use efficiency calculations. This study aims to assess the accuracy of NASA's MODIS daily GPP predictions against AmeriFlux GPP daily measurements from 2019-2024. Analysis included two forested AmeriFlux sites: US_xRM in Colorado (west of Loveland), and US_xHa in Massachusetts (north central area). The application of a 2D footprint model provided spatially averaged values of MODIS GPP over sunlight hours. The validation process compared this MODIS GPP data with Eddy Covariance GPP measurements for each site. Preliminary results showed that MODIS daily GPP prediction errors were $-0.52 \pm 1.96 \text{ gC m}^{-2} \text{ d}^{-1}$ (MBE \pm RMSE), indicating an underestimation of nearly 20% when assessing both sites' data combined. Site US_xHA provided the highest error with a normalized RMSE of 32%, while site US_xRM provided the lowest error with a normalized RMSE of 13%. Ultimately, this analysis demonstrates that MODIS satellite based GPP predictions closely align with flux-tower measured GPP over forested ecosystems.

Within-Canopy Height of Aerodynamic Surface Temperature and Its Environmental Dependencies in Sub-surface Drip-Irrigated Maize

Manish Giri - Colorado State University, Department of Civil and Environmental Engineering

Accurate estimation of sensible heat flux (H) is important for understanding surface energy balance and for correctly determining evapotranspiration (ET) in irrigated agricultural systems. Eddy covariance (EC) Energy Balance systems provide reliable H measurements, but their cost and complexity limit their use mainly to research applications. Other approaches rely on above-canopy air temperature profiles, which may not adequately represent local heat exchange processes due to its spatial representation requirements and sensitivity to surface conditions. Within-canopy air temperature, however, shows strong vertical gradients that change with irrigation treatment, biomass characteristics, crop growth stage, and atmospheric conditions. These profiles may provide more direct information about the aerodynamic temperature (T_o) that governs H exchange. This study determined the within-canopy height at which T_o is generated in a drip-irrigated maize field at the Limited Irrigation Research Farm (LIRF), near Greeley, Colorado, under full and deficit irrigation treatments. Multi-height within-canopy air temperature profiles, net radiation (R_n), soil heat flux (G), and eddy covariance-based sensible and latent heat fluxes were collected throughout the growing season. Specific stations were selected to relate to EC fluxes based on upwind direction contributing areas (heat flux footprints). T_o was estimated by inverting a bulk resistance-based H formulation. Different functions were fitted to characterize the temperature-height profiles and determine the within-canopy height associated with T_o . This height was expressed as a fraction of crop height to allow comparison across growth stages and irrigation treatments. Changes in this height were then examined in relation to wind speed, vegetation index, and canopy development to identify key factors influencing the within-canopy thermal structure. The origin height of T_o varied systematically with irrigation treatment, wind speed, and crop growth stage, reflecting how canopy structure and atmospheric conditions influence within-canopy vertical heat transport. These results suggest that within-canopy temperature profiles contain physically meaningful information about canopy-atmosphere heat exchange. This approach has the potential to improve ET determination and crop water stress monitoring using low-cost temperature sensors, especially in situations where advanced micrometeorological instrumentation is not available.

Hyperspectral Remote Sensing of Salinity Effects on Maize: A Greenhouse Study

Muhammad Fawad - Colorado State University, Department of Civil and Environmental Engineering

This study investigates maize physiological and spectral/thermal responses to salinity stress using greenhouse and field-based remote sensing observations, with the broader goal of supporting field-scale soil salinity detection in the South Platte River Basin (SPRB) and similar salinity-affected irrigated regions. A controlled greenhouse experiment was conducted in 2025 using the Pioneer 487Q drought-tolerant maize variety. Salinity treatments were applied through drip irrigation water using a mixture of sodium chloride ($NaCl$) and calcium chloride ($CaCl_2$). Five irrigation water salinity levels with electrical conductivity (EC_w) of 0.8, 2, 4, 6, and 8 $dS\ m^{-1}$ were imposed, each with five replications. Salinity inputs, drainage water salinity, pot mass change and leaf temperature were monitored throughout the experiment. Concurrently, maize spectral reflectance responses were collected using multi- and hyperspectral sensors. Data analysis identified potentially sensitive narrow spectral bands, particularly in the mid-infrared region, associated with salinity stress in maize. In addition, field campaigns and remote sensing observations were conducted in a center-pivot irrigated maize field within the SPRB using a UAS-based remote sensing system to collect hyperspectral and thermal imagery. UAS observations are being paired with ground-based hyperspectral measurements and laboratory-determined soil salinity data. These greenhouse and field datasets are being used to train and evaluate deep learning models for soil salinity detection using fused multi-modal remote sensing inputs. The study is intended to support actionable field-scale diagnostics in the SPRB and improve irrigation management, salinity mitigation, and water-use efficiency in semiarid agricultural systems.

Hydraulics, Geomorphology & River Processes

Stationary Wave Trains in Steep Gradient Channels

Brooke Pennington - Colorado State University, Department of Civil and Environmental Engineering

Stationary wave trains have been interpreted as indicators of near-critical flow and associated with undular hydraulic jumps (UHJs) in steep rivers. However, the hydraulic conditions under which these waves form, and the extent to which their observable properties reflect flow characteristics, remain incompletely understood. This study investigates stationary wave trains as a hydraulically definable class of surface gravity waves characterized by consistent wavelength across multiple downstream undulations and a mean water surface parallel to the bed slope. Controlled flume experiments were conducted across a range of slopes and discharges to quantify wave geometry, flow depth, and velocity, and to evaluate the applicability of wave-based velocity estimation methods derived from linear wave theory. Stationary wave trains were observed under both subcritical and near-critical flow regimes, with wave nonlinearity increasing systematically with slope. Despite this increase in nonlinearity, intermediate-depth dispersion relationships provided the most accurate estimates of mean flow velocity for all slopes tested. These results demonstrate that stationary wave trains are not restricted to classical UHJs and do not require strict critical flow conditions. Instead, they represent organized surface gravity waves that can persist across subcritical to near-critical regimes in steep, rough-bed channels. The findings support the use of wave-based approaches for velocity estimation and provide the hydraulic conditions for interpreting stationary wave trains in natural rivers.

Influence of Vegetation Density and Submergence on Drag Coefficient in Vegetated Open-Channel Flow

Towsibur Rahman - Colorado State University, Department of Civil and Environmental Engineering

Riverine vegetation strongly influences flow structure and hydraulic resistance, yet the combined effects of vegetation density and submergence on drag coefficient remain insufficiently understood. This study investigates how variations in vegetation density and submergence affect flow resistance in a controlled recirculating water flume. Simplified cylindrical stems were used to represent vegetation, and experiments were conducted under three vegetation-density conditions and different levels of submergence. Particle Image Velocimetry (PIV) was employed to obtain high-resolution velocity fields and to visualize turbulent flow structures around the vegetation. These measurements enabled detailed analysis of flow behavior and more accurate estimation of drag coefficients across varying experimental conditions. The findings improve understanding of how vegetation density and submergence conditions influence drag resistance in open-channel flow. This study contributes to parameterizing vegetation drag in hydraulic models and provides useful insights for improving predictions in river management, flood risk assessment, and ecological conservation.

Optimizing Freshening Flow Rates in Ponds and Reservoirs

Olivia Doehr - Colorado State University, Department of Civil and Environmental Engineering

In the absence of natural mixing, Colorado currently replenishes ponds and reservoirs to ensure a healthy water ecosystem. This presentation focuses on how properly-managed aquatic vegetation can aid in mixing and ensuring the dissolved oxygen rate in water remains at normal levels, allowing aquatic wildlife to survive. Properly-managed vegetation may facilitate mixing and, thus, decrease the amount of water resources required to replenish ponds and reservoirs. To test this hypothesis, Particle Image Velocimetry (PIV) was utilized in flume experiments to collect water particle velocity data. Concurrently, dissolved oxygen concentrations were collected. Through data analysis, the PIV velocities coupled with the dissolved oxygen data determined gas transfer efficiencies based on different flow conditions. With funding from the Colorado Water Conservation Board, the focus has been on vegetation mimicking emergent stems of Cottonwood trees native to Colorado. In the future, we will compare these results to those of submerged model vegetation mimicking the Eurasian Watermilfoil. The water was initially deoxygenated and a reaeration curve was determined based on collected dissolved oxygen concentrations. The results suggest the potential to conserve water by introducing native vegetation to facilitate mixing within a body of water. However, we also discuss the implications of the competing variables of turbulence and flow velocity, which impact the dissolved oxygen transfer efficiency. A brief discussion about the next steps will also be discussed as a new facet of water quality analysis (utilizing CE-QUAL-W2) and remote sensing are integrated into this research. This presentation explores the idea of combining water conservation efforts with a nature-based solution by supporting native ecosystems which require little human intervention once implemented. The research being presented and the experiments conducted were sponsored by the Colorado Water Conservation Board.

Preliminary Results for Characterizing Dispersion in Vegetated Flows with Fluorescent Dye

Sam Kraus - Colorado State University, Department of Civil and Environmental Engineering

Fluid mechanics within vegetation has been an ongoing area of research in recent decades. Contaminant and nutrient transport within and around vegetated canopies is affected by turbulent dynamics driven by flow-vegetation interactions. In this study, preliminary results are presented to characterize the effects of rigid-cylinder vegetation on 2-D dispersion in vegetated flows. A fluorescent dye was used in combination with Particle Image Velocimetry (PIV) to characterize flow hydrodynamics and scalar concentrations. Future work will quantify these results to characterize the effects of vegetation and flow characteristics on the diffusion process.

Legacies of Beaver Extirpation in a Dynamic Eolian-Fluvial System, North Sand Creek, North Park, CO

Dylan Davis - Colorado State University, Department of Geosciences

North Sand Creek is located in the northeastern corner of North Park, CO. The perennial uppermost segment of North Sand Creek (upstr) drains a mountainous catchment, then meets the creek's ephemeral tributary (actadj), which flows adjacent to the active dunefield of North Sand Hills. Below this confluence, the stream runs alongside inactive, vegetated dunes (inactadj). Previous work found evidence for a sediment wave in the actadj segment, which occurred as snowmelt runoff mobilized sand contributed to the channel by

recreational off-highway vehicles on the active dunes. Resultant channel instability threatens a protected downstream water right. Our objectives in this study were to (i) observe magnitude and timing of channel geometry adjustment, (ii) characterize sediment dynamics throughout the inactadj segment to determine if direct sand addition occurs throughout the channel network, instead of exclusively within the ephemeral tributary, and (iii) estimate past sediment storage by historical beaver dam complexes. Repeat cross-section surveys at 13 stations and long profile surveys were conducted from May to August 2025. UAV flights August 1-3 provided visible light orthomosaic imagery and a Lidar-derived digital elevation model of the stream. No continuous surface flow was observed in the actadj segment due to low snowpack and runoff. Based on repeat surveys, no actadj channel adjustment occurred; only minor adjustments were recorded at inactadj cross sections, and a sequentially translating sediment wave was not observed. Discontinuous sand addition to the inactadj segment from destabilized dune faces and reworked terrace deposits occurred along a total of 915 m of stream bank, 7.5% of total bank length. The inactadj segment contained over 306 relict beaver berms, with maximum densities of 14 berms/100m in the reaches surveyed. We estimate maximum past sediment storage behind historical beaver dams within the inset mainstem channel at 45,700 m³. Lack of a sediment wave in the ephemeral tributary and discontinuous sand addition throughout the inactadj reaches indicate that the stream's sediment regime is interannually dynamic. The large volume of past sediment storage by historical beaver dam complexes suggest that North Sand Creek's channel instability and channel export may be a legacy of local beaver extirpation. Addition of engineered beaver dam analogues or eventual reintroduction of beaver populations could attenuate future sand waves.

Evaluating Reservoir Application of Water Injection Dredging (WID) Efficacy Using Multibeam and Sediment Core Datasets

Lesli Key - Colorado State University, Department of Civil and Environmental Engineering

Reservoir sedimentation is an increasingly prevalent management issue which threatens water storage capacity, necessitating cost-effective solutions. Water Injection Dredging (WID) uses low-pressure, high-volume water jets to fluidize bed sediment and create a density current that moves along sloped beds to transport material. While WID has been used extensively in harbors, its use in reservoir sediment management is limited. Tuttle Creek Lake in Manhattan, KS is undergoing three WID demonstration tests to evaluate the technique's effectiveness at generating density currents and passing clay, silt, and fine sand through the dam outlet to the downstream channel. Through this practice, sediment continuity will be partially restored, and reservoir infilling could be reduced. To measure the effectiveness and quantify sediment mobilization, high resolution multibeam bathymetric surveys will be conducted before, during, and after the ongoing WID demonstration tests. We will be performing bed elevation differencing to calculate volumetric changes and estimate the total mass of sediment removed. Initial observations of data following the first demonstration period suggest that the mobilized bed material may interfere with multibeam signal returns necessitating more investigation and refinement before volume and mass estimates can be developed. We will analyze the bulk density of bed sediment cores taken before and after the demonstration to constrain mass change rates and present preliminary WID demonstration data assessing the application of WID as a viable solution for reservoir sediment management.

Snow, Climate & Mountain Hydrology

Spatio-temporal Density Variability Across Several Study Sites in Northern Colorado

Carson Bainbridge - Colorado State University, Department of Ecosystem Science and Sustainability

Density is a crucial indicator of snowpack characteristics that is combined with depth to yield snow water equivalent (SWE). Yet density's variability across space and time often leads to generalized assumptions and oversimplifications in data interpretations. This study assessed density measurements using the NASA Cold Land Processes Experiment (CLPX) dataset from February and March of 2002 and 2003, archived at the National Snow and Ice Data Center (NSIDC). A variogram analysis was performed to explore the spatial correlation of density (as well as depth and SWE) from 16 measurements across each of the Buffalo Pass, Walton Creek, and Fraser Alpine sites in Northern Colorado. The standard deviation of the density profile data were also evaluated. Spatial correlations were found only for the bulk density data, whereas depth, SWE, and density profile showed no correlations. The results indicate that density measurements are not uniform and should not be homogenized due to their temporal and spatial variability.

Snow Density Variability in Lodgepole Pine (*Pinus contorta*) Forests

Jocelyn Cramer - Colorado State University, Department of Ecosystem Science and Sustainability

Snowpack in the mountainous Western United States (U.S.) has large hydrological implications for those who depend on this resource, particularly in headwater states such as Colorado. Accurate estimation of snow storage and improved management strategies to enhance snow retention are increasingly important as snowpack availability declines under changing climate conditions. In Colorado, water and forest management decisions directly affect millions of downstream users who rely on seasonal snowmelt. However, quantifying snowpack properties throughout the winter is challenging due to limited ground-based measurements, especially in forested environments where airborne sensors often perform poorly. This study investigates snow density within lodgepole pine (*Pinus contorta*) stands to quantify spatial variability as a function of snow depth, tree height, diameter at breast height, neighboring tree density, distance to clearing, canopy cover, and measurement direction relative to tree boles. These field observations were used to develop binary regression tree (BRT) models for both snow density and snow depth within *P. contorta* stands. Model performance was assessed using drone-based Light Detection and Ranging (LiDAR) imagery to derive similar forest metrics. Results indicate that snow density and depth are strongly influenced by canopy structure, primarily in open (<45% canopy cover) and closed (>45% canopy cover) forests. These findings highlight the importance of forest characteristics in influencing snow accumulation. As lodgepole pine forests across the Rocky Mountains continue to require management in response to wildfire, insect outbreaks, and forest succession, understanding the effects of *P. contorta* forest structure on snowpack dynamics is essential. The modeling framework presented here provides an applicable tool for water and forest managers, offering improved confidence in predicting the seasonal availability of water resources within this forest type.

Hydrologic Trends for Central Chilean Andes Watersheds – Confining the Uncertainty of Snowcourse Data

Alex Hahnenberg - Colorado State University, Department of Ecosystem Science and Sustainability

Chile is a major agricultural provider, but much of these areas are semi-arid. The water used for agricultural production comes from snowmelt in the mountains. High mountain snow storage in the winters and spring allows for greater stream flows in Chile's austral spring and summer time. Here, our main question is how is the hydrology changing? From seven gauging stations in the central Chilean Andes, streamflow has been decreasing over the last 44 years (period of record 1980 – 2023). The precipitation stations are at low elevation for these snowmelt-dominated watersheds and do not show the same trends, thus we explored snowcourse data. The Chilean Water Resources Directorate (DGA) has been sampling the snowpack at least once per year at various sites in this area, some going back to 1951. However, the sampling does not occur at the same time each year. Here, we examine the impact of the inconsistency of the time series on the trends in the snowpack. We subsequently assess whether the snowpack trends are decreasing or if there has been a systematic shift in the snow climatology. The rate of change was computed using the Theil-Sen slope assessment and the significance of change using the Mann-Kendall test. Further, we used the Mann-Whitney-Wilcoxon test to assess if the changes in hydrometeorology are a trend and/or a stepwise change. We compare our results to a recent remote sensing assessment of the area using MODIS data from the past 25 winters.

From Snow Structure to Streamflow Signal: Investigating the Effects of SWE Heterogeneity on Runoff Timing and Magnitude

Anna Pfohl - University of Colorado Boulder, Cooperative Institute for Research in Environmental Sciences (CIRES)

Mountain snowpack spatial variability can impact snow-driven streamflow timing and magnitude. Near-peak, lidar-derived snow water equivalent (SWE) data were coarsened (50 m–1 km; elevation bands), re-gridded, and inserted into the Distributed Hydrology Soil Vegetation Model (DHSVM) to evaluate how snow heterogeneity at peak SWE influences streamflow in the Tuolumne River, California, and Blue River, Colorado. In the Tuolumne, peak simulated streamflow from the most homogeneous snowpack representation was 36% greater than heterogeneous simulations. In all years, the homogeneous snowpack representation did not produce a recession limb peak since snow melted more quickly. Streamflow during late summer was higher (up to 3.5 times) for finer-resolution snow heterogeneity simulations. In the Blue, streamflow simulations were more similar across different snowpack representations, and the sensitivity to heterogeneity was less pronounced. This difference between watersheds was attributed to differences in SWE variability and subsurface processes between the two basins. In the Blue, snowmelt infiltrated into the subsurface and was slowly released throughout summer. In the Tuolumne, mid-winter melt and rain resulted in higher soil moisture at peak SWE. The combination of high soil moisture and the Tuolumne's subsurface characteristics allowed water to move more efficiently through the subsurface than in the Blue. For both watersheds, altering snow heterogeneity had little effect (within 2%) on total end-of-water-year runoff or evapotranspiration because absolute differences balanced out throughout the melt season: a higher-resolution SWE

representation produced less streamflow at peak SWE but greater streamflow afterward relative to a coarser SWE representation. Experiments isolating radiation variability demonstrated that fine-scale accumulation processes at peak SWE had a stronger influence on streamflow timing than post-peak radiation heterogeneity. These results suggest that if basin-mean SWE is well constrained, capturing heterogeneity may not be necessary for water supply forecasting on quasi-annual timescales but can be critical for simulating late summer flows.

L-band InSAR Coherence Controls in a Mountain Snowpack: Incidence Angle, Canopy Cover, and Liquid Water Content

Preetika Kaur - University of Wyoming, Department of Civil Engineering

The Jemez Mountains of northern New Mexico support a seasonally transient snowpack that is critical for regional water supply, yet the snowpack's spatial distribution and its suitability for interferometric synthetic aperture radar (InSAR) monitoring remain poorly characterised. Using three UAVSAR L-band (1.26 GHz) interferometric pairs spanning 12–26 February 2020 — temporal baselines of 7 days (12–19 Feb), 7 days (19–26 Feb), and 14 days (12–26 Feb) — we quantify the linear relationships between InSAR coherence magnitude $|\gamma|$ and three environmental controls: (i) canopy cover (CC), (ii) incidence angle (θ), and (iii) snowpack liquid water content (LWC) simulated by the SnowModel physical snowpack model. We present three pairwise (simple) linear regressions, all three paired two-variable models, and a fully specified three-variable ordinary least squares model. Across all pixel-pair observations, CC is a significant negative predictor of $|\gamma|$ ($r=-0.520$; all CC coefficients $p<0.001$), incidence angle is the most stable predictor ($\beta_{\theta}\approx-0.0036^{\circ^{-1}}$; $r=-0.548$), and SnowModel LWC is significant in all pairs ($p<0.001$). The three-variable model achieves adjusted R^2 of 0.451, 0.394, and 0.329 for Pairs A, B, and C respectively, with all predictors independently significant and VIF below 1.3. These results provide the first quantitative decomposition of coherence controls in a semi-arid Southwestern US snowpack and inform the design of SWE retrieval strategies for the upcoming NISAR satellite mission.

Seasonal and Diel Regional Temperature-Elevation Gradients Across Northern Colorado

Ryder Hunt - Colorado State University, Department of Ecosystem Science and Sustainability

Air temperature decreases with increased elevation, and physics dictates that the change in temperature of free air is a function of the moisture in the air, called the lapse rate. For wet air, this is about 5.5 degrees Celsius per kilometer, and for dry air, it is about 9.8 C/km. However, for air temperature near the ground, this change in temperature with elevation can vary very locally, and even regionally. We used the hourly temperature data from 20 Natural Resources Conservation Service (NRCS) SNOTEL stations for six years (2019 to 2025) to assess the temperature-elevation gradient (Γ) over Northern Colorado. We also examined the fit of the Γ correlation from the Pearson correlation coefficient (ρ) as a function of time of day and time of year. It was found variability in the gradient (Γ) and in the fit (ρ) for day versus night (diel) and seasonally. Spring exhibited the strongest correlation (R^2) in a regression model of mean seasonal temperatures and elevation. Further, certain stations were persistent outliers from the Γ correlation. We examined the specific location and magnitude of those outlier stations. Further examinations using ASOS stations are applied to compare areas to pinpoint causes of inversions as well as to find relationships within outlying areas.

Remote Sensing, ET & Irrigation

Customized Tools for the pyFAO56 Evapotranspiration Software Package for Field Research at the USDA-ARS Limited Irrigation Research Farm

Reagan Ames - United States Department of Agriculture (USDA), ARS

Estimates of evapotranspiration (ET), the combination of soil evaporation and plant transpiration, are vital to managing irrigation. A versatile and adaptable water balance tool, pyFAO56, was developed as an open-source Python package to inform water budgeting decisions and influence irrigation practices. Based on the dual crop coefficient water balance method standardized in the Food and Agriculture Organization of the United Nations, Irrigation and Drainage Paper No. 56 (a.k.a. "FAO-56"), pyFAO56 automates and expands upon these methods to provide estimates of soil water depletion based on user input. Current efforts aim to increase usability for a public audience and streamline parameter incorporation. In this capacity, we have customized the package to incorporate specific objectives and data collected at the USDA-ARS Limited Irrigation Research Farm (LIRF) under a linear, variable-rate sprinkler system. Notably, changes in canopy cover are monitored to revise the basal crop coefficient (K_{cb}), and canopy temperature measurements are utilized to manage the crop stress coefficient (K_s). Additionally, soil water content (SWC) measurements are taken by both a neutron soil moisture meter and a time domain reflectometer (TDR) to verify soil water depletion. Examples of customized data processing and workflow optimization are shown, including development of graphical user interfaces (GUIs), incorporation of continuous soil moisture sensor data, and automatic irrigation scheduling for modeling future scenarios. With the recent 2025 revision of FAO-56, future efforts are targeted to update the pyFAO56 package.

Incorporating Cosmic Ray Neutron Rover Data in the Downscaling of Satellite Soil Moisture

Farhana Akter Meem - Colorado State University, Department of Civil and Environmental Engineering

Accurate soil moisture estimation is critical for terrain mobility assessments and many other applications, yet widely used satellite-based products such as Soil Moisture Active Passive (SMAP) provide coarse-resolution data (~9 km grid cells) that cannot resolve much of the spatial variability in soil moisture. The Equilibrium Moisture from Topography Plus Vegetation and Soil (EMT+VS) model addresses this limitation by downscaling coarse-resolution soil moisture to fine resolutions (3–30 m grid cells) using high-resolution topographic, vegetation, and soil datasets within a simplified water balance framework. Mobile cosmic ray neutron rovers can measure soil moisture at intermediate scales (~250–400 m radius), but such measurements have not been used in downscaling methods. The objectives of this study are to (1) extend the EMT+VS framework to incorporate cosmic ray neutron rover observations and (2) evaluate the value of rover data in improving downscaled soil moisture estimates. The new EMT+VS framework independently downscales satellite and rover soil moisture inputs and combines the resulting fine-resolution fields using a flexible weighting approach that controls the relative influence of the inputs. The new EMT+VS model was evaluated for Maxwell Ranch, a 4000-ha site located northwest of Fort Collins, Colorado, where point, rover, and satellite soil moisture

observations were collected during the summer of 2022. A structured set of model scenarios was developed to systematically assess different data-integration strategies, including satellite-only, rover-only, and combined-input scenarios. The accuracy of the generated fine-resolution soil moisture patterns was evaluated using a multi-scale approach to ensure consistency with both input datasets and independent point measurements of soil moisture. The results indicate that incorporating rover data improves the downscaled soil moisture patterns, particularly by capturing intermediate-scale variability that is not resolved by satellite or point data. Nonetheless, including rover data does not improve the ability of the EMT+VS model to reproduce the point measurements of soil moisture. Overall, this work demonstrates that rover-based observations can complement satellite data and improve the representation of soil moisture variability within the EMT+VS downscaling framework.

Mapping the Moisture of Unpaved Roads and Adjacent Rangeland Using a Cosmic Ray Neutron Rover

Luke Eddington - Colorado State University, Department of Civil and Environmental Engineering

Cosmic ray neutron sensors have been recently developed to measure soil moisture. These sensors count epithermal neutrons originating from cosmic ray interactions with the atmosphere which are attenuated by hydrogen in the land surface environment. After correcting the neutron counts for solar activity, atmospheric humidity, and biomass, a soil moisture estimate can be determined. Cosmic ray neutron rovers collect measurements over a shorter count accumulation time than more commonly used stationary sensors and thus can be driven on roads to map moisture along the path of travel. The rover measurements provide a composite moisture signal from both the road and the adjacent landscape because the effective radius of the measurement footprint is approximately 300 m. Road moisture measurements could support efforts to reduce fugitive dust, which causes adverse health and safety impacts. Measurement of landscape moisture could be useful for improving land management. The objective of this study is to isolate the signals of the road and landscape in the rover data. Two methods are being considered for this purpose: incorporating soil moisture data from a satellite and shielding the rover. The satellite data can potentially be used to estimate the landscape moisture, and by knowing the composite moisture from the rover sensor, the road signal can be isolated. Placing shielding below the sensor potentially blocks the road signal, so that the landscape signal can be isolated. These methods are being tested at the Central Plains Experimental Range (CPER), an experimental rangeland in northern Colorado. Four test sites were located on gravel roads, and four test sites were located on vehicle trails. Field measurements of the road and landscape moisture were collected along with cosmic ray neutron counts on eight field days between May and September 2025. The composite moisture from the rover exhibits a strong correlation with the composite moisture from the field data. The satellite-based approach has been tested, but its accuracy is limited by errors in the satellite soil moisture estimates. Data collection will continue in summer 2026 to test the shielding method and to gain a better understanding of the landscape and road moisture.

Estimating Irrigation Consumptive Use in the La Plata Basin Using Satellite-Based Observations

Soheil Nozari - Colorado State University, Department of Civil and Environmental Engineering

The La Plata Basin (LPB) is a transboundary watershed in South America spanning approximately 3.3 million km² across Argentina, Bolivia, Brazil, Paraguay, and Uruguay. The basin is a major center for agricultural and livestock production, contributing significantly to regional and global food security. Agriculture in the LPB has traditionally been rainfed under tropical to subtropical climates, but greater climate variability in recent decades has increased interest in supplemental irrigation to stabilize and enhance agricultural productivity. This growing reliance on irrigation has raised concerns about the long-term sustainability of food production systems in the region. Addressing these concerns requires reliable information on the spatiotemporal variability of irrigation water use, which remains limited across the LPB. In this study, satellite-based datasets are used to estimate seasonal irrigation consumptive use, defined as actual evapotranspiration (ET) minus effective precipitation, across the basin for the period 2004-2024. Both thermal-based and reflectance-based ET products are evaluated. Effective precipitation is estimated using two approaches: (1) the USDA-SCS method, incorporating precipitation data from multiple sources, and (2) assuming that actual ET simulated by land surface models represents effective precipitation. Results indicate that irrigation consumptive use estimates derived from thermal-based ET products are more robust than those obtained from reflectance-based ET products. In addition, effective precipitation estimated using the USDA-SCS method results in higher irrigation consumptive use estimates compared to estimates based on land surface model ET. These findings highlight the importance of ET product selection and effective precipitation methodology in regional assessments of irrigation water use.

Irrigation Water Use Response to Climate Variability Across Major Aquifer Regions of the Western United States

Md Fahim Hasan - Colorado State University, Department of Civil and Environmental Engineering

Irrigation water use (IWU) has been a major component of the water budget in the Western United States (Western US), sustaining intensive agriculture in the region under climate stress. While irrigation in this region is shaped by a complex set of factors, including water rights, state regulations, crop pricing, irrigation technology, and energy costs, the role of climate in shaping irrigation decisions over the past decades has rarely been studied at the aquifer-basin scale using long-term panel methods. In this study, we employ a fixed-effects panel regression model using ~40 years of monthly IWU, precipitation, and temperature data from 1986 to 2023 across major aquifer-based basins of the Western US to quantify the sensitivity of IWU to climate variability. The fixed-effects framework controls for time-invariant drivers of IWU, isolating the within-unit climate signals from confounding structural factors. Preliminary results reveal spatially heterogeneous IWU responses to climate anomalies. Precipitation anomaly coefficients exhibit a strong gradient from arid western to semi-arid eastern basins, while temperature anomaly coefficients show no consistent spatial pattern. Joint analysis of both anomalies on IWU reveals strong regional clusters, with some basins responding strongly to both anomalies while the others responding to only one. These clusters suggest that the sensitivity of IWU to climate drivers may be modulated by the groundwater versus surface water dependency of the basins. Additional analysis indicates that the stringency of water use reporting may also influence this climate sensitivity.

Water Systems Engineering & Applications

A Portable IoT and AI-Based Smart Irrigation Demonstration System for Education, Outreach, and Applied Research

Jay Ham - Colorado State University, Department of Soil and Crop Sciences

We developed a portable, self-contained smart irrigation demonstration kit designed for teaching, outreach, and applied research in water management. The system can be deployed in classrooms, community gardens, farms, and public venues to demonstrate how sensor technology, Internet of Things (IoT) connectivity, and emerging AI tools can improve irrigation efficiency.

The platform automates irrigation for two containerized plants, raised beds, or small garden plots using soil moisture sensors to trigger irrigation events and regulate application amounts. The system is connected to cloud-based services that integrate local weather data, data analytics, and adaptive control algorithms to dynamically adjust irrigation scheduling throughout the growing season. This allows users to observe how environmental conditions influence plant water demand and irrigation decisions in near real time. The kit includes on-site signage and supporting online educational materials that communicate system performance and introduce key concepts in soil moisture monitoring, evapotranspiration, and smart irrigation. The design emphasizes simplicity, portability, and accessibility, making it suitable for audiences ranging from K–12 students to university courses and community stakeholders. The system has been deployed and evaluated over two growing seasons across multiple locations in Colorado. Results demonstrate its effectiveness as a hands-on educational tool and applied research platform, and its potential to improve understanding and adoption of data-driven irrigation practices.

Detection of Undocumented Levees Using Convolutional Neural Networks

Alexandria Rodgers - Colorado State University, Department of Civil and Environmental Engineering

Flooding causes billions of dollars in damage annually and affects millions of people worldwide. Accurate flood modeling depends on reliable mapping of levees, which have the potential to significantly alter water flow paths, floodplain extent, and water storage. As precipitation intensity and frequency increase, maintaining accurate databases of levees is therefore pertinent for the accuracy of flood models. Recent studies suggest the national levee database (NLD) captures only roughly 20% of levees across the continental United States (CONUS). This discrepancy likely exists due to structures built before documentation began, unofficial construction for agricultural protection, and naturally occurring smaller levees. Though similar studies have not been scaled to a global spatial extent, these inaccuracies are likely not limited to the United States. To bridge the information gap, this research proposes to identify undocumented levees using Convolutional Neural Networks (CNNs) to detect topographic signatures from 1-m resolution open-source digital elevation models (DEMs). The initial results of running a U-HRNet model over a HUC12 area (~48km²) in western Iowa resulted in a 90% recall and the identification of almost 300 potential undocumented levees. This initial test study demonstrates the potential for high resolution mapping of undocumented levees using open-source data. While the scope of this work aimed to test the parameters and workflow of the CNN, this research will continue to scale up to cover the continental United States (CONUS) and eventually globally. Improved levee inventories could substantially enhance flood modeling accuracy, support hazard mitigation planning, and reduce human exposure to flood risk.

What the HEC is the Hydrologic Engineering Center?

Avital Breverman - US Army Corps of Engineers, Hydrologic Engineering

The Hydrologic Engineering Center (HEC) supports the nation's water resources management mission by strengthening the U.S. Army Corps of Engineers' (USACE) technical capability in hydrologic and hydraulic engineering as well as water resources planning and management. HEC's Hydrology and Statistics Division develops and delivers technical support for modeling studies using HEC's Hydrologic Modeling System (HEC-HMS) and Statistical Software Package (HEC-SSP). This presentation highlights ongoing software modernization and enhancements, applied modeling studies, and technology transfer resources. Key initiatives currently underway within the H&S Division at HEC include a research and development work unit to modernize USACE procedures for hydrologic modeling of probability-based ("hypothetical") precipitation events used in flood risk management, thus replacing guidance from the early 1990s. This abstract also highlights interagency collaboration supporting FEMA's Future of Flood Risk Data (FFRD) initiative and the Mixed Populations work unit to advance risk-informed National Flood Insurance Program products and improved flood hazard and risk information.

Finally, the presentation previews upcoming application development, including HEC-HMS 2030, a modern meteorology, hydrology, and reservoir simulation platform intended to become the preferred hydrologic modeling tool for typical USACE studies and broader community use, as well as HEC-Neptune, HEC's new statistical hydrology application. Public-facing technology transfer materials available through HEC's website, YouTube channels, and training content will also be showcased.

Dynamics of Desalination Across Carbon, Water, Energy, and Social Systems

Naomi Michael - Colorado State University, Department of Systems Engineering

I am working on a project for the National Science Foundation project 2452517: Solar-Driven Zero Liquid Discharge to Enable Inland Desalination for Climate-Adaptive Water Resilience, which looks at the zero liquid discharge (ZLD) method of desalination for inland desalination. My poster focuses on Tasks 6 and 7, examining the system dynamics, carbon flow analysis, and social mapping and public perceptions of solar-powered ZLD desalination. ZLD is an improved system that uses solar power for energy and produces less harmful brine than traditional desalination processes. The poster will display the system dynamic model I am creating to show how the ZLD desalination would affect the carbon, water, and energy nexus. The system dynamic model will help implement sustainable technology to combat water shortages without polluting Earth's natural systems. This model has been created using InsightMaker and Vensim. My poster will show a causal loop diagram and explanations for the different loops and linkages drawn. I found that a city's decision to use a ZLD system will be very dependent on water quality and availability. I found the ZLD system is strongly linked to water, energy, carbon, and social systems. Findings indicate cities facing water scarcity may be more likely to use ZLD. This claim is supported by water, energy, and social loops. I also found ZLD can impact the carbon loop. My poster will allow people to understand how a ZLD system affects all aspects of a city by highlighting the interconnections between energy, water, carbon, and social systems. The purpose of the systems dynamic model displayed is to help support communities looking to use ZLD to strengthen water security as climate change and system pressures rise.

Climate, Wildfire & Broader Water Systems

Process-Informed Flood Frequency Analysis for Colorado Watersheds: A Mixture Distribution Framework and Interactive Decision-Support Dashboard

Michael Talbot - Colorado State University, Department of Civil and Environmental Engineering

Flood frequency analysis (FFA) in mountainous watersheds is complicated by the co-occurrence of distinct flood-generating processes --- rainfall, snowmelt, and rain-on-snow (ROS) --- that produce statistically heterogeneous peak flow populations. Treating these mixed samples as identically distributed, as is standard practice, can substantially bias upper-tail quantile estimates. This study applies a mixture distribution FFA framework to peak-over-threshold (POT) flood records from Colorado GAGES-II watersheds, using output from the Western Land Data Assimilation System (WLDAS) to classify flood events by generating process. We evaluate three classification approaches of varying complexity: fixed thresholds based on the literature, an adaptive threshold scheme, and a population-level quartile-based classifier. All three rely on a single feature --- an antecedent window rainfall fraction computed from basin-averaged WLDAS flux accumulation curves --- applied through a sequential decision tree. Generalized Pareto (GPD) and Log-Pearson Type III (LP3) distributions are fit to each flood type subset where sample sizes permit, and combined into a mixture survival function. We present preliminary results on the prevalence of mixed flood populations across Colorado and how single-sample and mixture-based quantile estimates diverge, particularly in the upper tail. Results are accessible through an interactive Shiny dashboard currently under development, which allows users to explore flood classifications, distribution fits, and frequency curves by site, classification method, and distribution choice. We discuss tradeoffs among the classification schemes, the practical challenge of limited per-type sample sizes, and what this framework might offer for applied FFA in Colorado.

Large-Scale Prediction of Post-Wildfire Stream Water Temperature for Unmonitored Sites

Daniel Philippus - Colorado School of Mines, Department of Civil and Environmental Engineering

Stream water temperature (SWT) is a key water quality parameter with wide-ranging ecological (e.g., aquatic organism lifecycles) and infrastructure (e.g., water treatment) implications. SWT has been shown to shift after fire, but despite extensive analyses, post-fire SWT shifts remain difficult to predict. A central challenge is that relatively few watersheds have both pre- and post-fire SWT observations. Our work examines the suitability of SWT prediction at unmonitored sites (“ungaged modeling”) to expand post-fire SWT prediction and analysis over large scales. For this analysis, we validated an existing statistical ungaged SWT model, TempEst 2, on available pre/post-fire observations. We then analyzed post-wildfire shifts in modeled August mean SWT for 1,107 burned watersheds across the western U.S. TempEst 2 captured 43% of spatial variance in the observed change in August mean SWT over 20 test gages. While performance remained limited, modeled SWT shifts outperformed large-domain, observation-based models in the literature ($\leq 40\%$ of spatial variance). TempEst 2 predictions for 1,107 sites showed an increase in August mean SWT post-fire (mean $+0.19$ °C, $p \ll 0.001$), which was not explained by changes in site weather. Predicted post-fire SWT shifts were highly heterogeneous over large spatial scales, reinforcing the results of smaller-scale observational studies. The results suggest that post-fire SWT shifts are dominated by local burn severity with lesser influences from site location and climate, in agreement with the literature. Broadly, this study shows that ungaged SWT models can be a useful supplement for post-wildfire SWT observations, supporting improved post-fire SWT prediction and larger-scale analysis.

Hydroclimatic Impacts of Large-scale Climatic Circulation Patterns on Middle Latitude Streamflow Variability over the United States

Jai Hong Lee - South Carolina State University, Department of Civil Engineering

Understanding 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 streamflow patterns 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 streamflow 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 streamflow 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-streamflow relationships have a tendency of sign reversal of the streamflow 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 streamflow variation.

The Evolution of Instream Flows — IFIM to Eflows

Phil Harrison - ColoCreekConsultingC3

Power lies in prediction, these deterministic or mechanist models have been used to predict the effects of Dams and Diversions (regulated regimes vs natural flows). The E3 metric representing, Education, Experience and Expertise and other metrics will be used to compare the models.

The models to be compared are Hydrologic Alteration (IHA), IFIM/PHABSIM (SALMOD)- Mesohabitat Simulation Model (MesoHABSIM), ELOHA (Ecological Limits of Hydrologic Alteration) framework, California Environmental Flows Framework-CEFF; IBM- individual-based models- CompMech-ORNL-OAK RIDGE NATIONAL LAB, and inSTREAM and inSALMO. Other models and methods will be briefly mentioned.

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COLORADO STATE UNIVERSITY

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