44th Annual AGU

Hydrology Days

April 16-17, 2024

ONE WATER
SOLUTIONS INSTITUTE
COLORADO STATE UNIVERSITY

hydrologydays.colostate.edu

SCHEDULE: At-a-Glance

Tuesday April 16th

TIME	LSC Never No Summer Room	LSC Room #386	LSC Room #372-374
8:00 - 9:00 am	*Registration*		
9:00am - 10:30 am		Ecohydrology, Water, and Plants, Session 1 Chair: Sean Gleason	Climate & Meteorology Chair: Anna Pfohl
10:30 - 10:45 am	*Break*		
10:45 - 12:00pm		Ecohydrology, Water, and Plants, Session 2 Chair: Sean Gleason	Geoscience & Groundwater Chair: Ryan Bailey
12:00 - 1:00 pm	*Lunch*		
1:00 - 2:00pm	**Hydrology Days Award:** **Martha Anderson** *Taking the Earth's Temperature – Diagnosing Evaporative Fluxes Across Scales*		
2:15 – 3:45 pm		Hydraulics & Geomorphology Chair: Ryan Smith	

Wednesday April 17th, 2024

TIME	LSC Never No Summer Room	LSC Room #386	LSC Room #372-374
8:00 - 9:00 am	*Registration*		
9:00am - 10:30 am		Urban Water Systems Chair: Sybil Sharvelle	
10:30 - 10:45 am	*Break*		
10:45 - 12:00pm		Hydrologic Systems Chair: Jeffrey Niemann	
12:00 - 1:00 pm	*Lunch*		
1:00 - 2:00pm	**Borland Hydrology Award:** **Christa Peters-Lidard** *Data-Driven Hydrology: From Assimilation to Digital Twins*		
2:15 – 4:00pm	Student Showcase and Competition Chair: Sarah Millonig		

MEETING INFORMATION

Location

The conference will be held on **level 3** of the CSU [Lory Student Center.] Technical sessions will take place in rooms 372-374, and 386 (see map). The Keynotes, lunches, and Student Showcase take place in Never No Summer Ballroom.

Parking

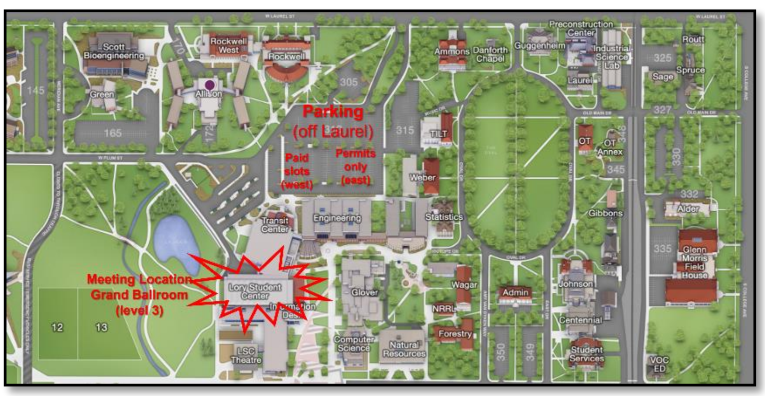
All vehicles parked on campus must have a valid CSU parking permit or park in designated hourly parking spaces and pay at a pay station!

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.

Where is the easiest place to park on campus for visitors?

Visitor parking permits are available for the areas listed below, also noted on the university's parking map (PDF and online), and connect to Around the Horn to get you around campus:



- Moby Lot #195
- Green Hall
- Engineering #310 (recommended)
- Ammons Hall # 315
- Administration #349
- MAX at University Station #440
- Lake Street Garage

PRESENTATION SCHEDULE

Tuesday April 16th, 2024

Location	Session	Time	Presenter	Title
LSC Room #386	Ecohydrology, Water, and Plants, Session1	9:00 - 10:30 AM	Dawit Asfaw	Capturing the Spatio-Temporal Variability of Groundwater Pumping Leveraging Public Domain Data and Machine Learning: An Assessment of Machine Learning Application for Data Scare Regions
LSC Room #386	Ecohydrology, Water, and Plants, Session1	9:00 - 10:30 AM	Emmanuel DeLeon	Low-Cost IoT Solutions for Collecting Water Quality Samples
LSC Room #386	Ecohydrology, Water, and Plants, Session1	9:00 - 10:30 AM	Catherine Schumak	Dynamic Claypan Modeling – Characterizing the Hydraulic Conductivity of Shrink-Swell Clay Soils of Goodwater Creek Experimental Watershed, MO Using Plot-Level Data
LSC Room #372-374	Climate & Meteorology	9:00 - 10:30 AM	Frances Davenport	Historical patterns of regional extreme precipitation change in observations and climate models
LSC Room #372-374	Climate & Meteorology	9:00 - 10:30 AM	Phoebe White	Spatiotemporal characteristics of precipitation in Colorado's mountains
LSC Room #372-374	Climate & Meteorology	9:00 - 10:30 AM	Steven Fassnacht	Rapid Snow Surface Deformation Due to Ablation
LSC Room #372-374	Climate & Meteorology	9:00 - 10:30 AM	Helen Flynn	Analyzing the correlation between melt-derived baseflow, peak SWE, and rainfall in small snow-dominated catchments over 40 years in Colorado
LSC Room #386	Ecohydrology, Water, and Plants, Session 2	10:45-12:00 PM	Brendan Allen	Point of No Return: Identifying Critical Thresholds for Plant Functioning and Recovery from Drought
LSC Room #386	Ecohydrology, Water, and Plants, Session 2	10:45-12:00 PM	Edson Costa Filho	A Combined Machine-Learning and Kriging Surface Temperature Approach for Crop Water Stress Mapping
LSC Room #386	Ecohydrology, Water, and Plants, Session 2	10:45-12:00 PM	Tyler Donovan	Nitrogen Fertilizer and Irrigation Effects on Soil and Plant Nitrogen Dynamics
LSC Room #372-374	Geoscience & Groundwater	10:45-12:00 PM	Julianne Robinson	Applied Hydrogeophysics for Improved Aquifer Characterization
LSC Room #372-374	Geoscience & Groundwater	10:45-12:00 PM	Abdullah Al Fatta	Groundwater Storage Trends in San Luis Valley, CO: Combined In-situ and Remote Sensing Approach
LSC Room #372-374	Geoscience & Groundwater	10:45-12:00 PM	Susmita Pant	Estimation of 52 years of groundwater level through Ordinary Kriging in the San Joaquin Valley, California

LSC Room #372-374	Geoscience & Groundwater	10:45-12:00 PM	Md Fahim Hasan	A Data-driven Approach for Estimating Irrigation Groundwater Use for the Western United States
LSC Room #386	Hydraulics & Geomorphology	2:15-3:45 PM	Ryan Smith	Mapping and modeling widespread alteration of the land surface caused by subsidence
LSC Room #386	Hydraulics & Geomorphology	2:15-3:45 PM	Amanda Innes	Floodplain analysis of extreme storm events and the inclusion of stormwater impacts on military installation floodplain modeling.
LSC Room #386	Hydraulics & Geomorphology	2:15-3:45 PM	Brianna Corsi	Bernalillo Reach of the Middle Rio Grande: Geomorphic Changes and Silvery Minnow Habitat
LSC Room #386	Hydraulics & Geomorphology	2:15-3:45 PM	Alexander Thornton-Dunwoody	From Ashes to Insights: Uncovering Sediment Dynamic Patterns in Post-Fire Watersheds through Drone Based SfM and Random Forest Bare Earth Classification
LSC Room #386	Hydraulics & Geomorphology	2:15-3:45 PM	Bijoux Schoner	Effective Monitoring of Large Wood Restoration in Colorado Urban Streams

Wednesday April 17th, 2024

Location	Session	Time	Presenter	Title
LSC Room #386	Urban Water Systems	9:00 - 10:30 AM	Mahshid Mohammad Zadeh	Characterization of the Relationship between Water Use Intensity and Land Use Planning
LSC Room #386	Urban Water Systems	9:00 - 10:30 AM	Mohamed Mahmoud	High-Resolution Future Land Use Forecasting by Integrating Spatial Deep Learning and Temporal Regression Techniques
LSC Room #386	Urban Water Systems	9:00 - 10:30 AM	Alec Jones	Development of a crystal scaffold within a sampling device for continuous capture of SARS-CoV-2 virions from water
LSC Room #386	Urban Water Systems	9:00 - 10:30 AM	Amanda Salerno	Assessing Sustainable Urban Stormwater Management: A Comparative Study of Green Roofs and Detention Basins Strategies in Three U.S. Cities
LSC Room #386	Hydrologic Systems	10:45-12:00 PM	Richard Koehler	The Enhanced Flow Duration Curve
LSC Room #386	Hydrologic Systems	10:45-12:00 PM	Anna Pfohl	Recent and Future Winter Recreation Opportunities in Colorado
LSC Room #386	Hydrologic Systems	10:45-12:00 PM	Joseph Bindner	Exploring how Soil Moisture and Strength Vary with Soil, Vegetation, and Topography Within a SMAP Grid Cell
LSC Room #386	Hydrologic Systems	10:45-12:00 PM	Boran Kim	Estimating Soil Moisture at High Spatial Resolutions Using Meteorological Variables at a Study Region in Northern Colorado
LSC Room #386	Hydrologic Systems	10:45-12:00 PM	Holly Proulx	Incorporating Vehicle Trails in Soil Moisture Downscaling for Mobility Assessments
LSC Room #386	Student Showcase and Competition	2:15-4:00 PM	Gillian Gallagher	Examining Annual Peak Snow Water Equivalent (SWE) and the Sensitivity of SWE to Climate Change in Colorado
LSC Room #386	Student Showcase and Competition	2:15-4:00 PM	Brendan Allen	Point of No Return: Identifying Critical Thresholds for Plant Functioning and Recovery from Drought
LSC Room #386	Student Showcase and Competition	2:15-4:00 PM	Naiara Doherty Garcia	Sunflower adaptations and resilience to embolism in drought conditions
LSC Room #386	Student Showcase and Competition	2:15-4:00 PM	Dawit Asfaw	Capturing the Spatio-Temporal Variability of Groundwater Pumping Leveraging Public Domain Data and Machine Learning: An Assessment of Machine Learning Application for Data Scare Regions
LSC Room #386	Student Showcase and Competition	2:15-4:00 PM	Julianne Robinson	Applied Hydrogeophysics for Improved Aquifer Characterization
LSC Room #386	Student Showcase and Competition	2:15-4:00 PM	Abdullah Al Fatta	Groundwater Storage Trends in San Luis Valley, CO: Combined In-situ and Remote Sensing Approach

LSC Room #386	Student Showcase and Competition	2:15-4:00 PM	Susmita Pant	Estimation of 52 years of groundwater level through Ordinary Kriging in the San Joaquin Valley, California
LSC Room #386	Student Showcase and Competition	2:15-4:00 PM	Isabella Ulate	Investigating potential recharge to the Denver Basin Aquifer System from the Front Range Mountain Block using water stable isotope tracers
LSC Room #386	Student Showcase and Competition	2:15-4:00 PM	Md Fahim Hasan	A Data-driven Approach for Estimating Irrigation Groundwater Use for the Western United States
LSC Room #386	Student Showcase and Competition	2:15-4:00 PM	Lucas Roy	Forest To Faucets - A Hands-On STEM Kit Examining Hillslope Hydrology and Transmountain Diversions
LSC Room #386	Student Showcase and Competition	2:15-4:00 PM	Andrea Loudenback	Beyond the Barnyard: Optimizing Nutrient Efficiency in Colorado's Dairy Production Through Precision Manure Management with NIRS Technology
LSC Room #386	Student Showcase and Competition	2:15-4:00 PM	Kieri Karpa	Using Remote Sensing Data to Highlight Salinization Patterns in the South Platte River Basin of Colorado
LSC Room #386	Student Showcase and Competition	2:15-4:00 PM	Kwabena Opoku	Mitigating salinity for improved watershed management and crop production
LSC Room #386	Student Showcase and Competition	2:15-4:00 PM	Muhammad Raffae	Assessing streamflow and groundwater fluxes in the Upper Colorado River Basin using the SWAT+gwflow model
LSC Room #386	Student Showcase and Competition	2:15-4:00 PM	Reid Maynard	The Future of Sustainable Food: Evaluating the Effect of Dynamic Life Cycle Assessment Methods on Agricultural Environmental Outcomes
LSC Room #386	Student Showcase and Competition	2:15-4:00 PM	Elizabeth Ellis	An interdisciplinary evaluation of regenerative agriculture in the Midwest
LSC Room #386	Student Showcase and Competition	2:15-4:00 PM	Mohamed Fawzy Mahmoud	High-Resolution Future Land Use Forecasting by Integrating Spatial Deep Learning and Temporal Regression Techniques

KEYNOTE SPEAKERS

AGU Hydrology Days Award

Dr. Martha Anderson – Research Physical Scientists, USDA Agricultural Research Center, Hydrology and Remote Sensing Laboratory

Bio*:* Martha C. Anderson received a B.A. degree in Physics from Carleton College, Northfield, MN, and a PhD in Astrophysics from the University of Minnesota, Minneapolis. Presently she is a Research Physical Scientist for the USDA Agricultural Research Service in the Hydrology and Remote Sensing Laboratory in Beltsville, MD. Her research interests focus on mapping water and energy land-surface fluxes at field to continental scales using thermal remote sensing, with applications in water management, drought monitoring, and yield estimation. She has served on the Landsat and ECOSTRESS Science Teams.

Keynote Lecture: April 16th, 2024 at 1 PM – CSU Lory Student Center, Never No Summer Ballroom

Taking the Earth's Temperature – Diagnosing Evaporative Fluxes Across Scales

Abstract: *Thermal infrared (TIR) and visible/near-infrared (VNIR) surface reflectance imagery from remote sensing can be effectively combined in surface energy balance models to map evapotranspiration (ET) and vegetation stress, with broad applications in agriculture, forestry, and water resource management. In addition, diagnostic estimates of evaporative losses to the atmosphere can provide valuable information to prognostic land-surface modeling systems, revealing ancillary sources/sinks of plant available water (e.g., irrigation, shallow groundwater, deep rooting zones, tile drainage) that may be difficult to know in detail a priori but can have a notable impact on the land-surface temperature and on the system water balance. In this presentation we will discuss the unique information content conveyed by the land-surface temperature signal regarding the surface moisture status and vegetation health at field up to global scales. We will explore applications for temperature and ET retrievals in promoting sustainable water use and agricultural practices and for improving land-surface modeling systems used in hydrologic, weather, and climate forecasting system. Widespread and routine generation of ET data at field scale has been enabled by cloud computing technologies, with the OpenET ensemble modeling system as an example of collaborative geospatial information development. Looking forward, integration of Landsat with new sources of medium-resolution TIR imagery (e.g., ECOSTRESS, LSTM, TRISHNA, SBG, Landsat-Next, and Hydrosat), as well as all-sky microwave-based temperature retrievals, will improve ability to detect rapid changes in water use and availability – a key factor in decision making.*

Borland Hydrology Award

Dr. Christa D. Peters-Lidard– Director in Sciences and Exploration Directorate, National Aeronautics and Space Administration

***Bio**:* Dr. Christa D. Peters-Lidard is currently the Director in the Sciences and Exploration Directorate, where she has been Deputy Director since November 2021. She was Deputy Director for Hydrosphere, Biosphere, and Geophysics in the Earth Sciences Division from 2015-2021, and she was the Acting GSFC Chief Scientist from 2020-2021. She was a Physical Scientist in the Hydrological Sciences Laboratory from 2001-2015, and Lab Chief from 2005-2012. Her research interests include land-atmosphere interactions, soil moisture measurement and modeling, and the application of high-performance computing and communications technologies in Earth system modeling, for which her Land Information System team was awarded the 2005 NASA Software of the Year Award. She is a member of Phi Beta Kappa and was awarded the Committee on Space Research (COSPAR) Scientific Commission A Zeldovich Medal in 2004 and the Arthur S. Flemming Award in 2007. She was elected as an AMS Fellow in 2012, an AGU Fellow in 2018 and a member of the National Academy of Engineering in 2023. She has served as Chief Editor for the American Meteorological Society (AMS) Journal of Hydrometeorology and as an elected member of the AMS Council and Executive Committee. Her Ph.D. is from the Water Resources Program in the Department of Civil Engineering and Operations Research at Princeton University, and she holds a B.S. in Geophysics Summa Cum Laude from Virginia Tech.

Keynote Lecture: April 17th, 2024 1pm – CSU Lory Student Center, Never No Summer Ballroom

Data Driven Hydrology: From Assimilation to Digital Twins

Abstract: *Over the last thirty years, Land Data Assimilation Systems (LDAS; e.g., http://ldas.gsfc.nasa.gov; http://lis.gsfc.nasa.gov) have advanced from precipitation-driven systems at the Air Force Weather Agency (AGRMET) through community collaborations such as the North American (NLDAS), European (ELDAS), Global (GLDAS) and FEWS NET (FLDAS), and most recently the Global Hydro-Intelligence (GHI) system. As these systems developed, land data assimilation techniques have evolved from surface temperature-based nudging to filter-based approaches that assimilate satellite-based observations such as soil moisture, snow cover and snow water equivalent, terrestrial water storage, leaf area index, vegetation optical depth, and albedo. These systems are now widely used for multiple applications, including numerical weather prediction, sub-seasonal to seasonal forecasting, drought monitoring and forecasting, and hydrological forecasting. In this lecture, I will present examples of hydrologic data assimilation, which has led to a new "fourth paradigm" for hydrology with a focus on data-driven models including hydrology digital twins.*

Climate & Meteorology

Historical patterns of regional extreme precipitation change in observations and climate models

Frances Davenport
Department Civil and Environmental Engineering, Colorado State University, USA

Abstract. *Accurate projections of future extreme precipitation are important for informing risk management and climate change adaptation. However, projections of future extreme precipitation are relatively uncertain, especially at the regional scale, in part because of uncertainty in how well extreme precipitation processes are captured by earth system models. In current research, we are analyzing different metrics of historical extreme precipitation change to determine where historical observations and climate models agree and disagree. Simultaneously, we are developing machine learning-based pattern classification methods to determine what processes have driven historical changes in extreme precipitation.*

Rapid Snow Surface Deformation Due to Ablation

Steven R. Fassnacht [1,4], Michael Talbot, Julio López, Anotion-Juan Collados-Lara, Javier Herrero, Jesús Revuelto, Juan Ignacio López-Moreno, Helen Flynn, David Pulido Velázquez, Marin S. MacDonald [1], Jessica E. Sanow
[1]Department of Ecosystem Science and Sustainability, Colorado State University, USA
[2]Department of Civil and Environmental Engineering, Colorado State University, USA
[3] Civil and Environmental Engineering, Universidad de Granada, Spain
[4]Instituto Geológico y Minero de España, Spain
[4]US Geological Survey, Colorado Water Science Center, USA
[4]UCooperative Institute for Research in Atmosphere, USA

Abstract. *Snow is dynamic. The snow surface can be especially dynamic. For an isothermal snowpack, a cloud-free day can add enough short-wave radiation to cause rapid melt at the snow surface and a constant wind can cause further ablation. Due to a combination of meteorological forcing, a rapid change in snow surface geometry was observed over two days at a site in the Pyrenees Mountains. This included melt rills, melt holes, and ablation bumps. These were characterized several statistics and spatial surface data collected from various platforms including drone photogrammetry, tablet scanning-lidar, roughness board imagery, and photography. The fresh snow surface changed rapidly. On the first morning, the snow surface was relatively flat. After a day of sunshine, the surface developed melt rills and melt holes. Over night, the features flattened. Over the next day, they became for accentuated. Over the next night, the features again became less rough. Concurrently, ablation features evolved over a few hours due to sun and wind. Here we investigate these dynamic changes, as they are pertinent to the melt and sublimation of the snowpack, and meteorological dynamics across the snow surface.*

Analyzing the correlation between melt-derived baseflow, peak SWE, and rainfall in small snow-dominated catchments over 40 years in Colorado

Helen Flynn[1,2], Steven R. Fassnacht [1,3], Marin S. MacDonald [1], Anna K.D. Pfohl [4]

[1]Department of Ecosystem Science and Sustainability, Colorado State University, USA
[2]Instituto Pirenaico de Ecología, Spanish National Research Council (IPE-CSIC), Spain
[3]Instituto Geológico y Minero de España, Spanish National Research Council (IGME-CSIC), Spain
[4]National Oceanic and Atmospheric Administration, Earth System Research Laboratories, Physical Sciences Laboratory, USA

Abstract. *Baseflow is the primary driver of streamflow in snow-dominated watersheds for most of the year after the high-volume melt period has passed. The Colorado Front Range relies on low flows from late spring and early summer snowmelt for municipal, agricultural, and recreational purposes. Changes in the timing and amount of snowmelt due to climate change will impact water availability for millions of people on the Front Range. This study seeks to find the correlation between peak snow water equivalent (SWE) and post-peak SWE precipitation, and subsequent baseflow characteristics, including any yearly lag between the variables.*

Streamflow data from US Geological Survey stations and SWE data from Natural Resource Conservation Service SNOTEL stations were examined for drainage basins of varying latitude, elevation, and area across Colorado. In snow-dominated ecosystems, the hydrograph shows a well-defined peak when snowmelt occurs in the spring that is followed by low flows in the fall and winter months. The traditional water year (WY, in the US October 1 through September 30) separates a single season's peak melt and baseflow into two different WYs. To reflect the hydrologic processes that are occurring in snow-dominated watersheds, we propose using a melt year (MY) beginning with the onset of snowmelt contributions (the first deviation from baseflow) and ending with the onset of the following year's snowmelt contributions. We identified the beginning of a MY and extracted the subsequent baseflow values using flow duration curves (FDC). This is a dynamic approach to analyzing the correlation between peak SWE, post-peak SWE precipitation and baseflow. Further, we consider precipitation in the window after peak SWE and before snow-all-gone, as well as rain on the ground after snow-all-gone and prior to the subsequent winter's snow accumulation. By studying winter baseflow and its antecedent conditions, this research has important implications for quantifying water availability at times of the year when demand is high while supply (e.g. precipitation) is low in snow-dominated systems.

Spatiotemporal characteristics of precipitation in Colorado's mountains

Phoebe White and Peter Nelson
Department of Civil and Environmental Engineering, Colorado State University, USA

Abstract. *In Colorado and throughout the United States, agricultural is being recognized as a contributor to nutrient pollution in both state and federal waters. Nutrients like nitrogen and phosphorus run off farmland and accumulate in surface water, leading to water quality problems. While agricultural nonpoint sources are not currently subject to regulation in Colorado, efforts have been made to promote the adoption of Best Management Practices (BMPs) to safeguard surface water quality. However, accurately assessing the impact of these BMPs on water quality requires robust monitoring systems that can measure flow and collect water samples for analysis of nutrients and sediment. Unfortunately, the current equipment requirements for edge-of-field (EoF) monitoring set by the Natural Resources Conservation Service (NRCS) are often too expensive for practical and scalable research. Recognizing this need, the Colorado State University Agricultural Water Quality Program (AWQP) has developed a cost-*

effective automated water sampler (LCS) that utilizes Internet of Things (IoT) technology for scalable and near-real-time water quality research. This work directly follows deliverables from an awarded NRCS Conservation Innovation Grant titled, "Next Generation Technology for Monitoring Edge-of-Field Water Quality in Organic Agriculture". The AWQP-developed LCS is comprised of six main components, a cellular-enabled microcontroller, a 12V battery and solar charger, a peristaltic pump with tubing for water sample collection, a 12V, 10W solar panel, a water depth detecting sensor and, a cooler for sample preservation. The LCS operates in a similar manner to commercial samplers, as it detects flow and collects water samples at predetermined intervals for analysis at a later time. The LCS costs approximately $700-1,000 to build and deploy, this is approximately 1/15th of the cost of a commercial sampler. A preliminary comparison study performed by the AWQP indicates strong agreement between LCS depth measurements and commercial bubbler units. Additionally, measured analyte concentrations (total suspended solids, NO3, NO2, Total N, Orthophosphate, Total Phosphorous) were similar. We'll continue investigating water quality and quantity measurements obtained from commercial-grade EoF equipment and the AWQP-developed LCS IoT sampler at surface irrigated study sites to improve functionality. Additionally, in accordance with the grant requirements, we have made the resources for constructing an affordable sampler available to the public. This sampler is governed by the GNU GPL V2.0 open source, copyleft license.

Ecohydrology, Water, and Plants

Low-Cost IoT Solutions for Collecting Water Quality Samples

Emmanuel Deleon, Ansley Brown, Erik Wardle, Christina Welch
Soil and Crop Sciences Department, Colorado State University, USA

Abstract: *Plant growth and yield are the ultimate outcomes of a complex set of physiological processes that begin with the exchange of water for atmospheric CO2. However, this basic understanding of plant growth oversimplifies the numerous combinations of physiological and structural traits, soil properties, and environmental conditions that influence plant performance. Given that it is impossible to test every combination of plant, soil, and climate variable, process-based physiological modeling provides a feasible alternative for identifying beneficial trait networks. Here, using this framework, I take a step back from simple single trait performance outcomes and ask, what specific traits and trait connections would confer improved performance in a particular climate context? Using the Terrestrial Regional Ecosystem Exchange Simulator (TREES), I focus on the evolutionary linkage between water expenditure and carbon income – water uptake, water transport to the sites of evaporation, and the exchange of water for CO2. Model results are compared against what we might expect from theory, as well as real world empirical results. Trait networks most likely confer success under hotter and drier climate scenarios are discussed in the context of current crop improvement efforts.*

Dynamic Claypan Modeling – Characterizing the Hydraulic Conductivity of Shrink-Swell Clay Soils of Goodwater Creek Experimental Watershed, MO Using Plot-Level Data

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

Abstract. *Hydraulic conductivity (Kf) is an essential parameter for understanding soil hydrology. Hydrology models frequently use a single Kf value for a soil; however, this is likely not appropriate for claypan soils. Claypan refers to a subsurface argillic layer with much higher clay content (50-60% clay content) than overlying layers and often exhibits shrink-swell behavior. When saturated, swelling of montmorillonite clay minerals causes very low hydraulic conductivity, producing high runoff while dry periods cause shrinking and cracking, allowing for percolation. Claypan-driven hydrology makes watersheds vulnerable to surface transport of sediment, herbicides, and nutrients. Goodwater Creek Experimental Watershed (GCEW), located near Centralia, Missouri, is a case in point. Atrazine, a common agricultural herbicide used with corn and sorghum, has surface water concentrations in GCEW consistently amongst the highest for a watershed in the US.*
Previously, the discharge of GCEW was simulated at a daily time scale using the fully distributed AgES model developed by the USDA using a single Kf value. While the performance metrics indicated a good fit (Nash-Sutcliffe Efficiency of 0.72), manually comparing the simulated and observed discharge showed consistent underprediction of large flow events, lower peak flows, and overprediction of low flow events. Using subdaily, plot-level data, we will model the hydraulic conductivity of the claypan dynamically, with multiple values or functions, to better capture the hydrology of claypan soils. The hydrology modeling sets the stage for future efforts to predict atrazine concentrations and quantify the impacts of different management practices with the goal of informing mitigation strategies to decrease atrazine concentrations in the surface waters of GCEW.

Capturing the Spatio-Temporal Variability of Groundwater Pumping Leveraging Public Domain Data and Machine Learning: An Assessment of Machine Learning Application for Data Scare Regions

Dawit W. Asfaw[1], Ryan Smith[2], Sayantan Majumdar[3], Katherine Grote[4], Venkataraman Lakshmi[5], Bin Fang[5], James Butler[6], Brownie Wilson[6]
[1]Department of Geoscience, Colorado State University, USA
[2]Department of Civil and Environmental Engineering, Colorado State University, Fort Collins, CO, USA,
[3]Division of Hydrologic Sciences, Desert Research Institute, Reno, NV 89512, USA,
[4]Department of Geosciences and Geological and Petroleum Engineering, Missouri University of Science and Technology, Rolla, MO, USA,
[5]Department of Engineering Systems and Environment, University of Virginia, Charlottesville, Virginia, USA,
[6]University of Kansas, Lawrence, KS, USA

Abstract. *Groundwater level decline has increased globally threatening major aquifer systems' sustainable supply of water for irrigated crop production. Anthropogenic driven groundwater depletion is mainly attributed to agriculture. Groundwater pumping data collection is very limited around the world due to lack of policies. Future groundwater sustainability depends on monitoring of groundwater pumping. Machine learning has been used in some areas to estimate withdrawals, but data paucity has limited wider application of these approaches. The reliability of outcomes from machine learning analysis heavily relies on available data quality and quantity. Few studies have used machine learning techniques to study groundwater withdrawals in regions where data is abundant. Nevertheless, the data quality and quantity requirements to produce a robust estimate of groundwater withdrawals are not well studied. In this study, we built point scale groundwater withdrawal prediction machine learning models using a Random Forest algorithm. Data is split into training and testing where the training data is used to build the model and assess the model's ability by comparing the model prediction values with the testing data. The point scale prediction values are aggregated over a 2 km by 2 km grid. We evaluated a combination of different training and testing split to understand model performance variability. We performed the analysis in the Northwestern Kansas Groundwater Management District 4. The model used public domain remote sensing, land surface model output, and hydrogeological variables for the period from 2008 – 2020. We observed that a model trained on 10 % of the total available data showed coefficient of determination (R2) values of 0.96 and 0.77 for training and testing, respectively. Knowledge of crop irrigation area enabled estimate aggregation over a grid, and we find that aggregation of estimates improved the spatial and temporal groundwater withdrawals estimates. The result of this study has a significant implication for effective groundwater management in regions where there is limited data.*

Diurnal temperature range is an important but perhaps overlooked driver of plant community composition in topographically complex places

Adam Mahood
United States Department of Agriculture, Agricultural Research Services

Abstract. *How organisms interact with their environment is a classic problem in ecology with important implications for systems functioning. Coarse-scale data products are commonly used to account for climate when modeling systems-level attributes such as plant community composition and biophysical functioning. Because vegetation responses to climate are highly variable at fine scales, we often downscale climate data using higher resolution topography data products. But those downscaling methods are often too simplistic to capture topo-climatic processes like cold air drainage, which can dominate topographically complex systems. Here, we established dense sensor networks along topographic gradients at two sites in the Southern Rockies ecoregion, Manitou Experimental Forest (27 sensors) and Valles Caldera National Preserve (21 sensors), and documented vegetation composition at each sensor. We found that diurnal temperature range (DTR) and daily minimum VPD were correlated with species composition at both sites, while more commonly used variables like mean temperature were less predictive. This illustrates the importance of accounting for topoclimatic processes in ecohydrological analysis, since minimum VPD and DTR can be signatures of cold air drainage.The importance of topoclimate on vegetation structure highlights the need for better physically based models that capture topoclimate gradients, allowing for improved representation of complex ecological processes in hydrologic and earth systems models.*

Point of No Return: Identifying Critical Thresholds for Plant Functioning and Recovery from Drought

Brendan S. Allen[1,2], Jared J. Stewart[1,3], Stephanie K. Polutchko[1,3], Troy W. Ocheltree[2], Sean M. Gleason[1,2]
[1]Water Management and Systems Research Unit, USDA-ARS
[2]Department of Forest and Rangeland Stewardship, Colorado State University
[3]Department of Ecology and Evolutionary Biology, University of Colorado

Abstract. *The efficient transport of water to the sites of photosynthesis and other plant tissues is essential for the processes of carbon assimilation, growth, and maintenance of turgor. Water transport in plants occurs through xylem conduits which operate under negative pressure. As a consequence of water stress, the tension within the xylem can exceed critical thresholds which can result in embolism, the loss of function by the replacement of liquid with gas. Embolism formation represents a physiological weakness in plants, leading to permanent damage, particularly following drought. Due to the complexity of observing xylem functioning in crop species, artifacts from invasive methods likely skew our interpretations of when hydraulic systems fail. Our study focuses on pinpointing the stages of embolism occurrence and exploring the potential for refilling and repair in intact plants by utilizing non-invasive methods of optical vulnerability. We quantify leaf embolism and leaf shrinkage in the canopy leaves of maize during a near-fatal dry-down in a controlled environment. Continuous monitoring of gas exchange, chlorophyll fluorescence, and whole plant transpiration allows us to present the sequence of physiological failures leading to leaf mortality and senescence. Additionally, we find that recovery from extreme water stress is highly dependent on the accumulation of embolism within the xylem. By understanding the relationships between embolism occurrence, plant physiology, and agricultural practices, we aim to enhance crop productivity and resilience in the face of evolving environmental challenges.*

A Combined Machine-Learning and Kriging Surface Temperature Approach for Crop Water Stress Mapping

Edson Costa-Filho and José L. Chávez
Department of Civil and Environmental Engineering, Colorado State University, USA

Abstract. *This study evaluated different machine learning regression models and kriging methods to determine the best combination to interpolate ground-based surface radiometric temperature data from proximal infrared thermometry to map crop water stress spatially. The pseudo-thermal imagery, in combination with spaceborne optical imagery and agricultural weather data, was used to produce crop water stress index (CWSI) maps. The algorithm used to produce the CWSI maps is a land surface energy balance (SEB). The SEB method used high-resolution images from satellite platforms Sentinel-2 and PlanetDove, as well as interpolated surface temperature imagery. The different machine learning regressions implemented included the following: Ensemble of Trees, Regression Tree, Linear Regression, Supporting Vector Machine, and Gaussian Process Regression. The Kriging methods for spatial*

interpolation were Simple Kriging, Universal Kriging, Ordinary Kriging, Empirical Bayesian Kriging, and Co-Kriging. The Limited Irrigation Research Farm (LIRF) in Greeley, CO, housed the research site for this study. Two maize (drought-tolerant hybrids) fields (fully and deficit irrigated plots) provided the area for data collection. Each field is 190 m x 110 m (2.09 ha). The irrigation system was subsurface drip, with the drip emitters buried 0.23 m deep. Stationary surface temperature data at locations further from interpolated values were used to assess the accuracy of spatial temperature predictions. The performance of the hybrid machine-learning and Kriging surface temperature approach was similar regardless of the satellite data used. The mean bias error (MBE) for the hybrid approach using data from PlanetDove was 0.50 K (0.17%), and the RMSE was 1.87 K (0.62%). For the case scenario where Sentinel-2 multispectral data were used, the error (MBE ± RMSE) when creating the pseudo-thermal imagery was 0.17 K (0.06%) ± 1.85 K (0.61%). When using the resulting pseudo-thermal imagery to map CWSI, the estimated CWSI had a 0.002 (1%) ± 0.033 (21%) error compared to CWSI values derived from an Eddy Covariance Energy Balance system. These results were within similar accuracy as reported in previous published studies in the literature (i.e., normalized RMSE of 20%). The hybrid approach for developing pseudo-thermal imagery of cropland fields provided valid means to create CWSI maps.

Nitrogen Fertilizer and Irrigation Effects on Soil and Plant Nitrogen Dynamics

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Abstract. *Cropping systems can be exposed to different nitrogen (N) and water availabilities for a variety of reasons. Both N and water have been shown to have both positive and negative; direct and indirect effects on soil and plant N dynamics. Given that agronomic crops require large amounts of N to achieve high yields and often acquire a majority of their N from soil nitrogen mineralization (N min), it is important to understand how nitrogen and water interactions alter soil and plant N dynamics. Our study was conducted on continuous no till corn at the USDA-ARS Central Great Plains site in Akron, CO during the 2021 and 2022 growing season. We utilized two irrigation treatments of 100% ET and 70% ET representing full water and near dryland conditions for the region, and three N fertilizer treatments ranging from 22 – 275 kg / ha capturing low, optimal, and excess N. We used an in-situ undisturbed soil core with ion exchange resin beads to measure net N min and found that there was an N fertilizer by irrigation interaction. N-acquiring soil enzyme activity increased with N fertilizer and was not affected by irrigation regime. Plants in the water limited environment were still able to acquire large amounts of N, though that did not translate to large yield gains due to water limitations especially during reproductive growth stages. A follow up 15N tracer study is being conducted to better understand what sources of N plants are utilizing under different resource availabilities.*

Geoscience & Groundwater

Applied Hydrogeophysics for Improved Aquifer Characterization

Julianne Robinson, Jiawei Li, Ryan Smith
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Abstract. *There is a growing need to characterize and monitor groundwater resources as the climate changes and water use increases, particularly in regions of the world that depend on groundwater for irrigated agriculture and domestic water supply. Geophysical measurement methods like time-domain electromagnetic surveys can address the need for cost-effective, high-resolution hydrostratigraphic data collection with greater spatial and temporal coverage than direct-sampling methods. Applying geophysical data to improve conceptual groundwater models requires integration with other forms of data like lithology from well drillers' logs. This project analyzed hydrogeological characteristics in the Parowan Valley in Utah by interpolating geophysical datasets collected using towed time-domain electromagnetic (tTEM) surveys with lithology data from well logs. Co-kriging, a form of spatial interpolation, was used to conduct the analysis. Geophysical data were converted from resistivity to lithology through a rock-physics transform process prior to interpolation. Higher variance was observed in kriging results relying on geophysical data alone, compared to the combined datasets. Reliability of resistivity data as an indicator for lithological properties relies on the accuracy of the rock-physics transform, which was affected by varying levels of saturation in the Parowan Valley. Results of this analysis show that geophysical data can inform conceptual models through greater spatial and temporal coverage compared to direct-sampling measurements but must be used in conjunction with other types of data and rely on an understanding and consideration of site-specific characteristics for accurate interpretation. Geophysical datasets collected through time-domain electromagnetics can serve as an important addition to other forms of data to inform water management in the Parowan Valley and other arid and semi-arid regions dependent on groundwater.*

Estimation of 52 years of groundwater level through Ordinary Kriging in the San Joaquin Valley, California

Susmita Pant, Ryan Smith
Department of Civil and Environmental Engineering, Colorado State University, Fort Collins

Abstract. *The San Joaquin Valley, one of the most agriculturally significant areas of California, has experienced large groundwater withdrawal. This study presents the estimation of long-term (1971-2023) groundwater level data over large area of San Joaquin Valley. Available groundwater level records were analyzed, and the groundwater level data was interpolated for the entire region using Ordinary Kriging with a spherical variogram. Each year's model accuracy was assessed using a 5-fold K-fold cross-validation procedure. The result showed considerable shift in groundwater levels between 1971 and 2023, with the levels falling over most of the region. The findings also uncovered a reduction of up to 210 feet in the water table in 2023 when compared to the levels observed in 1971. Our Validation approach showed diverse performance metrics across different years: MAE (17.111 to 71.156), RMSE (30.27 to 101.54), ME (-2.83 to 3.708), NRMSE (0.045 to 0.138), and r^2 (0.512 to 0.93). Notably, there was a sharp fall of the water table after 2010. This study revealed that the fall in groundwater table has been compounded by the effect of drought occurring at various intervals in the 52-year time span. The result of this research can be used for analyzing long term groundwater modeling and water level analysis in the San Joaquin Valley. We will also combine Ordinary Kriging with the Small Baseline Subset Approach (SBAS), which uses change in head across different time periods to minimize noise by leveraging data*

from overlapping years. Following this, we will also evaluate the yearly changes in head derived from both approaches and compare the results.

Groundwater Storage Trends in San Luis Valley, CO: Combined In-situ and Remote Sensing Approach

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Abstract. *Groundwater is a critical freshwater source, but climate change-induced shifts in precipitation patterns and extreme droughts are leading to increased groundwater use in agriculture and municipalities. This overexploitation depletes groundwater sources worldwide, particularly in arid and semiarid regions. To ensure sustainable groundwater management, we need accurate estimations and a clear understanding of groundwater storage changes and their drivers. However, this is challenging due to limited spatiotemporal in-situ measurements and uncertainties in storativity estimates. To address this, we combined in-situ water level, pumping, and diversion data with Interferometric Synthetic Aperture Radar (InSAR) satellite data to estimate aquifer properties and groundwater storage changes. We also used gridded remote sensing products (such as PRISM precipitation and OpenET evapotranspiration) to assess the water balance for comparison. Our study focused on the San Luis Valley, Colorado, an agriculturally dependent region with quality temporal and spatial data on withdrawals and water levels. We estimated storativity values for subdistricts based on the relationship between pumping and water levels. Our study revealed a declining trend in groundwater storage, highlighting the need for immediate action to ensure the long-term stability of aquifers. This research provides water managers with valuable insights into how to stabilize groundwater storage by maintaining a balance between recharge rates and groundwater extraction. The knowledge gained from this study can be transferrable to regions with similar climatic and geological conditions.*

A Data-driven Approach for Estimating Irrigation Groundwater Use for the Western United States

Md Fahim Hasan, Ryan Smith
Civil and Environmental Engineering, Colorado State University

Abstract. *The Western United States (Western US) consists of some of the most significant and heavily pumped aquifers in the country. A significant portion of the pumped groundwater is supplied to irrigate the farmlands of this region. To ensure sustainable agriculture and avert detrimental effects like land subsidence and aquifer depletion, monitoring and quantifying groundwater use at a high spatiotemporal scale has become essential for the Western US. The current monitoring capacity lacks spatial and temporal resolution and limits the ability to assess irrigation groundwater use at the regional level. We plan to leverage existing satellite products, in conjunction with in-situ datasets and data-driven* *techniques, to bridge this gap. One key concept related to satellite-based groundwater use estimation is "effective precipitation", which is very challenging to quantify and validate with no currently available dataset. Effective precipitation can be defined as the fraction of precipitation that supplements irrigation. Knowledge of effective precipitation is crucial to understand the dynamics between precipitation, evapotranspiration, and groundwater pumping, as effective precipitation drives the amount of irrigation required. In this study, we employed a machine learning approach to measure effective precipitation utilizing high-resolution OpenET datasets. The machine learning model uses gridded precipitation, weather, and land use products as input variables and generates effective precipitation estimates at a high spatial resolution of 2 km. In the next step, these estimates are applied in a water balance equation to measure consumptive groundwater use for the Western US. As consumptive groundwater use and groundwater pumping are separated only by the factor of irrigation efficiency, the produced consumptive groundwater use dataset serves as a reliable proxy for groundwater pumping. Moreover, the consumptive groundwater use estimates can validate the effective precipitation estimates. Comparison of the consumptive groundwater use estimates with groundwater pumping data in basins over Kansas and Arizona showed good agreement, validating our effective precipitation approach. This is a step forward toward producing historic groundwater pumping estimates for the entire Western US. Our high-frequency effective precipitation and consumptive groundwater use datasets will provide valuable information in regional-scale groundwater pumping estimation, water budget estimation, and sustainable groundwater planning.*

Hydraulics & Geomorphology

From Ashes to Insights: Uncovering Sediment Dynamic Patterns in Post-Fire Watersheds through Drone Based SfM and Random Forest Bare Earth Classification

Alex Thornton-Dunwoody
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Abstract: *Digital elevation models (DEMs) derived from LIDAR are widely available and can be easily filtered to represent the bare earth surface, but due to coarse spatial resolution they have limitations in accurately representing sediment dynamics in small, mountainous watersheds. Drone-based Structure from Motion (SfM) can create very fine spatial resolution (VFSR) digital terrain models (DTMs) and orthomosaics at an appropriate scale for small watersheds, but the DTMs include vegetation that limits their utility in assessing geomorphic change. In this study we propose a workflow for evaluating geomorphic change over a time series of drone-based SfM surveys, using two separate random forest algorithms to first identify and mask vegetation from each survey, and then identify watershed characteristics associated with erosion and deposition.*

The vegetation masking workflow described in this study classifies bare earth pixels based on an RGB orthomosaic and roughness raster input. This approach outperformed a Linear Discriminant Analysis (LDA) classification method, with 98% precision and 78% recall in bare earth identification. The resulting bare earth classification masks were applied to each DTM, which were each differenced with the initial survey to create a DEM of Difference (DoD) time series.

Each DoD in the time series was then processed in a second random forest algorithm that correlated areas above the 95th percentile in geomorphic change to various watershed characteristics, such as

valley width, stream power, slope, and aspect. This correlation aims to predict areas at high risk for future geomorphic change, allowing for targeted conservation and remediation efforts. Further research will focus on validating the model with additional datasets and exploring its applicability to different geographical regions.

Floodplain analysis of extreme storm events and the inclusion of stormwater impacts on military installation floodplain modeling.

Amanda Innes, Asma Hanif
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Abstract. *Since 2016, the Center for Energy Water Sustainability (CEWS) at Colorado State University's (CSU) Department of Civil and Environmental Engineering (CEE) has been contracted by the Department of Defense (DoD), primarily the U.S. Air Force (USAF) to conduct floodplain analysis for USAF installations across the globe. This analysis is used to identify flood risk associated with extreme storm events (100-year and 500-year) and the accompanying precipitation, stream, and coastal flooding. Accurate floodplain modeling helps decision makers identify high-risk areas, prioritize mitigation measures, and reduce potential damage to critical infrastructure in order to support military planning and preparedness for USAF bases. CSU has developed a sophisticated methodology in generating comprehensive 100-year and 500-year flood maps, utilizing 2D hydraulic modeling and high-resolution elevation and land cover data. CSU has developed a methodology to integrate stormwater modeling in the previously established 2D surface modeling procedure. Surface floodplain analysis without incorporating subsurface infrastructure is often common practice by the industry and FEMA. However, including stormwater diversions improves the accuracy and reliability of the floodplain results since it accounts for redistribution of water during a storm event. There is no industry standard software that executes real 2D surface hydraulic modeling with subsurface asset integration while maintaining the resolution that can be produced by CSU-developed flood maps. The coupling of a stormwater modeling software (PCSWMM) with the established 2D hydraulic modeling software (GeoHECRAS) allows CSU to capture floodplain information more appropriately in areas of concern based on mission needs and priorities. Although this technique will provide more precision in floodplain analysis, sufficient data on a base's stormwater infrastructure is needed to accurately model its impacts. CSU aims to incorporate stormwater modeling and its effects on floodplain analysis for USAF bases and installations in highly developed, urban environments, as those bases will have more subsurface infrastructure in place.*

Bernalillo Reach of the Middle Rio Grande: Geomorphic Changes and Silvery Minnow Habitat

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Abstract. *The Middle Rio Grande is a dynamic river still responding to anthropogenic impacts from the last century, including construction of Cochiti Dam (1973), channelization, levee construction, urban development, and changes in channel maintenance activities. This study summarizes morpho-dynamic processes across 16 miles of the river in the Bernalillo Reach, which spans between Bernalillo and Albuquerque in New Mexico. We assessed spatial and temporal trends in the hydrology and channel morphology using cross-sectional channel geometry, (surveyed for 5 years between 1962 and 2012), LiDAR data (2012), aerial imagery (1918-2021), hydrology (1926-present), and suspended sediment (1955-present). Channel geometry shows 3-8 feet of channel degradation in the two upstream-most subreaches (B1 and B2) and an average decrease in channel width from 1,100 feet in 1918 to 290 feet in 2019. We used a geomorphic conceptual model to interpret channel planform and profile changes over time. An overall trend of channel degradation since the 1970s indicates that this reach has excess transport capacity. We see a similar trend over time throughout the reach whereby the channel classifies as Stage 1 (wide and braided) throughout the early- to mid-1900s and transitions towards Stages M4 and M5 (narrow, straight, and single-threaded) planform in the 1990s and 2000s. This has led to coarsening of the bed, increased flow channel conveyance, and greatly reduced floodplain connection at lower frequency flood events (>3,000 cfs), resulting in significantly reduced habitat availability for the endangered Rio Grande Silvery Minnow. Reductions in habitat availability correlate with channel narrowing and floodplain disconnection.*

Mapping and modeling widespread alteration of the land surface caused by subsidence

Ryan Smith, Fahim Hasan, Susmita Pant
Civil and Environmental Engineering, Colorado State University

Abstract. *Groundwater extraction causes roughly 17 km3 of land subsidence globally every year (Hasan et al., 2023). This massive alteration of the land surface is often pronounced in coastal areas and valleys with high water use due to agricultural irrigation or municipal water use, including the Central Valley of California, the North China Plain, Taiwan, Mexico City, and lacustrine valleys in Iran. Each of these regions has substantial areas (>10 km2) that are experiencing greater than 10 cm/year of subsidence, with as much as 9 m of total subsidence documented in the Central Valley of California (Poland et al., 1975). Here we explore the main drivers of groundwater-induced land subsidence, as well as its occurrence globally, with a particular focus on the western United States, using statistical analyses and processbased models. We also demonstrate how groundwater withdrawals can increase the risk of flooding, particularly in regions with long-term, high magnitude subsidence.*

Effective Monitoring of Large Wood Restoration in Urban Colorado Streams

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Abstract. *Urban communities will continue to experience increased frequency of natural disasters due to the impacts of climate change. The solution to mitigating these disasters is multi-pronged, one of which*

includes strengthening natural system resilience. Rivers with floodplain connection and diverse ecosystems are shown to mitigate the effects of fires, drought, and flood. There are a number of restoration practices that look to increase floodplain connection and geomorphic diversity but tend to occur either in rural areas or some urban areas within the Pacific Northwest. Few of these projects are monitored resulting in uncertainty around how process-based restoration performs long term. There are also a distinct lack of floodplain connection, large wood projects done in urban corridors within Colorado. In April 2023 the first large wood project was completed along the Cache La Poudre River in Fort Collins, Colorado. Construction included placing wood in the channel and graded floodplain to reduce mainstem velocities and increase geomorphic complexity. Considering the novelty of implementing these techniques in this ecosystem, it is important to build a systematic and effective monitoring framework by which projects can be assessed and compared. In the summer of 2023, a bathymetric and cross-sectional survey was conducted to evaluate changes in channel morphology after the first runoff season. Post construction structure from motion (SfM) imagery will be analyzed for geomorphic units and corroborated with a secondary survey conducted in November 2023. Data will be compared to pre-construction geomorphic unit analysis to determine the efficacy of the project to increase geomorphic complexity, increase habitat and thus increase ecosystem resilience. Results of this case study can be used to evaluate success and inform future projects design and monitoring methods, specifically for process-based restoration along urban Colorado streams.

Hydrologic Systems

Recent and Future Winter Recreation Opportunities in Colorado

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Abstract. *Beyond supplying water for agricultural, residential, and industrial purposes, the seasonal snowpack is an essential requirement for winter recreation, especially in mountainous areas of the Western United States. Winter sports in Colorado in particular generate billions of dollars for the local economies. Climate change is affecting the seasonal snowpack in terms of timing (e.g., peak snow water equivalent, SWE) and amount of snow. Past research that has examined the consequences of climate change on the ski industry have been dependent on coarse resolution datasets and has been limited to resorts in Europe or the Eastern United States. This research uses a 100-m, daily modeled snow dataset to examine snow conditions (snowmaking opportunities, ski days, and powder days) at nine different ski resorts in Colorado for the recent past and under a future warming scenario.*

For snowmaking, increased wet bulb temperature (the temperature to which air can be cooled at constant pressure by water evaporating) in the future will result in an increase in the number of days that are too warm to make snow and a decrease in the number of days where conditions produce ideal snow. Under future warming, lower elevation (< 3000 m) resorts will have fewer ski days (snow depth greater than 50 cm) throughout the year in a high snow year, but early season ski days will increase in a low snow year. Early and late season powder days (considered to be ideal conditions for snow sports) will

decrease in a warming scenario, particularly at lower elevations, whereas mid-season and mid- to upper-elevations (> 3000 m) powder days will increase. These findings have important implications for those who manage ski resorts and participant in winter recreation in Colorado. Future research should incorporate an interdisciplinary approach to quantify these changes in physical processes in terms of societal and economic implications.

Exploring how Soil Moisture and Strength Vary with Soil, Vegetation, and Topography Within a SMAP Grid Cell

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Civil and Environmental Engineering, Colorado State University

Abstract. *Assessments of off-road vehicle mobility require fine resolution (~10 m) estimates of soil moisture and strength across the terrain of interest. Soil moisture estimates are often produced from soil moisture downscaling procedures using microwave satellite data, and soil strength can be estimated based on downscaled soil moisture and soil composition. Many soil moisture downscaling procedures assume the relationships between soil moisture, soil composition, vegetation cover, and topographic attributes are consistent across each microwave satellite grid cell (~9 km). The objective of this study is to explore how these relationships vary within a SMAP grid. Soil moisture and strength measurements were collected on 10 dates at 86 sites divided between four regions within a 9-km SMAP grid cell in northern Colorado. Soil attributes were characterized using laboratory methods and pedotransfer functions. Vegetation and topography were characterized using remote sensing data. Pearson correlation analyses in the four regions indicate that the relationships of both soil moisture and strength with regional characteristics (soil composition, vegetation cover, and topography) can vary substantially within a SMAP grid cell extent. These findings suggest that soil moisture and soil strength modeling procedures may have improved performance when using spatially variable parameters across a downscaling extent.*

Estimating Soil Moisture at High Spatial Resolutions Using Meteorological Variables at a Study Region in Northern Colorado

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Civil & Environmental Engineering, Colorado State University

Abstract. *Soil moisture is a key variable for monitoring droughts, forecasting wildfire ignition, optimizing crop productivity, managing grazing lands, and various other applications. While satellites equipped with passive microwave sensors such as NASA's SMAP satellite provide soil moisture estimates for most of the Earth almost daily, the spatial resolution of these soil moisture patterns is notably coarse (9 km grid cells or larger), limiting their utility for many applications. Moreover, these satellites have finite lifespans and may experience data interruptions due to instrument failure. The objective of this study is to develop and* *evaluate a procedure for soil moisture mapping that generates fine-resolution soil moisture maps (10 m grid cells) when satellite data feeds are interrupted. In this procedure, coarse-resolution (4 km) soil moisture estimates are initially generated by calibrating an antecedent precipitation index (API) model to the time series of NASA-USDA enhanced SMAP soil moisture data. This API model also considers recent reference crop evapotranspiration rates. Subsequently, the API-based coarse-resolution sol moisture estimates are downscaled to 10 m resolution using fine-resolution vegetation cover data from Sentinel-2 and topographic data from the USGS National Elevation Dataset. The effectiveness of this procedure is assessed using a field dataset obtained from the 4000-ha Maxwell Ranch, located in the mountains-plains transition region of north-central Colorado. The vegetation primarily consists of herbaceous cover with scattered shrubs and pine trees. Soil moisture measurements (ranging from 0 to 50 mm) were recorded using portable HydraProbes at 86 locations on 10 dates during the summer of 2022. Overall, the proposed soil moisture estimation method effectively captures a significant portion of the spatial variation observed in the soil moisture measurements and consistently outperforms the SMAP input.*

Incorporating Vehicle Trails in Soil Moisture Downscaling for Mobility Assessments

Holly E. Proulx[1], Jeffrey D. Niemann[1*], Joseph Scalia[1], Samantha C. Fischer [1], Matthew D. Bullock[1], Boran Kim[1], and Timothy R. Green[2]

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[2] Center for Agricultural Resources Research, Agricultural Research Service, USDA, USA

Abstract. *Vehicle mobility in many applications (including forestry, recreation, military, and agriculture) relies on fine resolution soil moisture maps (10-30 m). Soil moisture can be obtained from satellite remote sensing products, but the coarse spatial resolution of these products is inadequate for many practical applications. Downscaling methods, such as the Equilibrium Moisture from Topography Plus Vegetation and Soil (EMT+VS) model, are used to estimate fine resolution soil moisture from a coarse resolution input. However, current downscaling models, including the EMT+VS model, lack explicit consideration for vehicle trails. In this study, the EMT+VS model is generalized to estimate soil moisture on vehicle trails. The trails are incorporated using adjustments to the porosity and vegetation cover, which are both hypothesized to be lower on trails due to vehicle traffic. Data were collected from a 4,000-ha cattle ranch in the foothills of Northern Colorado and used to test the generalized EMT+VS model. This dataset consists of porosity and soil moisture observations at paired trail and landscape locations along with unpaired landscape locations. Soil moisture data were collected on six dates in Summer 2023. The porosity of trail locations had an average of 86% of the paired landscape locations. The soil moisture at trail locations was on average 77-102% of the paired landscape locations. Adjusting the vegetation and porosity at trail locations improved the root mean square errors of the EMT+VS model's soil moisture estimates and reduced the model's tendency to overpredict soil moisture on trails.*

The Enhanced Flow Duration Curve

Richard Koehler, PhD, PH, CEO

Water Resources Division, Visual Data Analytics, LLC, USA

Abstract. *Flow duration curves (FDCs) are a common hydrologic analysis technique examining the cumulative distribution of a streamflow record. Yet despite multiple variations developed over the past 100 years, FDCs have never been able to display or quantify day-to-day streamflow information…until now. Presented is a way to create "enhanced" flow duration curves (eFDCs) simply by adding the lag (1) autocorrelation scatterplot to the basic FDC. This produces a graphic showing the daily streamflow properties of magnitude, frequency, duration, timing, day-to-day discharge change, and temporal autocorrelation across different flow ranges. Also displayed are graphical regions of flow increases (dQ/dt > 0), decreases (dQ/dt < 0) , or persistent flow (dQ/dt = 0). The result is a set of eFDCs which can provide detailed historic streamflow summaries, provide guidance for restoration efforts, monitor hydrologic alterations, quantify streamflow change on a day-to-day basis, or provide a detailed model analysis technique.*

Student Showcase & Competition

Assessing streamflow and groundwater fluxes in the Upper Colorado River Basin using the SWAT+gwflow model

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Abstract. The Upper Colorado River Basin (UCRB) contributes to 90% of the streamflow in the Colorado River, with over half derived from groundwater discharge into streams. However, persistent drought, compounded by anticipated climate change, necessitates accurate hydrological forecasting for effective water resource management. We utilize the Soil and Water Assessment Tool Plus (SWAT+) model, augmented with the *gwflow* module, to conduct physically based, spatially distributed surface water and groundwater modeling across 60 8-digit watersheds in the UCRB from 2000 to 2015. Our approach simulates surface and subsurface flows, groundwater-surface water interactions, reservoir dynamics, and various hydrological fluxes, including floodplain interactions, agricultural groundwater pumping, and canal seepage. Each cultivated field is treated as a distinct hydrological response unit, with its unique irrigation source, i.e., stream, aquifer, or reservoir. Results reveal significant spatial heterogeneity and varied watershed responses across the basin to changing climate variables. These findings serve as a foundation for predicting future streamflows, groundwater levels and storage, and fluxes under different climate change scenarios. Our findings will guide adaptive water management strategies, including conservation efforts, groundwater abstraction and recharge initiatives, and the determination of environmental flow requirements. This study underscores the importance of integrating surface water and groundwater modeling for informed decision-making and the formulation of sustainable water management policies in the face of climate change challenges in the UCRB.

Using Remote Sensing Data to Highlight Salinization Patterns in the South Platte River Basin of Colorado

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Civil and Environmental Engineering, Colorado State University

Abstract. *The land within the Colorado (CO) South Platte River Basin (SPRB) is primarily used for agriculture. Like many regions of the world, intensive irrigated agriculture in the SPRB seems to be leading to an increase in soil and water salinity. Increases in soil and water salinity negatively affect the crops by reducing yields. To understand the changes in salinity in the CO SPRB, and link them to contributing factors, multispectral remote sensing data are being utilized. Approximately 20 years of remote sensing data from Landsat 5, 7, 8, and 9 satellites are being processed in GIS to calculate the soil saturation and extract electrical conductivity (ECe, dS/m) – a proxy for salinity. Since the primary focus is irrigated agricultural land, only data from the crop growing season (March – October) are being included in the study. In addition, actual evapotranspiration rate estimates for crops will assist in understanding crop water stress and yield throughout the SPRB. Further, monitoring wells have been placed in selected agricultural fields in the CO SRPB to understand fluctuations in the water table depth, salinity, and temperature and assist in the determination of contributing factors to the salinity issue. Field surveys of ECe, using electromagnetic inductance, will be used to evaluate the accuracy of produced ECe maps. Generated ECe maps will inform where to install future monitoring wells and field surveys to continue understanding the salinity process and to improve the calibration of ECe models.*

Mitigating salinity for improved watershed management and crop production

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Abstract. *This study explores the impacts of on-farm irrigation water desalination on the environment and agricultural sustainability in a semi-arid watershed. The purpose is to assess how varying desalination intensities affect hydrology, soil and water quality, and crop yield. We apply a comprehensive modeling approach using the SWAT-MODFLOW-Salt coupled surface-subsurface flow and salt reactive transport model to the Lower Arkansas River Basin. We found that increased desalination intensity reduces surface runoff and increases evapotranspiration rates. Notably, desalination significantly reduces salt ion concentrations in soil (up to 56%), which could positively impact soil health and plant productivity. In-stream salt ion concentrations also decrease, with up to 16% reductions seen for some salt ions. More intensive desalination efforts yielded greater reductions in Total Dissolved Solids (TDS) concentrations in groundwater highlighting improvements in groundwater quality. Crop yield analyses show increases in crop yield with increasing desalination intensity. Alfalfa is seen as the most responsive crop, showing a remarkable 18% increase in yield with 100% salt ion removal from irrigation water. These findings have implications for food security and agricultural sustainability, particularly in semi-arid and arid regions facing water scarcity and salinity issues. For future research, socio-economic analysis is needed to evaluate the economic viability and societal implications of desalination in agriculture, providing a holistic understanding of its potential benefits. This study contributes valuable*

insights into the impacts of desalination on agriculture and the environment, underscoring its potential as a sustainable water resource management strategy.

An interdisciplinary evaluation of regenerative agriculture in the Midwest

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Abstract. *Agricultural management practices that fall under the umbrella of regenerative agriculture, including but not limited to no-till planting, cover crops, diversified rotations, nutrient management, and edge-of-field plantings, are touted as a win-win strategy to increase soil organic carbon (SOC) stocks and improve agronomic outcomes on croplands. The most substantial benefits of regenerative agriculture are realized when practices are adopted on as many acres as possible while addressing leakage (i.e., further land use conversion) and permanence (i.e., temporary practice adoption) concerns. Studies evaluating the agroecological benefits of regenerative agriculture are mostly carried out on long-term experiments under controlled conditions that fail to account for the diversity of conditions encountered on real commercial farms and/or factors impacting producer's yearly management decisions. Systems-level, on-farm measurements integrating biogeochemical and socio-economic analysis are needed to understand both the agroecological impacts of regenerative practice use and the socio-economic variables impacting farmers decision to adopt these practices. We conducted an "across-the-fence" study of neighboring corn/soybean farms in the upper Midwest using one of two management systems: 1) no-till + cover crops (regenerative) and 2) conventional tillage without cover crops to compare the impacts of management system on soil C stock, GHG footprint, and agronomic outcomes. Ten years of detailed management data were obtained from farmers involved in the study, which we use to evaluate economic outcomes associated with each management system. Further, we collected social network analysis survey data from 38 farmers across the study region to understand how their social connections and information networks influence their decision to adopt regenerative practices. Our systems-level approach enables analysis of factors impacting RA practice adoption and success, as well as impacts on soil C storage and stability in cropland soils.*

The Future of Sustainable Food: Evaluating the Effect of Dynamic Life Cycle Assessment Methods on Agricultural Environmental Outcomes

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Abstract. *In the coming decades, agricultural systems will face rapid and profound change. Responding to emissions targets and net-zero initiatives, new methods and technologies will emerge to reduce the sector's greenhouse gas (GHG) emissions. At the same time, already locked-in global warming will transform the climate, altering weather patterns and influencing outcomes like yield and irrigation demand. To prepare for this evolving future, stakeholders will need tools to understand not only how systems perform now, but how they will perform over many years. One such systems-modeling tool, life cycle assessment (LCA), calculates environmental impacts like GHG emissions and water footprint; however, standard LCA is static, capturing a "snapshot" that reflects the current data available. Dynamic LCA (DLCA) addresses this shortcoming by incorporating temporal resolution into different aspects of the changing natural and technological systems that underly production.*

This study expands on previous LCA work with outdoor lettuce crop modeling by incorporating two DLCA methods: dynamic inventory modeling and dynamic process modeling. Dynamic inventory modeling considers the mix of energy and chemical resources that support a production system: in this study, a decarbonizing electrical grid, renewable resources replacing diesel, and green ammonia-based fertilizers are considered. Meanwhile, this study's dynamic process model considers how warmer weather under climate change scenarios may affect crop yield and irrigation demands, changing the associated environmental impacts.

Preliminary results for dynamic inventory modeling suggests that the deployment of renewable energy in heavy machinery can have a significant impact on global warming outcome (up to 20% reduction), particularly if electrification is combined with renewable generation. Green ammonia fertilizer also enables a reduction in GHG emissions, but to a lesser extent (12% reduction). Additionally, ongoing dynamic process modeling will examine expected climate change effects in 2050 on conventional lettuce cultivation sites in California and Arizona, including a consideration of how higher temperatures and changing precipitation may affect irrigation demand. The effects of this dynamic process model on LCA results will then be compared to the different dynamic inventory effects, providing food-energy-water system stakeholders with insights into what technologies and strategies will have the greatest future impact.

Beyond the Barnyard: Optimizing Nutrient Efficiency in Colorado's Dairy Production Through Precision Manure Management with NIRS Technology

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Abstract. *Manure fertilizer from dairy production creates environmental impacts on many levels, but of specific concern are the environmental impacts from nutrient losses that occur from application of manure fertilizers. In Colorado, current gaps exist in managing nutrients from livestock manure systems, instating a need for evaluating how to address these gaps and efforts to mitigate them. With my research, I aim to do so through the use of near-infrared-reflectance (NIRS) technology. The HarvestLab3000 by John Deere is a commercial NIRS sensor available to manure handlers and livestock producers. It can be used to predict manure dry matter, organic matter, total nitrogen, ammonium, phosphorus, and potassium. This system provides on-the-go nutrient analysis of manure fertilizers to*

adjust application rates in real time and better meet plant and soil needs. The driving question behind my study is how can using manure sensors improve the environmental impacts from manure fertilizers in Colorado? To answer this question I am using a mixed methods approach that couples quantitative and qualitative methods of data collection and analysis. The objectives of my study are 1) compare ammonia losses from manure application with and without NIR manure sensors with those of the most common CO manure management practices, 2) evaluate the impact of manure application with and without NIR manure sensors on soil N dynamics and key soil health parameters (e.g., bulk density, soil organic carbon, aggregate stability, electrical conductivity, and soil microbial communities), 3) compare the impact of manure application with and without manure sensors on crop yield and quality, 4) complete an economic analysis of dairy manure application with and without the use of manure sensors, 5) hold focus groups with different stakeholder groups in Colorado necessary to successful adoption of more sustainable nutrient management practices, and 6) work with collaborative groups in at the academic and governmental level to establish a manure nutrient shed in Northern Colorado. Ultimately, my aim with this research is to aid producers in honoring their roles as stewards of the lands and environment while supporting their economic and production goals. The results of this study will help drive decisions that support industry needs while facing changes to environmental regulation.

High-Resolution Future Land Use Forecasting by Integrating Spatial Deep Learning and Temporal Regression Techniques

Mohamed F. Mahmoud, Mazdak Arabi
Department of Civil and Environmental Engineering, Colorado State University

Abstract. *High-resolution land use maps are essential for many applications in fields such as hydrology, water resource management, and urban planning that rely on future scenario modeling. However, predicting future land use is complex due to the interacting drivers of change over time. This study develops a novel method to forecast high-resolution land use maps by combining the strengths of convolutional long shortterm memory (ConvLSTM) neural networks and machine learning regression techniques. The ConvLSTM model is trained on eight historical land use maps to learn intrinsic spatial patterns and predict the likelihood of each pixel belonging to different land use categories. This captures the spatial dependencies in the data. A separate regression model then correlates the percentages of land use categories within a given area with its population over different years. By analyzing these trends, the model can forecast future land use percentages based on anticipated population, accounting for temporal changes. By combining the outputs of the ConvLSTM and regression models, high-resolution land use maps are constructed that not only depict probable future scenarios but also incorporate population-driven changes in land use. The resulting land use maps will provide critical information for hydrology, water resource management, urban planning, and environmental management applications that require realistic future land use scenarios.*

Forest to Faucets – A Hands-On STEM Kit Examining Hillslope Hydrology and Transmountain Diversions

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Abstract. *Colorado relies heavily on its freshwater resources. From drinking water supply and agriculture to recreation and ecologic function, every drop of water is important for in- and out-of-state users. While 90% of Colorado's residents live east of the Continental Divide, 80% of the state's streamflow is on the West Slope. Residents of Colorado should be aware of this discrepancy, in addition to understanding where their water comes from and the basic hydrologic processes that govern its movement. We have designed the Forest to Faucets STEM Kit to expose middle and high school students, and even community stakeholders, to hillslope hydrology and transmountain diversions. The goal of the kit is to guide students through an engaging, one-hour-long experiment through the lens of a hydrologist. They will work in pairs and follow a twenty-page illustrated booklet.*

In the first half of the kit, students will explore the effects of disturbances in headwater areas on streamflow generation and rainfall partitioning. Using a laser-cut hillslope cross-section model, they will apply water to simulated old-growth, clear-cut, and burned forests and examine the separation of rainfall into a groundwater well and an overland flow well. They will practice measuring water depth, recording information, and graphing hydrologic data.

In the second half, students will zoom out and investigate precipitation patterns across the state of Colorado, including the concepts of orographic lift and the Continental Divide. They will apply rainfall to a 3-D printed topographic model of Grand Lake, Estes Park, and the Alva B. Adams tunnel, a critical piece of the Colorado-Big Thompson Project. Furthermore, students will quantify the relative amount of water on Colorado's West and East slopes when the transmountain tunnel is closed and open. Ultimately, the kit will help students better understand Colorado's water disparities and solutions.

Once the kit is completed, it will become part of the Education and Outreach Center's STEM Kit Lending Library. Teachers around the state of Colorado will be able to check out a set of fifteen kits, enough for thirty students, at no cost.

Investigating potential recharge to the Denver Basin Aquifer System from the Front Range Mountain Block using water stable isotope tracers

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Abstract. *The Denver Basin Aquifer System (DBAS) is an important groundwater resource for Front Range communities and is increasingly so as populations grow and surface water supplies remain limited. As demand on the DBAS increases, it is necessary to better constrain aquifer recharge mechanisms to enable sustainable use of this resource. In other sedimentary basin aquifer systems, mountain front recharge has been shown to be a significant contributor to local basin groundwater recharge. In the DBAS, inputs from the mountain block are poorly understood, and previous numerical models have treated large segments of the mountain-front boundary as impermeable. However, there exist potential connections between the mountain block and the DBAS, either by direct contact of permeable units,*

which would facilitate underflow recharge into the basin, or by surface water infiltration to the aquifer units where they outcrop near the mountain front. To observe relationships between mountain block water and DBAS water, we measured the d^2H and $d^{18}O$ of surface waters, ground waters, and precipitation in and around the Front Range. Using these water stable isotope tracers, we seek to understand the unique signature of mountain-block water and compare these tracers with DBAS water stable isotope data. We hypothesize that the low d^2H and $d^{18}O$ typical of the high-elevation Front Range will result in DBAS groundwater d^2H and $d^{18}O$ values that are lower than basinal streams and precipitation. Our initial results indicate that streams originating in the Front Range provide recharge via downward seepage into the basin aquifers, rather than direct recharge from the mountain block aquifer to DBAS units. These results help to better inform models of aquifer recharge and to promote sustainable use of DBAS water resources.

Examining Annual Peak Snow Water Equivalent (SWE) and the Sensitivity of SWE to Climate Change in Colorado.

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Department of Civil, Environmental and Architectural Engineering, University of Boulder Colorado

Abstract. *Snowpack is an essential source of water in the Western United States, particularly in semiarid, mountainous regions. Throughout the winter season, snow accumulates at higher elevations, creating a natural reservoir of water that gradually releases during the spring. This annual cycle is important for water supply forecasting as it directly influences the availability and distribution of water in the region. Decreased snowfall and milder winter temperatures are anticipated outcomes of climate change. These changes alter the traditional timeline of winter snowpack behavior, which threatens future water security by shifting the peak date of snowpack earlier and accelerating the ablation processes. In this study, a statistical framework centered on multivariate regression is used to try to capture trends in the drivers of mountain-snowpack in Colorado. The primary goal is to assess the ability of a data-driven model to quantify the sensitivity of snowpack to various predictors, in a way that maintains simplicity and interpretability. For the period 1985-2020, the relationship between the snow water equivalent (SWE) on April 1st, and the following predictors is examined: seasonally accumulated precipitation, temperature, seasonal radiative flux, and elevation. Historical observations are taken from high resolution gridded datasets including the UCLA Snow Reanalysis (500m) and DAYMET (1000 m) products. Multiple snowdominated basins in Colorado, chosen on the basis of being snowmelt-dominated, are used to build a data-driven model. The strength and sensitivity of the relationships between SWE and the predictor variables are assessed using leave-one-out (LOOCV) jackknifing, in conjunction with a sensitivity analysis. This approach aims to evaluate how changes in predictor variables influence variations in snow water equivalent (SWE) and to identify climate-influenced snowpack thresholds, which may be useful for improving future water supply predictions.*

Capturing the Spatio-Temporal Variability of Groundwater Pumping Leveraging Public Domain Data and Machine Learning: An Assessment of Machine Learning Application for Data Scare Regions

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[6]University of Kansas, USA

Abstract. *Groundwater level decline has increased globally threatening major aquifer systems' sustainable supply of water for irrigated crop production. Anthropogenic driven groundwater depletion is mainly attributed to agriculture. Groundwater pumping data collection is very limited around the world due to lack of policies. Future groundwater sustainability depends on monitoring of groundwater pumping. Machine learning has been used in some areas to estimate withdrawals, but data paucity has limited wider application of these approaches. The reliability of outcomes from machine learning analysis heavily relies on available data quality and quantity. Few studies have used machine learning techniques to study groundwater withdrawals in regions where data is abundant. Nevertheless, the data quality and quantity requirements to produce a robust estimate of groundwater withdrawals are not well studied. In this study, we built point scale groundwater withdrawal prediction machine learning models using a Random Forest algorithm. Data is split into training and testing where the training data is used to build the model and assess the model's ability by comparing the model prediction values with the testing data. The point scale prediction values are aggregated over a 2 km by 2 km grid. We evaluated a combination of different training and testing split to understand model performance variability. We performed the analysis in the Northwestern Kansas Groundwater Management District 4. The model used public domain remote sensing, land surface model output, and hydrogeological variables for the period from 2008 – 2020. We observed that a model trained on 10 % of the total available data showed coefficient of determination (R2) values of 0.96 and 0.77 for training and testing, respectively. Knowledge of crop irrigation area enabled estimate aggregation over a grid, and we find that aggregation of estimates improved the spatial and temporal groundwater withdrawals estimates. The result of this study has a significant implication for effective groundwater management in regions where there is limited data.*

Point of No Return: Identifying Critical Thresholds for Plant Functioning and Recovery from Drought

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[1]Water Management and Systems Research Unit, USDA-ARS
[2]Department of Forest and Rangeland Stewardship, Colorado State University, USA
[3]Department of Ecology and Evolutionary Biology, University of Colorado, USDA

Abstract. *The efficient transport of water to the sites of photosynthesis and other plant tissues is essential for the processes of carbon assimilation, growth, and maintenance of turgor. Water transport*

in plants occurs through xylem conduits which operate under negative pressure. As a consequence of water stress, the tension within the xylem can exceed critical thresholds which can result in embolism, the loss of function by the replacement of liquid with gas. Embolism formation represents a physiological weakness in plants, leading to permanent damage, particularly following drought. Due to the complexity of observing xylem functioning in crop species, artifacts from invasive methods likely skew our interpretations of when hydraulic systems fail. Our study focuses on pinpointing the stages of embolism occurrence and exploring the potential for refilling and repair in intact plants by utilizing non-invasive methods of optical vulnerability. We quantify leaf embolism and leaf shrinkage in the canopy leaves of maize during a near-fatal dry-down in a controlled environment. Continuous monitoring of gas exchange, chlorophyll fluorescence, and whole plant transpiration allows us to present the sequence of physiological failures leading to leaf mortality and senescence. Additionally, we find that recovery from extreme water stress is highly dependent on the accumulation of embolism within the xylem. By understanding the relationships between embolism occurrence, plant physiology, and agricultural practices, we aim to enhance crop productivity and resilience in the face of evolving environmental challenges.

Sunflower adaptations and resilience to embolism in drought conditions

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[1] Department of Molecular, Cellular & Developmental Biology, University of Colorado Boulder, USA
[2] Department of Ecology & Evolutionary Biology, University of Colorado Boulder, USA
[3] Water Management Research Unit, USDA-ARS, USA

Our research delves into the physiological impacts of drought on plants, considering the intricate biological processes underlying photosynthesis and transpiration. Water transport in plants, crucial for functions like CO2 assimilation and turgor maintenance, occurs through xylem conduits under significant negative pressure. However, under drought conditions, embolism formation in xylem tissues can impede water transport to sites of photosynthesis, affecting plant productivity and survival. Climate change-induced extreme environments pose significant risks to crop yield and survival. Sunflowers, a staple in the diets of numerous cultures and renowned for their high oil content, serve as an ideal subject as they vary markedly across, as well as within, genotypes, enabling them to thrive in different environments. Our interdisciplinary approach combines anatomical, physiological, and genomic analyses to study how sunflowers respond to drought stress and the potential for adaptation to extreme environments. Through trait scoring and genomic bioinformatics, we aim to identify genetic markers associated with adaptive traits for embolism resistance or refilling and predict plant responses to drought and varying levels of stress. Additionally, our research uses non-destructive assessments, including turgor loss analysis, continuous leaf imaging, and µ-CT scans of xylem tissues to detect embolism formation. By correlating genetic and physiological data, we seek to uncover genes and alleles associated with plant responses to environmental stressors. This integrated approach will deepen our understanding of sunflower resilience to drought and aid in the development or screening of crop varieties suitable for different conditions, contributing to global food security initiatives.

Applied Hydrogeophysics for Improved Aquifer Characterization

Julianne Robinson, Jiawei Li, Ryan Smith
Department of Civil and Environmental Engineering, Colorado State University, USA

Abstract. *There is a growing need to characterize and monitor groundwater resources as the climate changes and water use increases, particularly in regions of the world that depend on groundwater for irrigated agriculture and domestic water supply. Geophysical measurement methods like time-domain electromagnetic surveys can address the need for cost-effective, high-resolution hydrostratigraphic data collection with greater spatial and temporal coverage than direct-sampling methods. Applying geophysical data to improve conceptual groundwater models requires integration with other forms of data like lithology from well drillers' logs. This project analyzed hydrogeological characteristics in the Parowan Valley in Utah by interpolating geophysical datasets collected using towed time-domain electromagnetic (tTEM) surveys with lithology data from well logs. Co-kriging, a form of spatial interpolation, was used to conduct the analysis. Geophysical data were converted from resistivity to lithology through a rock-physics transform process prior to interpolation. Higher variance was observed in kriging results relying on geophysical data alone, compared to the combined datasets. Reliability of resistivity data as an indicator for lithological properties relies on the accuracy of the rock-physics transform, which was affected by varying levels of saturation in the Parowan Valley. Results of this analysis show that geophysical data can inform conceptual models through greater spatial and temporal coverage compared to direct-sampling measurements but must be used in conjunction with other types of data and rely on an understanding and consideration of site-specific characteristics for accurate interpretation. Geophysical datasets collected through time-domain electromagnetics can serve as an important addition to other forms of data to inform water management in the Parowan Valley and other arid and semi-arid regions dependent on groundwater.*

Groundwater Storage Trends in San Luis Valley, CO: Combined In-situ and Remote Sensing Approach

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[2]Department of Geosciences and Geological and Petroleum Engineering, Missouri University of Science and Technology, USA
[3]Department of Computer Science, University of Colorado Boulder, USA

Abstract. *Groundwater is a critical freshwater source, but climate change-induced shifts in precipitation patterns and extreme droughts are leading to increased groundwater use in agriculture and municipalities. This overexploitation depletes groundwater sources worldwide, particularly in arid and semiarid regions. To ensure sustainable groundwater management, we need accurate estimations and a clear understanding of groundwater storage changes and their drivers. However, this is challenging due to limited spatiotemporal in-situ measurements and uncertainties in storativity estimates. To address this, we combined in-situ water level, pumping, and diversion data with Interferometric Synthetic Aperture Radar (InSAR) satellite data to estimate aquifer properties and groundwater storage changes. We also used gridded remote sensing products (such as PRISM precipitation and OpenET* *evapotranspiration) to assess the water balance for comparison. Our study focused on the San Luis Valley, Colorado, an agriculturally dependent region with quality temporal and spatial data on withdrawals and water levels. We estimated storativity values for subdistricts based on the relationship between pumping and water levels. Our study revealed a declining trend in groundwater storage, highlighting the need for immediate action to ensure the long-term stability of aquifers. This research provides water managers with valuable insights into how to stabilize groundwater storage by maintaining a balance between recharge rates and groundwater extraction. The knowledge gained from this study can be transferrable to regions with similar climatic and geological conditions.*

Estimation of 52 years of groundwater level through Ordinary Kriging in the San Joaquin Valley, California

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Abstract. *The San Joaquin Valley, one of the most agriculturally significant areas of California, has experienced large groundwater withdrawal. Despite a dense network of wells, there are notable gaps in the long-term data on groundwater levels. This study provides estimates of groundwater levels from 1971 to 2023 over a vast area of the valley. It uses two main tools: Kriging, a geostatistical method, and a computational technique similar to SBAS (Small Baseline Subset), which is commonly employed in InSAR remote sensing to analyze surface deformation. Available groundwater level data were filtered to include only spring season readings. We then calculated the change in groundwater level for every 1, 2, 5, 10, 15, and 20 years from 1971 to 2023, applying Kriging to each interval across the entire study area. We then employed a novel technique that utilizes groundwater data from overlapping years to determine the annual changes in groundwater levels, ensuring the best fit with observed measurements for each time interval. Our findings indicate a general decrease in groundwater levels, with the maximum drop reaching up to 167 feet from 1971 to 2023. The average decrease was approximately 57.75 feet. To verify the accuracy of our analytical methods, data from 13 high-quality wells were excluded from the primary analysis. We subsequently evaluated the changes in groundwater levels in these wells. This resulted in R^2 value of 0.775, RMSE of 18.0892, MAE of 13.14, ME of -0.568, and NRMSE of 0.0829. This study revealed that the fall in groundwater table has been compounded by the effect of drought occurring at various intervals in the 52-year time span, which increased the reliance on groundwater for irrigation and reduced recharge.*

Characterization of the Relationship between Water Use Intensity and Land Use Planning

Mahshid Mohammad Zadeh, Sybil Sharvelle, Mazdak Arabi
Department: Civil and Environmental Engineering

Abstract. *City planners face myriad challenges in providing adequate and sustainable water supply for growing populations in a rapidly changing world. Typically, increasing water demands are addressed by building new water supply infrastructure systems and treatment facilities. However, recent studies show* *that climate change and extremes may undermine the reliability, resiliency, and affordability of water supply infrastructure. Thus, water demand management, including conservation and recycling, are increasingly relied upon to reduce vulnerabilities to water shortage. This study characterizes the relationship between water use intensity and land use practices in cities within the Front Range of Colorado. Specifically, a cloud-based web tool entitled Polaris is developed that reconciles water consumption data and urban development patterns to provide robust water use projections at the city to regional scales. The tool calculates various water use intensity measures and land use metrics and establishes the patterns in water consumption by land use and economic sectors in time and space. Through robust statistical analysis of historical patterns, Polaris provides water use projections by population and land development while offering capacities to develop scenarios for water use reduction goals by end-use water management in indoor residential, outdoor, and commercial/institutional/industrial (CII) sectors. Furthermore, the tool provides capacities for regional assessment of water use patterns by generalizing land use patterns from multiple water utilities, land use planning, and municipal jurisdiction. The tool has been tested on water use data collected from four different water utilities within Colorado. This presentation discusses how water consumption and land use metrics quantified within the Polaris tool can be used to make sound water supply decisions at various scales, from city neighborhoods to regional scales, using the results from the analysis of the water utilities data.*

High-Resolution Future Land Use Forecasting by Integrating Spatial Deep Learning and Temporal Regression Techniques

Mohamed F. Mahmoud, Mazdak Arabi
Department of Civil and Environmental Engineering, Colorado State University

Abstract. *High-resolution land use maps are essential for many applications in fields such as hydrology, water resource management, and urban planning that rely on future scenario modeling. However, predicting future land use is complex due to the interacting drivers of change over time. This study develops a novel method to forecast high-resolution land use maps by combining the strengths of convolutional long shortterm memory (ConvLSTM) neural networks and machine learning regression techniques. The ConvLSTM model is trained on eight historical land use maps to learn intrinsic spatial patterns and predict the likelihood of each pixel belonging to different land use categories. This captures the spatial dependencies in the data. A separate regression model then correlates the percentages of land use categories within a given area with its population over different years. By analyzing these trends, the model can forecast future land use percentages based on anticipated population, accounting for temporal changes. By combining the outputs of the ConvLSTM and regression models, high-resolution land use maps are constructed that not only depict probable future scenarios but also incorporate population-driven changes in land use. The resulting land use maps will provide critical information for hydrology, water resource management, urban planning, and environmental management applications that require realistic future land use scenarios.*

Urban Water Systems

Characterization of the Relationship between Water Use Intensity and Land Use Planning

Mahshid Mohammad Zadeh, Sybil Sharvelle, Mazdak Arabi
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Assessing Sustainable Urban Stormwater Management: A Comparative Study of Green Roofs and Detention Basins Strategies in Three U.S. Cities

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Abstract. *In 2022, floods caused nearly 2.8 billion U.S. dollars worth of property and crop damage across the United States, and 127 people die annually from flood hazards. Impervious city surfaces do not allow rain or snowmelt to infiltrate onsite, directing this runoff to storm conduits. Therefore, to protect the surface and underground watersheds from serious harm, it is necessary to implement intentional infrastructures that allow interception and treatment of water in urban areas. We evaluated three cities in three of the midcontent EPA ecoregions: Denver, Colorado, High Plains; Omaha, Nebraska, Temperate Prairies; and Dallas, Texas, Semi-Arid. Each has different climate and ecoregion classification characteristics, but share similar challenges to stormwater management. City boundaries, land cover, elevation models, and building footprints were collected from city open GIS data servers, the Multi-Resolution Land Characteristic Consortium (MRLC) and the U.S. Geologic Survey (USGS). We completed 288 predictive modeling scenarios to compare proposed percentages of impervious surfaces for green roofs (GR) and detention basins (DB) with climate change predictions using CLASIC - a screening tool that utilizes a lifecycle cost framework to inform decisions about stormwater infrastructure. We found that the costs of implementing GR are always higher than DB because GR is still an emerging technology in the U.S., with developing incentives and demand. As GR does not consider the capture of runoff from adjacent, impervious surfaces, the area needed to capture the same volume of water is larger than for DB. GR reduced more runoff than DB in Denver, while Dallas and Omaha had opposite results. All three cities presented increased evapotranspiration when GR were implemented and increased infiltration with DB. In Denver, GR had a greater contaminant load reduction than in DB. In Dallas and Omaha, GR had a greater reduction of total suspended solids and smaller total phosphorus reduction than DB, while total nitrogen reduction is close to both technologies. Finally, GR presented a more significant indicator for social, economic, and environmental benefits. By intentionally integrating green infrastructure, we can prevent flooding, provide additional ecosystem services, and improve social and climate justice for urban residents.*

Development of a crystal scaffold within a sampling device for continuous capture of SARS-CoV-2 virions from water

Alec Jones,[1] Semin Barlak,[2] Susan De Long,[2] Carol Wilusz,[3] John Mizia,[4] Matt Willman,[4] Christopher Snow[1,5]
[1]School of Biomedical Engineering, [2]Department of Civil and Environmental Engineering, [3]Department of Microbiology, Immunology, and Pathology, [4]Department of Mechanical Engineering, [5]School of Chemical and Biological Engineering, Colorado State University, USA

Abstract: *Surveillance and detection of pathogens in water and wastewater has been deployed nationwide since the SARS-CoV2 pandemic. However, the utility and broad application of this approach is limited by sensitivity and the difficulty of collecting and transporting biohazardous samples from sewers and remote locations. Any upstream method that can concentrate very small quantities of virus from a large volume of sample in situ (prior to transportation) can increase sensitivity and at the same time reduce the risk to personnel.*

We have engineered porous protein microcrystals that have an inherent affinity for nucleic acids to specifically bind and capture viruses. As a proof of concept, we have shown that biotinylated crystals are able to selectively capture streptavidin-coated microspheres (viral surrogates). Furthermore, we have demonstrated successful installation of peptides that mimic ACE2 (the target receptor for SARS-CoV-2) onto the crystals. We observed binding of Texas Red-labeled SARS-CoV-2 virions to the crystals. We also recovered the viral genome following lysis and detected it via digital RT-PCR.

The microcrystals will be integrated into a novel pump housing and upstream tangential flow filter to allow continuous scavenging and concentration of virus from several liters or more of wastewater, or any environmental water source, over a 24-hour period. This innovative device can be easily installed at a sewer access point or in remote locations and will allow workers to recover the sample with minimal exposure to pathogens.