41st Annual AGU Hydrology Days

March 30-31, 2021

ONE WATER
SOLUTIONS INSTITUTE

COLORADO STATE UNIVERSITY

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Schedule: At-A-Glance

Tuesday March 30, 2021

Time	Session	Chair
8:00 AM	Welcome	Sarah Millonig
8:15 - 9:30 am	**Agricultural Water**	Tim Green
	Break	
9:45 - 10:45 am	**Hydraulics & Geomorphology**	Tim Green
	Break	
11:00am - 12:30pm	**Geoscience & Groundwater**	Ryan Bailey
	Break	
1:00 - 2:30 pm	**Snow Hydrology**	Steven Fassnacht
	Break	
3:00 - 4:15pm	**Snow Hydrology**	Steven Fassnacht

Wednesday March 31, 2021

Time	Session	Chair
8:15 – 8:30 am	**Citizen Science**	Sarah Millonig
8:30 - 10:00 am	**Hydrologic Systems**	Sarah Millonig
	Break	
10:15 - 11:00am	**Climate & Meteorology**	Hadi Heidari
	Break	
11:30am - 12:30pm	**Statistical & Stochastic Hydrology**	Hadi Heidari
	Break	
1:00 - 2:45 pm	**Urban Water Systems**	Sybil Sharvelle
	Break	
3:00 - 4:00pm	**Water Quality**	Sarah Millonig

PRESENTATION SCHEDULE

Tuesday March 30, 2021

Session	Time	Presenter	Presentation Title
Agricultural Water	8:15 AM	Joey Blumberg	*Double Trouble: The Impact of Drought and Litigation on Colorado's Agricultural Practices*
	8:30 AM	Calvin Bryan	*What's Past Is Prologue? The Effect of Prior Losses on Agricultural Risk Management*
	8:45 AM	Chuyang Liu	*Uncertainties of Atrazine Leaching and Accumulation Under Future Climate Scenarios Under Irrigated Corn Production Areas*
	9:00 AM	Kaitlyn Barnes	*The Impacts of Farm-Scale Desalination Technology on Crop Relative Yield*
	9:15 AM	Michael Johnson	*Impacts on Curve Number Runoff Hydrology Due to Changes on The Initial Abstraction Ratio*
BREAK			
Hydraulics & Geomorphology	9:45 AM	Celeste Wieting	*Channel Morphologic Change Associated with Invasive Vegetation Removal*
	10:00 AM	Daniel White	*How Does Floodplain Vegetation Affect Flood-Stage Hydraulics? Flume Observations in a Compound, Meandering Channel with A Mobile Gravel Bed*
	10:15 AM	Anna Marshall	*Characterizing Logjams as Drivers of Transient Storage in a Flume Environment*
	10:30 AM	Nicolas Brouillard	*3D Modeling the Effects of Emergent Floodplain Vegetation in Meandering Compound Channels*
BREAK			
Geoscience & Groundwater	11:00 AM	Fatemeh Aliyari	*A Versatile River Basin-Scale Approach in Assessing Groundwater Vulnerability to Climate Change*
	11:15 AM	Nicholas Chohan	*Determining the Contribution of High-Elevation Wetlands to Baseflow in the Senator Beck Basin, San Juan Mountains, Colorado*
	11:30 AM	Fangyu Gao	*A Synthetic Model and Field Application Study of a Novel Inverse Method to Simultaneously Estimate Aquifer Thickness and Boundary Conditions*
	11:45 AM	Liz McConnell	*Prediction of Groundwater Contaminant Fate Using Statistical and Machine Learning Approaches*
	12:00 PM	Mary "Ragan" Anthony	*Forecasting Benzene Concentrations in Legacy Petroleum Impacted Aquifers*
	12:15 PM	Maria Irianni-Renno	*New Science and Technology Supporting Sound Management of Legacy Petroleum Releases in Soil and Groundwater*
BREAK			
Snow Hydrology	1:00 PM	Danielle Reimanis	*Light Penetration into and off the Snowpack: An Analysis of Ground and Snowpack Properties on Albedo*
	1:15 PM	Adrian Marziliano	*Measuring Variability of a Moderate Snowpack Across a Forest Stand Boundary in New Mexico*
	1:30 PM	Davis Rice	*Hillslope-Scale Temperature Gradients that Cause Downward Moisture Fluxes*

	1:45 PM	Megan Sears	*Near-Surface Air Temperature Gradients for a Small Snow-Dominated Watershed in Colorado*
	2:00 PM	Lenka Doskocil	*Estimating Double Peak Streamflow Timing in the Uncompahgre River Using Snowpack Metrics*
	2:15 PM	Engela Sthapit	*Understanding Snow Representation in the Noah-MP Model Through a Single Column Experiment*
			BREAK
	3:00 PM	Ella Bump	*Reconstructing Winter Precipitation in the San Juan Mountains of Colorado Using Paleo Data*
	3:15 PM	Felipe Perez Peredo	*Streamflow Forecasting in a Snow-Dominated River of Chile*
	3:45 PM	Alison Kingston	*Recent and Future Snowpack Modeling Driven by High Resolution Convection-Permitting Meteorological Simulations*
	4:00 PM	Marin MacDonald	*Assessing Baseflow in Nested Snow-Dominated Watersheds*

Wednesday March 31, 2021

Session	Time	Presenter	Presentation Title
Citizen Science	8:15 AM	Jumana Aljafari	*A Citizen Science Approach to Characterize the Microbial Quality of Roof Runoff*
Hydrologic Systems	8:30 AM	Ben Irvin	*Flood Hydrograph Prediction in Ungauged Mountain Basins of Colorado*
	8:45 AM	Ryan Wells	*Observed and Simulated Effects of Wildfire on Mountain Hydrology In New Mexico*
	9:00 AM	Stacy Wilson	*Characterization of Hydrologic Response to Urbanization in Denver Watersheds and Monitoring of Pre-Development Hydrology in a Semi-Arid Rangeland*
	9:15 AM	Haider Addab	*Simulating the Effect of Subsurface Tile Drainage on Watershed Salinity Using SWAT*
	9:30 AM	Boran Kim	*Probabilistic Downscaling of Soil Moisture Over A Large Spatial Extent*
	9:45 AM	Omar Nofal	*Community-Level Probabilistic Quantitative Flood Risk Analysis Approach*
			BREAK
Climate & Meteorology	10:15 AM	Mackenzie Warden	*Extraction of Past Eco-Hydro-Climatological Information from Medieval Spanish Poetry*
	10:30 AM	Muhammad Ukasha	*Application of Multiplicative Random Cascades to Spatially Downscale Observed Terrestrial Water Storage Anomalies*
	10:45 AM	Alexandra Mazurek	*Using High-Density Observations to Track Heavy Rainfall Rates and Mesoscale Rotation in Tropical Storm Imelda (2019)*
			BREAK
Statistical & Stochastic Hydrology	11:30 AM	Meena Raju	*Trend and Change Point Analysis of Hydrological Variables in the Lower Mississippi River Basin*
	11:45 AM	Matthew Lurtz	*Connecting Irrigation Return Flow and Hydrologic Data to Riparian Greenness Using Bayesian Linear Regression*

	12:00 PM	Mahshid Ghanbari	*Compound Coastal-Riverine Flooding Along the U.S. Coasts: The Effects of Sea Level Rise and River Flow Change*
	12:15 PM	Carolien Mossel	*Analysis of Uncertainty in Using GEFS to Drive the NWM*
BREAK			
Urban Water Systems	1:00 PM	Donya Dezfooli	*A Review on the State Of 'One Water' In Different Cities Across the World*
	1:15 PM	Galen Macpherson	*Correlation of Urban Water-Demand with Municipal Land-Use Categories and Development of a Web-Tool to Assist Water and Land-Use Planners*
	1:30 PM	Sonali Chokshi	*Local Forecast Accuracy and the Implications to Smart Irrigation Technology*
	1:45 PM	Benjamin Choat	*Insights from a Synthesis of Municipal Stormwater Control Measure Inventories Across 23 United States Cities*
	2:00 PM	Mahshid Mohammadzadeh	*Assessing the Performance Validity of the CLASIC Tool for the Characterization of Urban Hydrologic Components Compared to a Full SWMM Model*
	2:15 PM	Jessica Seersma	*Spatial Location and Type Ranking of Green Stormwater Infrastructure Practices Combining Site Based Assessments with Fully Integrated Hydrologic/Hydraulic Model Results*
	2:30 PM	Ahmed Gharib	*Changes in Water Delivery to Agricultural and Municipal Sectors Under Current Institutions in Response to Climate Change, Population Growth and Rapid Urbanization*
BREAK			
Water Quality	3:00 PM	Anthony Pimentel	*Improving Natural Water Quality Through Wastewater Reuse*
	3:15 PM	Catherine Schumak	*Addressing Sediment and Phosphorus Impairment in Beaver Creek, WI*
	3:30 PM	Jan Sitterson	*Quantifying Temporal and Spatial Distribution of Microplastics in a Northern Colorado Watershed*
	3:45 PM	Carly Zimmer	*Salt Mobilization and Transport in Upland Catchments of the Lower Arkansas River Basin*

AGRICULTURAL WATER

Double Trouble: The Impact of Drought and Litigation on Colorado's Agricultural Practices

Joey Blumberg, Chris Goemans, Dale Manning
Department of Agricultural and Resource Economics, Colorado State University

The 2002 drought in Colorado received considerable media attention and is widely reported as the most severe in recent history. Concurrent with the drought, the State Engineer lost authority in approving Substitute Water Supply Plans as a result of litigation between water users. This institutional change made it more difficult for groundwater users to obtain augmentation plans. In this presentation we examine how the untimely coupling of record low stream flows and increased reliance on surface water affected water right curtailment frequency and irrigation practices in the South Platte River Basin. Using publicly available data on irrigated cropland, water rights, and administrative calls from the Colorado Division of Water Resources, we leverage this unique period as a natural experiment. Results suggest that producers who experienced an unprecedented increase in the curtailment of their water right (treatment) transitioned 11% more land from flood to sprinkler irrigation by 2015 than those characteristically impacted by the event (control), with corn and alfalfa predominately planted on the sprinkler-irrigated land. We also find no significant differences in total irrigated acreage between treatment and control groups, indicating that the shock to water availability incentivized the adoption of water conserving technologies. This analysis provides useful insights into the relationship between changing hydrological systems and water allocation mechanisms, as well as how producers respond to perceived changes in the reliability of their water rights portfolio.

What's Past Is Prologue? The Effect of Prior Losses on Agricultural Risk Management

Bryan, Calvin; Goemans, Christopher; Manning, Dale; Sloggy, Matthew
Department of Agricultural and Natural Resource Economics, Colorado State University

As participation in the U.S. Federal Crop Insurance Program continues to grow, it becomes more important to understand the behavioral drivers of insurance purchasing decisions. Although several previous studies have addressed drivers of participation in the US Crop Insurance Program, there is still uncertainty and disagreement on the extent to which previous production outcomes influence insurance purchases. In this paper, we estimate the impact of insured drought losses on subsequent crop insurance and planting decisions with a focus on isolating behavioral mechanisms. In this research, we construct a unique dataset that links the USDA's Cause of Loss data with the Summary of Business reports at the county-year, along with several additional county level datasets on weather, the environment, and farm financial characteristics. We focus our analysis on corn producers in the eastern United States, merging in data from NASS on corn prices and planted acres. We then evaluate how previous indemnity payments for drought events affect farmers' decisions related to planted acres, insured acres, the ratio of insured acres to planted acres, liability purchased, and liability purchased per insured acre. This study makes several important contributions to the literature. We reinforce a finding in previous studies that past indemnifying events influence present-day insurance

purchases. However, we expand on these studies by disentangling the behavioral effects from financial effects, weather effects, and market effects. To the best of our knowledge we are the first to do so in a comprehensive and systematic way. Our findings provide evidence that each of these is a mechanism by which past indemnifying events influence present day insurance purchases, including behavioral factors such as risk aversion. We are the first to also compare the magnitudes of these different effects because we isolate effects of each mechanism. Future work by the authors will extend this analysis to other crops to more completely characterize which of the behavioral mechanisms dominate.

Uncertainties of Atrazine Leaching and Accumulation Under Future Climate Scenarios Under Irrigated Corn Production Areas

Chuyang Liu, Shannon Bartelt-Hunt, and Yusong Li
Department of Civil and Environmental Engineering, University of Nebraska-Lincoln

Atrazine, one of the most widely used herbicides on croplands, is commonly detected in the groundwater and surface water, and threatens the local ecology. Predicting the leaching and accumulation of atrazine in the vadose zone beneath agricultural production areas is critical to balance the tradeoff between sustainable water resources and intensified food production. In this research, we evaluated the impacts of climate variability and parameter uncertainties on predicting the transport and accumulation of atrazine in a center pivot-irrigated cornfield in Nebraska. Twenty Localized Constructed Analogs downscaled climate projections of an ensemble of General Circulation Models under Representative Concentration Pathway 8.5 (RCP 8.5) were evaluated. Additionally, uncertainties of fate and transport parameters, including atrazine application rates, atrazine concentration in groundwater, sorption, and biodegradation coefficients, were considered. Future groundwater recharge and elevation at the field site were estimated using an inverse modeling method and a calibrated groundwater model. Latin hypercube sampling method was used to produce 100 combinations of parameters to run a three-dimensional atrazine fate and transport model under each climate scenario (years 2057 to 2060). Preliminary findings indicate that the mean predicted groundwater elevation from 20 climate scenarios under RCP 8.5 will gradually decrease 2 m from years 2057 to 2060. Declining groundwater elevation in the future may threaten sustainable water management. Our study also reveals that atrazine accumulation and migration in corn production areas are mightily impacted by climate

The Impacts of Farm-Scale Desalination Technology on Crop Relative Yield

Kaitlyn Barnes, Ryan T. Bailey, Miguel F. Acevedo, Breana Smithers
Civil and Environmental Engineering, Colorado State University

The use of farm-scale desalination technology could greatly impact the sustainability of agriculture in the Upper Arkansas River Valley (UARV) and other semi-arid regions. A groundwater transportation model (UZF-RT3D/SEC Model) is being used to simulate the removal of salt from irrigation water and then further analyze the soil electrical conductivity (EC) and crop relative yield (Yr). Simulations are run for time periods ranging 1 to 25 years, allowing for a greater understanding of local and downstream impacts. Within the model, the amount of salt removed from irrigation water can be changed based on the technology's capability. Field data from a desalination unit have been used to realistically determine the percentage of removal for each major salt ion (Ca+ , Mg2+ , Na+ , K, SO4 2- , CO3 2- , HCO3 - , and Cl-). The concentration of salts in soil water is taken from the model data and EC is calculated for all cells in the study region. The Yr is then calculated using the EC and crop salinity threshold. Some grid cells include more than one crop type so the percent of which a specific crop occupies the cell is considered. Crop root depth is used to determine which layers within the model should be averaged to get total concentration - the first and second layers of the model are used, accounting for the top one meter of the soil profile. Crops considered when determining root depth were those commonly grown in the UARV (e.g., corn, alfalfa, melons, onions). This method is used for a variety of scenarios including no salt reduction (current irrigation water quality), 100% salt reduction (best scenario irrigation water quality), and the field data results (attainable irrigation water quality). Different scenarios are being studied to understand which field locations would benefit the most from irrigating crops with desalinated water. The research is expected to show that as salt concentration in irrigation water decreases, crop Yr and overall system health will increase, promoting soil and water sustainability.

Impacts on Curve Number Runoff Hydrology Due to Changes on the Initial Abstraction Ratio

Michael S. Johnson, John J. Ramirez-Avila, Ing, PH
Watersheds and Water Quality Research Lab, Richard A. Rula School of Civil and Environmental Engineering, Mississippi State University

The Natural Resources Conservation Service (NRCS) Curve Number methodology is widely used by hydrologists to determine the amount of direct runoff generated by a rainfall event. The ratio of initial abstraction (Ia) to maximum potential retention (S) has been the subject of research to improve the method's performance. By analyzing measured rainfall-runoff events, this study evaluates the effect of changing Ia/S on the estimation of the representative Curve Number values and runoff depths for six (6) agricultural watersheds in the Mississippi Delta. The original Ia/S value of 0.2, a modified value of 0.05, and the estimated value that better fits the experimental dataset, are to be used to perform the analysis. Four (4) to six (6) years of rainfall and runoff events are available from each monitoring site. Preliminary results indicate a reduction in the estimation of the representative Curve Number for each watershed and a

better prediction of runoff depths when Ia/S decreases from 0.2 to 0.05. Final results are expected to support recent updates proposed to the Curve Number methodology, currently in evaluation by NRCS.

HYDRAULICS & GEOMORPHOLOGY

Channel Morphologic Change Associated with Invasive Vegetation Removal

Celeste D. Wieting[1], Sara L. Rathburn[1], and Jonathan M. Friedman[2]
[1]Geosciences Department, Colorado State University
[2]U.S. Geological Survey, Fort Collins, CO

Expansion of invasive vegetation such as tamarisk, Russian olive, and giant cane contributes to channel narrowing of streams in the southwestern US (SW). Invasive vegetation is removed to benefit native vegetation and wildlife, increase flows, and restore channel morphology. Removal of woody plants promotes erosion by reducing root reinforcement of banks and hydraulic roughness and increasing flow velocity and shear stress. Where vegetation removal is followed by flooding, large increases in channel area and migration may result. River restoration removing invasive vegetation is now common practice, yet post-removal monitoring of channel change is lacking. We are using repeat aerial imagery to investigate channel morphologic response following invasive vegetation removal and link response to stream power. We hypothesize that large flows after removal increase channel cross-sectional area and migration. Removal method should influence channel response such that whole-plant removal (WP) has a larger effect than cut-stump (CS) and other less invasive techniques. Data were compiled from the literature on SW rivers including vegetation type, method of vegetation removal, duration of removal, time since removal, record of high flows, and channel morphologic changes. Using remote sensing techniques, the active channel was delineated for pre- and post-vegetation removal efforts in control and treatment reaches. We analyzed change in channel area and width, center-line migration, and new channel formation following removal. Approximately 40 sites have been inventoried, with preliminary results from 10 sites. For example, along Chinle Creek in Canyon de Chelly National Monument (CACH), the WP and CS methods were used to control invasive vegetation in 2005-2006. Aerial imagery collected in 2005 and 2019 indicate statistically significant increases in channel width in WP reaches compared to CS and control reaches. WP reaches experienced greater variability in channel area compared to CS reaches. Preliminary analyses from other inventoried locations show a range of channel responses including channel avulsion, ongoing meander migrations, and minimal channel response to vegetation removal efforts. Quantifying channel response will help identify riparian areas sensitive to change, inform management to enhance channel mobility where desired, and limit erosion where this is a concern.

How Does Floodplain Vegetation Affect Flood-Stage Hydraulics? Flume Observations in a Compound, Meandering Channel with a Mobile Gravel Bed

Daniel White, Nicolas Brouillard, Ryan Morrison, Peter Nelson
Department of Civil and Environmental Engineering, Colorado State University

Floodplain vegetation, flow, and channel topography have strongly linked dynamic interactions. Emergent floodplain vegetation produces roughness and altered flow fields both in the active channel and on the floodplain, but the effect of floodplain vegetation densities remains poorly understood. Here we present results from an ongoing flume experiment performed at Colorado State University's Engineering Research Center. We have constructed a 1 m wide, 15.7 m long, compound meandering channel in a 4.9 m wide by 14.6 m long basin. The channel follows two sine-generated curves with a crossing angle of 30 degrees, and we placed 32 mm-diameter PVC cylinders vertically in the floodplain at a density of 3.4 per m2 to represent floodplain vegetation. The channel geometry and artificial vegetation dimensions and spacing were roughly scaled to match properties of the Cache la Poudre River in Fort Collins, CO. We supplied the channel with a constant water discharge and a constant supply of a sandgravel mixture until equilibrium conditions were achieved for overbank flow depths ranging from a relative depth (ratio of floodplain depth to channel depth) of 0 to 0.4. We use an acoustic doppler velocimeter to measure the three-dimensional flow field at 10 cross-sections along one half-wavelength of the main channel and large-scale particle image velocimetry (LSPIV) from drone-based video to characterize the velocity field of the water surface over the channel and floodplain. The flow field characteristics and channel bed topography will be analyzed and used to quantify the impact of floodplain vegetation on secondary currents, bar-pool relief, near-bed shear stress, flow momentum transfer, and floodplain residence times. An improved understanding of channel-floodplain flow dynamics will contribute to the efforts of the river restoration community to recognize biological drivers such as floodplain vegetation as important factors in assessment and design.

Characterizing Logjams as Drivers of Transient Storage in a Flume Environment

Anna Marshall, Ellen Wohl
Geosciences Department, Colorado State University

River spatial heterogeneity describes variation in geomorphic characteristics such as grain-size distribution, cross-sectional channel geometry, or planform. Spatial heterogeneity within a river corridor promotes retention of water flow paths as water connected to the surface flow is delayed in its downstream transport by a stream feature in zones of transient storage. Transient storage (TS) has numerous implications for river corridor ecosystem services and processes including 1) increased residence time of stream solutes and opportunity for microbial uptake; 2) processing nutrients and pollutants; 3) increased habitat diversity for microbial and macroinvertebrate communities; and 4) buffering water temperature fluctuations. Recent research describes wood as a driver of channel spatial heterogeneity and TS. However, there remain significant gaps in understanding the relative importance of longitudinal densities and

porosities of logjams and varying flow regimes in creating TS. We address some of these gaps by assessing the relative importance of different discharges and logjam characteristics in influencing surface TS based on physical experiments in a flume. We conducted two sets of experiments focusing on (i) the effect of successive additions of logjams, from a single jam to multiple jams that were progressively more closely spaced longitudinally and (ii) how changing porosity in a single logjam affects TS over varying discharges. For the first set of experiments, preliminary results suggest localized TS as logjams become more closely spaced. More TS occurs upstream of the logjams at low flow unless there is an additive effect of local backwaters during high flow. Preliminary results downstream provide no clear trend in TS. For the second set of experiments, preliminary results suggest that TS generally declines as flow increases, regardless of jam porosity. Below the jam, TS decline is greatest at low porosity. Backwater effects above the jam limit the TS decline with increasing discharge. Limited understanding of logjam processes constrains our ability to design wood-based river restoration targeted to restore habitat and ecosystem function. Results from this study provide insight into understanding logjam characteristics as a source and driver of transient storage.

3D Modeling the Effects of Emergent Floodplain Vegetation in Meandering Compound Channels

Nicolas Brouillard, Danny White, Peter Nelson, Ryan Morrison
Department of Civil and Environmental Engineering, Colorado State University

When a river floods, the amount or density of emergent floodplain vegetation influences the interplay between main channel and floodplain flows. This interplay impacts the flow velocity field which governs functions important to channel evolution, sustaining aquatic habitats, biogeochemical processing of nutrients and pollutants, and controlling flood severity. However, little is known about how emergent floodplain vegetation density at various relative depths affects the flow field in meandering compound channels. Here we use a three-dimensional hydrodynamic model to investigate how emergent floodplain vegetation density and relative depth influence flow velocities, conveyance capacities in the main channel and floodplain, secondary flow cells, boundary shear stresses, and floodplain residence times in a meandering compound channel. We first validate the model by simulating the conditions of an experiment conducted in a meandering compound channel with a rigid, rectangular main channel cross section and a smooth floodplain at various relative depths. The predicted free surface elevations and average velocities among other components of the flow field are compared with the physical model results to evaluate the accuracy of the numerical model. We then perform numerical experiments with emergent, cylindrical elements representing vegetation at different densities on the floodplain. For each floodplain condition, we expect a minimum average streamwise main channel velocity to occur at a threshold relative depth above bankfull. As floodplain vegetation density increases, the average streamwise main channel velocity minimum should vary in magnitude and occur at a higher relative depth. The influence of altering floodplain vegetation density on the flow field should decrease with increasing relative depth. When predicting flows and subsequent channel responses during floods, restoration and river management practitioners should consider how emergent vegetation densities affect flow and channel evolution processes in meandering compound channels. With improvements in our

predictions of these processes in meandering channels with vegetated and non-vegetated floodplains, we can better protect the natural and built environments as well as those who occupy those spaces.

GEOSCIENCE & GROUNDWATER

A Versatile River Basin-Scale Approach in Assessing Groundwater Vulnerability to Climate Change

Fatemeh Aliyaria, Ryan T. Bailey, Mazdak Arabi
Department of Civil and Environmental Engineering, Colorado State University

Groundwater depletion has been exacerbated worldwide due to changes in population and climate. However, few studies have focused on quantifying groundwater vulnerability at large spatial (e.g. river basin) scales, and they have reported an uncertainty for making predictions on groundwater stress under future climate change and other anthropogenic activities. To decrease the level of uncertainty, a variety of temporal and spatial factors, climate data, and modeling methodologies are needed. This study provides a new methodology for assessing and quantifying future groundwater vulnerability by 1) employing several Global Climate Models (GCMs), downscaled by Multivariate Adaptive Constructed Analogs (MACA) method, for a long simulation period of 2000-2099; 2) using an integrated SWATMODFLOW model, developed for large, complex, agro-urban river basins to account for both groundwater and surface water resources; 3) studying the combined effects of climate change together with humaninduced stresses such as land use and population growth; and 4) assessing the long-term effects of predicted groundwater stresses on groundwater hydrological response variables such as groundwater levels, groundwater storage, and groundwater discharge to rivers. This method is outlined for the South Platte River Basin, which is predicted to undergo significant changes in population and climate in the coming decades within a paradigm of overall water scarcity. The same approach could be applied to quantify the groundwater stress across nations with complex agricultural and urban interactions.

Determining the Contribution of High-Elevation Wetlands to Baseflow in the Senator Beck Basin, San Juan Mountains, Colorado

Nicholas Chohan[1], Lenka Doskocil[2], William Sanford[1], Steven R. Fassnacht[2], Jeffrey E. Derry[3]
[1]Department of Geosciences and [2]Watershed Science Program, Colorado State University,
[3]Center for Snow and Avalanches Studies, Silverton, Colorado

Climate variability may influence the hydrologic cycle in high-elevation headwater basins, including changes in timing, amount, and phase of precipitation. These changes can impact snowpack accumulation, distribution, and the timing of snowmelt. In these systems, snowmelt recharges the groundwater in wetlands, whose slow drainage may be a significant contributor to baseflow in mountain basins. It is hypothesized that headwater wetlands provide a meaningful contribution to baseflow, a factor crucial in maintaining late season streamflow. A group of high-elevation wetlands in the Senator Beck Basin (SBB), near Red Mountain Pass, San

Juan Mountains, Colorado, were examined for their potential impact on streamflow. In August 2020, the SBB stream was observed to be dry immediately upstream of the Swamp Angel wetland, yet a stream gauge (SBSG) located downstream, operated by the Center for Snow and Avalanche Studies, recorded flow. During this time, seeps originating from the wetland were observed entering the stream channel. These observations suggest that drainage from wetlands in the basin contributes to late season baseflow. The contribution of baseflow to streamflow was estimated by using streamflow and specific conductance data from the SBSG with the Conductivity Mass Balance approach for the period 2005 to present. Baseflow was calculated for each year, both for the year (approx. April to October, when the gauge can operate) and for the period following snowmelt. Yearly and seasonal baseflow index (BFI) values were determined to quantify the proportion of streamflow coming from baseflow. BFI values will be related to whether there was a wet or dry year. For example, 2018 and 2019 were dry and wet, respectively, and in 2018, baseflow accounted for 50% or more of the total streamflow for 65% of the year, whereas in 2019, baseflow accounted for 50% or more of the total streamflow for 13% of the year. A better understanding of the correlation between wetlands and baseflow is important for downstream water users interested in variations in annual water quantity. Findings from this project will bring about increased awareness of the importance of high-elevation wetlands when considering the effects of climate change on headwater basins.

A Numerical and Field Application Study of Simultaneous Estimation of Aquifer Geometry and Boundary Conditions Based on Borehole and Hydrodynamic Data

Fangyu Gao and Ye Zhang
Department of Geology and Geophysics, University of Wyoming

A novel inverse method is developed to simultaneously estimate aquifer thickness and boundary conditions using borehole and hydrodynamic measurements from a heterogeneous confined aquifer under steady-state ambient flow condition. This method extends a previous groundwater inverse technique which had assumed known aquifer geometry and thickness. In this research, thickness inverse was successfully demonstrated when hydrodynamic data were supplemented with measured thicknesses from boreholes. The method is tested using a synthetic model first, and then applied to a field case with limited data. For the synthetic model, different pattern realizations of three hydraulic conductivity zones are generated using sequential simulation. Based on a set of hybrid formulations that describe approximate solutions to the groundwater flow equation, the new inverse technique can incorporate noisy observed data (i.e., thicknesses, hydraulic heads, Darcy fluxes, or Darcy flow rates) at measurement locations as a set of conditioning constraints. Given sufficient quantity and quality of the measurements, the inverse method yields a single well-posed system of equations that can be solved efficiently with nonlinear optimization solvers (i.e., Levenberg-Marquardt method). The solution is stable when measurement errors are increased with error magnitude reaching up to +/- 10% of the range of the respective measurement. When error-free observed data are used to condition the inverse method, the estimated thickness is within a +/- 1% error envelope surrounding the true value; when data contain increasing errors, the estimated thickness becomes less accurate as expected. For the field application, hydraulic conductivity of each

compartment of the study site is inverted. Results of the hydraulic conductivities are compared with those estimated using other methods. The data requirement of the new inverse method is not much different from that of interpreting classic well tests.

Prediction of Groundwater Contaminant Fate Using Statistical and Machine Learning Approaches

Elizabeth McConnell, Kayvan Karimi Askarani, Jens Blotevogel
Department of Civil and Environmental Engineering, Colorado State University

Modern industrial activities have resulted in a legacy of contaminated sites that are difficult and costly to clean up. The multiparameter data from long-term groundwater monitoring at these sites, often accumulated over several decades, are extensive and challenging to interpret. However, our understanding of contaminant fate and transport in the subsurface is far from complete, leading to unexpected costs and unpredictable time frames for site remediation. In this study, we have compiled contaminant concentration and geochemical data that have been collected at various industrial sites over the past thirty years. Using these historical data, we aim to unravel the complex relationships of the measured parameters in order to increase our understanding of ongoing processes and improve decision making. At legacy contaminated sites the pseudo-first order rates of degradation of contaminants can vary widely spatially and temporally. These rates are highly dependent on the subsurface environment. We are working to discern if the historical data can be analyzed with modern tools to uncover relationships in the monitored parameters that could allow for more efficient site treatment. Costs to continue treatment and monitoring over extended periods of time can add up to millions of dollars, and uncertainty in the amounts of time that are required makes planning for cleanup of these sites challenging. Supervised and unsupervised analysis can be used to explain and classify some of the patterns in the historical data of these sites that could provide for improved forecasting of future conditions. Our ongoing studies employ a combination of statistical and machine learning tools, such as regression analysis, positive matrix factorization, support vector machines, and decision trees, are used to unravel the interconnectivities of environmental parameters in complex data sets. Based on these analyses, we develop a deeper understanding of contaminant degradation rates, factors governing contaminant degradation, parameters necessary for contaminant fate monitoring, and suitable remediation approaches. Ultimately, our efforts will lead to more efficient contaminated site management and the return of these contaminated properties to productive reuse.

Forecasting Benzene Concentrations in Legacy Petroleum Impacted Aquifers

Mary Ragan Anthony, Joe Scalia, Tom Sale
Walter Scott, Jr. College of Engineering, Colorado State University

Longer than anticipated time frames for restoration of aquifers impacted by historic petroleum releases is often governed by benzene concentrations. Benzene is a carcinogen that is naturally occurring in petroleum, is soluble in water, and has a low U.S. Environmental Protection Agency maximum contaminant level (MCL) in drinking water (0.005 mg/L). To forecast the longevity of

benzene at contaminated sites, and effectively design interventions to expedite the restoration of impacted aquifers and protect human health and the environment we must first understand the distribution of benzene in the subsurface. High-resolution data from cryogenic coring of legacy petroleum impacted aquifers is used to illustrate that benzene is present in both transmissive and low-permeability zones. Even after petroleum is exhausted or removed from impacted aquifers, benzene will back diffuse from the low-permeability zones creating a long-lived benzene source. Numerical modeling based on understood degradation of petroleum smear zones in the subsurface and the advective-diffusive transport of dissolved benzene is used to understand different benzene persistence behavior types as viewed from down-gradient monitoring wells. The longevity of benzene is shown to be controlled by the architecture and processes effecting the petroleum source zone and the heterogeneity of the aquifer. This research provides a guide for understanding the conditions of groundwater downgradient from a legacy petroleum release to aid in forecasted benzene longevity and implementing strategic remedial measures.

New Science and Technology Supporting Sound Management of Legacy Petroleum Releases in Soil and Groundwater

Maria Irianni Renno, Jorge Rico, Kayvan Karimi Askarani, Susan De Long, Tom Sale
Department of Civil & Environmental Engineering, Colorado State University

Colorado State University and Exxon Mobil are collaboratively advancing cryogenic coring and real-time internet of things (IoT) sensors in support of improved conceptual site models for legacy releases of petroleum liquids to soils and groundwater. The vision is to bring new science and technology to bear on best site management practices. The focus of this work is a former refinery located adjacent to a major US river. Cryogenic cores were collected from three locations separated by 100-m in a former tank farm. First, 22- m of frozen core was cut at 8-cm intervals and characterized with respect to geology, fluid saturations, dissolved gases, and concentrations of total petroleum hydrocarbons, gasoline range organics, diesel range organics, and benzene. Second, 16 samples were selected at critical elevations for microbial ecology characterization at the taxa level using DNA and RNA. Strings of multiple level temperature and ORP (oxidation-reduction potential) sensors were installed in the three cryogenic core holes. Each sensor string also includes a water level pressure transducer and barometric pressure sensor. Sensor data are uploaded via cellular communications to cloud-based data storage, analytics, and visualization platforms. Temperature data are used to 1) resolve the extent of subsurface petroleum liquids, and 2) resolve rates of natural depletion of petroleum liquids based on generated heat. ORP data in combination with biogeochemical data are used to resolve metabolic processes (i.e., electron acceptors used) driving site restoration. Work to date illustrated that biologically mediated natural source zone processes are restoring the site at rates that are expected to largely deplete remaining petroleum liquids in the next few decades. Contaminant storage in low permeability zones may sustain water quality exceedance in groundwater for longer periods of time. Sensors are providing a sustainable approach to documenting protection of the environment and progress to site restoration.

SNOW HYDROLOGY

Light Penetration into and off the Snowpack: An Analysis of Ground and Snowpack Properties on Albedo

Danielle Reimanis, Steven R. Fassnacht, Jeff E. Derry
Department of Ecosystem Science & Sustainability, Colorado State University

The understanding of albedo, or ratio of outgoing to incoming solar radiation, is necessary for modeling the snowpack in snow-dominated watersheds. The timing and supply of meltwater downstream is influenced by the energy balance which includes the radiative transfer of solar radiation. Albedo is often considered a surface property, but since snow is a porous medium, a portion of the reflection happens below the surface and therefore this needs to be included when evaluating albedo. For example, a fresh layer of snow does not necessarily reset the albedo, as the reflective properties of the underlying surface being buried will influence the net albedo. With the recent increase in forest fires in Colorado, the burned surfaces may be impacting albedo during initial snow accumulation. We used the hourly shortwave radiation (incoming and outgoing), snow depth, and other meteorological data from the Senator Beck Basin in the San Juan Mountains of Southwest, Colorado to evaluate albedo changes during snowfall events and snowmelt. Using values at solar noon from September 2006 to October 2014, we were able to track albedo through nine consecutive years of winter seasonal snowpack, defined as the first snow event, to the snow all gone date. Early season albedo is dependent on the depth and frequency of snow events that start snowpack accumulation, while late season albedo is highly influenced by the underlying snow, which includes the presence of aeolian dust. Comparing the observed albedo to a first order albedo decay model shows an average underestimated absorption of 15kW per season, with most of the discrepancy occurring early (signs of accumulation) and late (melt) season.

Measuring Variability of a Moderate Snowpack Across a Forest Stand Boundary in New Mexico

Adrian Marziliano[1] and Ryan Webb[2]
[1]Water Resources Program, University of New Mexico
[2]Civil, Construction, and Environmental Engineering, University of New Mexico

Mountain snowpacks provide much of the water resources for the southwestern United States. Due to limited freshwater supply and mounting climate stressors, accurate water budget forecasts have become increasingly important. Many regions, such as the lower-latitude mountains found in central New Mexico, lack valuable snow data that could improve these forecasts. The purpose of this research is to measure and analyze the variability of a moderate snowpack in this region to better understand the snow depth distribution and more accurately estimate snow water equivalence (SWE). A site with a 1,200 square meter plot in the Sandia Mountains has been established to perform this analysis. Fourteen transects and 173 depth measurements across a forest stand boundary have been compared for the 2019 and 2020 winter seasons to evaluate annual snowpack distribution and interannual variability. A snow pit in both the open and forest areas provided detailed snowpack information. Snow depth at this

plot reached a maximum of 148 cm (mean 83 cm) and 125 cm (mean 57 cm) in 2019 and 2020, respectively. Coefficients of variation ranged from 0.2 to 2.6 for both years, though spatial variability was noticeably higher in 2020. A transition period as the snowpack ripens has been identified, whereby snow depth is increasing in spatial variability through time. The timing of this transition period can be used to adjust the number of survey depth points to more accurately account for variability as the snowpack begins to melt. One depth point per 200 m2 during the accumulation period was enough to achieve a representative measurement, while one depth point per 20 m2 was needed during the melt period as spatial variability increased. One transect per 100 m2 was required for an accurate measurement into the melt period during both seasons. A better understanding of snowpack distribution in these water-stressed regions will improve spring runoff forecasts and assist in more proactive water management decisions.

Hillslope-Scale Temperature Gradients that Cause Downward Moisture Fluxes

Davis Rice, Steven R. Fassnacht
Department of Ecosystem Science and Sustainability, Colorado State University

When we go out in the morning and see dew on the grass or frost on the car, we think of our feet getting wet if we walk through the dew or having to scrape the windows of the car so we can drive. But these are downward latent heat fluxes that have a hydrological and climatological significance. However, it can be a challenge to estimate these fluxes from standard meteorological data since measurements are typically only at one height above the ground. Understand the process is further complicated on a hillslope where nighttime cold air drainage and temperature inversions occur. Such is the case at the Colorado State University Mountain Campus (CSU-MC) where inversions occur often in the early morning where the top of the lateral moraine remains warm while the riparian area around the South Fork of the Cache la Poudre River experiences fog (see Collados Lara et al., 2021; https://doi.org/10.1002/joc.6778). Along the hillslope above the dining we set up six stations to measure air temperature at three heights, from 15 to 140 cm above the ground. Relative humidity (RH) was measured at the top height for three of the stations. The stations were operated from late July through October 2020, with data being collected hourly. At half hour intervals, two game cameras captured photographs of the lower portion of the hillslope from 05:30 to 07:30 each morning. These images were used to identify the presence of dew or frost on vegetation. Due to the Cameron Peak fire, analysis was limited to late July, early August and October. During depositions events, we found horizontal temperature gradients down the slope and vertical gradients towards the ground. The horizontal gradient was also observed from the RH data.

Near-Surface Air Temperature Gradients for a Small Snow-Dominated Watershed in Colorado

Megan G. Sears and Steven R. Fassnacht
Watershed Science, Colorado State University

Near-surface air temperature is an important control on snowfall and snowmelt in subalpine and alpine settings, and is commonly dependent on elevation and canopy characteristics. Understanding spatial variability of air temperatures in such settings is essential for estimating snowmelt magnitude and timing. Joe Wright Creek is a tributary of the Cache la Poudre River, and an indicator of snowmelt characteristics and seasonal water yield from headwaters basins in the greater Cache la Poudre River. To evaluate the correlation between surface elevation and air temperature, 15 low-cost temperature and relative humidity sensors were deployed along two transects within the Joe Wright Creek watershed. The sensors collected data for approximately one year and enabled fine-scale measurements to better understand near-surface air temperature gradient with elevation (NSTGE). These NSTGE values ranged from approximately -30 to 30 ºC km-1. For comparison, the commonly used environmental lapse rate (ELR = -6.5 ºC km-1) is applied to interpolate/extrapolate near-surface air temperature using elevation. The NSTGEs estimated in this study were generally more positive (increasing with elevation) in early morning hours and more negative (the assumed decreasing with elevation) in afternoon and evening hours, with the weakest correlation (R2) occurring around mid-day. Additionally, the NSTGEs were found to vary seasonally with the strongest correlations occurring in the fall and winter months. We evaluated the sensitivity of a snowmelt model to using the observed NSTGEs across Joe Wright Creek versus using the standard ELR.

Estimating Double Peak Streamflow Timing in the Uncompahgre River Using Snowpack Metrics

L.G. Doskocil[1], S.R. Fassnacht[1], J.E. Derry[2]
[1]Watershed Science, Colorado State University; [2]Center for Snow and Avalanche Studies, Silverton, Colorado

Water resources in the southern Rocky Mountains are driven primarily by snowmelt and rely on natural and artificial storage systems to deliver water throughout the year. However, climate driven changes to annual accumulation and melt patterns, specifically, decreases in maximum snow water equivalent (SWE) and earlier melt onset and peak streamflow dates, pose complications for water users and could increase runoff forecasting errors. This study focused on using snowpack metrics from highelevation snow stations to forecast peak streamflow timing in the Uncompahgre River near Ridgeway, Colorado. This river system exhibits two peaks in streamflow during snowmelt and is an important tributary to the Colorado River basin. Daily streamflow data were used with snowpack data from Red Mountain Pass SNOTEL (RMP), Swamp Angel Study Plot (SASP), and Senator Beck Study Plot (SBSP) for water years 2005-2020 to (1) determine the correlation between two peak streamflow events and meltout timing in sub-alpine and alpine basins, and (2) develop a linear forecasting model. The analysis used peak streamflow amounts and dates in the Uncompahgre River, peak SWE amount and date at

RMP, peak depth amount and date at SASP and SBSP, and snow-all-gone dates at the three snow stations for each water year. The Nash-Sutcliffe Coefficient of Model of Efficiency (NSE) was used to evaluate both correlation and model fit. Snow all gone at Senator Beck Study Plot served as a good estimator of the second peak streamflow occurrence when the outlier years of 2009 and 2012 were removed (NSE= 0.82), while 50% peak SWE date at Red Mountain Pass proved the best estimator of the first peak streamflow occurrence (NSE=0.84) after removal of outlier years 2012 and 2020. The second peak streamflow occurrence was also successfully modeled using 50% peak SWE date at RMP (NSE=0.79), 50% peak depth date and SASP (NSE=0.77), and 50% peak depth date at SBSP (NSE=0.76).

Understanding Snow Representation in the Noah-MP Model through a Single Column Experiment

Engela Sthapit
Department of Civil Engineering, City College of New York

Although snow is one of the most important parameters of any hydrological model in snow influenced areas, it is also one of the most difficult variables to estimate. Estimating snowpack properties, such as snow depth (SD) and snow water equivalent (SWE), from a model simulation, remains a challenge in part due to uncertainties in the atmospheric forcing variables, such as precipitation, irradiance, temperature, relative humidity etc. The project focused on understanding snow representation in the Noah-MP land surface model, through a single column experiment for a station located in Caribou, Maine. The ultimate goal is to test snow representation in the National Water Model (NWM), a hydrologic modelling framework that simulates observed and forecast streamflow over the entire continental United States. Comparing the Noah-MP-simulated SWE and SD using forcings from two datasets -- the North American Land Data Assimilation System version 2 (NLDAS2) versus an in-situ station measured meteorological (Station) -- revealed that the snow variables estimated from NLDAS2 (NLDAS2-Noah-MP simulation) were consistently higher than those estimated from the Station (StationNoah-MP simulation). The SWE and SD observed at the station were higher than those simulated from both models. The higher SWE and SD simulated from NLDAS2-Noah-MP was consistent with the low bias in temperature and outgoing radiation in NLDAS2 compared with the in-situ station measured forcing. In terms of the observed SWE and SD, the results suggested that the higher observed values at the in-situ station could be due to windblown re-deposition of snow, likely a prominent effect at a point location, although this hypothesis needs further research. *This study is supported by The National Oceanic and Atmospheric Administration – Cooperative Science Center for Earth System Sciences and Remote Sensing Technologies under the Cooperative Agreement Grant #: NA16SEC4810008. I would like to thank NOAA Educational Partnership Program/ Minority Serving Institutions for this fellowship support and my NOAA mentors - Rob Cifelli, Mimi Hughes, and Kelly Mahoney and campus advisors - Reza Khanbilvardi and Tarendra Lakhankar for guidance. The statements contained within the report are not the opinions of the funding agency or the U.S. government, but reflect the author's opinions.*

Reconstructing Winter Precipitation in the San Juan Mountains of Colorado Using Paleo Data

Elayna (Ella) R. Bump, Steven R. Fassnacht
Department of Ecosystem Science and Sustainability, Colorado State University

The snow in the San Juan Mountains in southern Colorado contributes to streamflow for major rivers, including the Rio Grande, Animas, San Juan, and other rivers that provide water for multiple uses. This region has experienced an extended drought or emerging megadrought (defined as greater than 20 years) that covers southwestern North America and is linked to anthropogenic climate change. The San Juan Mountains have a snowfall deficit categorized as 'exceptional.' With rising water shortages causing issues, including losses or changes in agricultural production in the San Luis Valley (SLV), devastating wildfires in the mountains, and sub-optimal low streamflow, a greater understanding of the trends of snowpack in the San Juan Mountains is warranted. Here, an investigation in the variability of the snowpack is performed using paleo methods and historical instrumental records, specifically tree-ring records dating back 300 to 400 years. The recent extended drought period is compared to the reconstructed winter precipitation record to determine its historical recurrence. Further, the winter precipitation patterns are evaluated for several periods when European settlement occurred in the SLV, to understand the rationale for water management initiatives during those times.

Streamflow Forecasting in a Snow-Dominated River of Chile

Felipe Perez Peredo, Steven R. Fassnacht
Department of Ecosystem Science and Sustainability, Colorado State University

The combination of 10 years of drought in the Chilean Andes and an increased demand water supply and agricultural activities has create the need to have better water forecast information for management and decision making. The forecast information and the controlled information are both, important inputs for an appropriate management. The existing water supply forecasts have been insufficient for the snow-dominated systems originating in the mountains, especially under the new drought conditions. Future climate change and inter-annual variability will further require the use of more detailed snowpack information to create better water supply forecasts. This research focuses on the monthly water supply forecast for the basin upstream the flow gauging station called Río Aconcagua en Chacabuquito, in central Chile. This basin is located in the Mediterranean climate zone, originating at the highest peak in the Andes, Aconcagua. Meteorological data are collected at several stations in the lower elevations, and snowpack information, specifically monthly snow water equivalent (SWE) has been collected at the higher elevation Portillo snow course, established in 1951. Here, a new methodology is created to improve the seasonal volume and the monthly distribution streamflow forecasts, using available information from operative and properly located stations. Results are being evaluated for the current snowmelt period (September 2020 to March 2021), with monthly updates. Improvements have been seen in the seasonal volume, due the use of historical data and because the new methodology also incorporates the recent dry years, unlike the previous forecast model. Improvement in the monthly distribution are expected due the methodology distribution adopted.

Recent and Future Snowpack Modeling Driven by High Resolution Convection-Permitting Meteorological Simulations

Alison P. Kingston and Steven R. Fassnacht
Department of Ecosystem Science and Sustainability, Colorado State University
Graham A. Sexstone
U.S. Geological Survey, Denver Federal Center, Denver, Colorado
Kristen L. Rasmussen
Department of Atmospheric Science, Colorado State University
Daniel McGrath
Department of Geosciences, Colorado State University
Glen E. Liston
Cooperative Institute for Research in the Atmosphere, Colorado State University

The implications of climate change to properly manage water resources, especially in snowmelt-dominated regions such as Colorado, require accurate modeling at a fine scale. Rasmussen et al. (2020; Colorado Water) used the high-resolution convection-permitting climate simulations from the Weather Research and Forecasting Model (WRF) provided input conditions to drive the distributed snowpack model SnowModel. The WRF Model simulations for the continuous 13-year span (2000-2013) used ERA-Interim reanalysis of the current climate with revised simulation to consider likely future climate conditions, i.e., global warming. These 4-km WRF simulations were downscaled to drive SnowModel at a 100-m resolution over a region in the northern Colorado Rocky Mountains. This presentation provides a comparison of the current climate snowpack trends and the possible future snowpack patterns. While we see a shorter snowpack duration and an overall decrease in snow water equivalent, this is not consistent over space or time. By going into more spatio-temporal detail, we explore where any why the snowpack is expected to change, such as less snow at lower elevation but more snow in some higher elevation areas.

Assessing Baseflow in Nested Snow-Dominated Watersheds

Helen Flynn, Marin MacDonald, Steven R. Fassnacht
Department of Ecosystem Science and Sustainability, Colorado State University

This study uses flow duration curves (FDCs) to examine baseflow in snow-dominated river systems. The FDCs are derived from ranking annual daily streamflow in decreasing order, and plotting the streamflow versus the probability of exceedance computed as the rank divided by the number of the days in the year. The mean and standard deviation were computed for the streamflow with 50 to 90% probability of occurrence; assumed to be the annual baseflow. The goal is to evaluate the correlation between snowpack properties prior to the onset of snowmelt and the following mean base flow. First of the month snow water equivalent (SWE) data from snow courses are used to represent the snowpack. Since these are snow-dominated systems, we reevaluated the chronology of a water year. Traditionally a water year (WY), in the US this is from October 1 of the previous to September 30 of the WY, is used as the annual period. However, the snowmelt streamflow occurs in the middle or later in any specific water year, and thus the low flow values are from before and after the snowmelt contribution. We propose

using a melt year rather than the standard water year, where the melt year begins with the onset of melt in the specific year and continues through the onset of melt in the subsequent year. As such the length of the "melt year" varies based on snow accumulation and melt characteristics. Baseflows computed using the water year are compared to those derived for the period of the melt year. We are evaluating historical streamflow data collected in the 1960s around the CSU Mountain Campus, specifically within the Little South Fork of the Cache la Poudre River (South Fork). We have examined three stations nested within South Fork, specifically Upper Little Beaver Creek, Lower Little Beaver Creek, and Fall Creek. These stations are in close proximity to one another, and since they vary in magnitude of flow due to different drainage areas, the assessment used runoff in millimeters. Four nearby snow course stations were evaluated, including Cameron Pass, Chambers Lake, Lake Irene, and Milner Pass. The April and May 1st SWE measurements are compared to the baseflow computed from FDCs using water and melt year. One and two year lags between SWE and baseflow are also evaluated to determine the best correlation.

CITIZEN SCIENCE

A Citizen Science Approach for the Microbial Characterization of Roof Runoff

Jumana Alja'faria[1], Sybil Sharvelle[1], Nichole Brinkman[2], Michael Jahne[2], and Jay Garland[2]

[1]Department of Civil and Environmental Engineering, Colorado State University

[2]National Exposure Research Laboratory, United States Environmental Protection Agency

Roof runoff has the potential of becoming an important alternative water resource in regions with growing populations and limited traditional water resources. Given the scarcity of guidance regulating the use of roof runoff, a need exists to properly characterize the microbial quality of roof runoff. The objective of this 2 – year research effort was to examine roof runoff microbial quality in four U.S. cities: Fort Collins, CO; Tucson, AZ; Baltimore, MD; and Miami, FL. Seven participants, i.e. homeowners and schoolteachers, were recruited in each city to collect roof runoff samples across 13 precipitation events. The presence and amounts of indicator organisms and potentially human – infectious pathogens in roof runoff were determined using culture methods and digital droplet Polymerase Chain Reaction technique (ddPCR), respectively. The analyzed pathogens included Salmonella spp. invA, Campylobacter ceuE, Campylobacter mapA, Giardia duodenalis, and Cryptosporidium parvum 18S. Several factors were evaluated to explore their influence on the presence of potentially human – infectious pathogens; these factors included the physicochemical parameters of roof runoff, concentrations of indicator organisms, the presence / absence of trees, storm properties (i.e. rainfall depth and antecedent dry period), the percent of impervious cover surrounding each sampling location, seasonality, and geographical location. E. coli and Enterococci were detected in 73.4% and 96.2% of the analyzed samples, respectively. The concentrations of both E. coli and Enterococci had the following range: < 1 to > 2419.6 MPN / 100 mL. Salmonella spp. invA, Campylobacter spp. ceuE, and G. duodenalis β – giardin were detected in 8.8%, 2.5%, and 5% of the analyzed samples, respectively. Campylobacter spp. mapA and C. parvum 18S were not detected in any of the analyzed samples. The detection of Salmonella spp. invA was influenced by the

geographical location of the sampling site and the number of antecedent dry days prior to a rain event. The antecedent dry period influenced the occurrence of Campylobacter spp. ceuE as well. On the other hand, the presence of Giardia duodenalis β – giardin in roof runoff was affected by rainfall depth. The collected data will inform treatment targets for different end uses such as irrigation and toilet flushing.

HYDROLOGIC SYSTEMS

Flood Hydrograph Prediction in Ungauged Mountain Basins of Colorado

Ben C. Irvin IV[1], Jeffrey D. Niemann[1], Mark A. Perry[2], Kallie E. Bauer[2], and William T. McCormick III[2]

[1]Department of Civil and Environmental Engineering, Colorado State University
[2]Dam Safety Branch, Colorado Division of Water Resources

Accurate hydrologic modeling plays an important role in ensuring the safety of Colorado's dams by determining the flows that spillways must safely convey. Recent research has shown that infiltration-excess runoff, saturation-excess runoff, and subsurface stormflow can all contribute to stream flow from major storms in Colorado's mountains, and the soil moisture accounting (SMA) method in HEC-HMS has been suggested as an appropriate approach to model these mechanisms. However, SMA requires estimation of parameters that have not been previously considered in hydrologic analyses for dam safety. The objectives of this work are to (1) evaluate simplifications to the modeling process that would reduce the number of required parameters and (2) develop a methodology to estimate the remaining parameters in ungauged mountain basins of Colorado. Geometric characteristics of the subbasins and reaches are estimated using USGS digital elevation models and new terrain processing tools within HEC-HMS. Soil parameters are estimated using the Gridded National Soil Survey Geographic Database (gNATSGO), and vegetation parameters are estimated using the Normalized Difference Vegetation Index (NDVI) from Landsat imagery. The parameter estimates are then refined by comparing the model results to peak envelop curves and other regional information. The simplifications and parameter estimation techniques are implemented for five Front Range basins and three San Juan basins, and they are evaluated by comparing the stream flows from the uncalibrated models to the observed stream flows and the predictions from calibrated models. Overall, the model simplifications have little impact on model performance. The models with uncalibrated parameters have lower performance than the models with calibrated parameters, but the same streamflow generation mechanisms are active for both sets of models. Key sources of uncertainty are the incomplete coverage of soil data and the limited body of research on subsurface stormflow parameter estimation.

Observed and Simulated Effects of Wildfire on Mountain Hydrology in New Mexico

Ryan Wells, Kyle R. Mankin, Holm Kipka, Tim Green
USDA, Agricultural Research Service (ARS), Agricultural Systems Research Unit, Fort Collins, CO

As the risk associated with wildfires increases throughout much of the American West, enhancing our understanding of how watershed processes change following fire is critical. To address this research question, the Agricultural Ecosystems Services (AgES) watershed model was calibrated to match pre-fire and post-fire conditions in a sub-alpine watershed in south-central New Mexico, which burned in 2012. Calibration results demonstrate that AgES adequately simulates both pre-fire and post-fire conditions in a mixed-conifer watershed. In this presentation, the following topics will be discussed: 1) the observed changes to a watershed's precipitation-runoff response following wildfire; 2) a comparison of model agreement between pre-fire and post-fire scenarios; and 3) the key changes to hydrological parameterization following wildfire.

Characterization of Hydrologic Response to Urbanization in Denver Watersheds and Monitoring of Pre-Development Hydrology in a Semi-Arid Rangeland

Stacy Wilson and Aditi Bhaskar
Department of Civil and Environmental Engineering, Colorado State University

Urbanization leads to increases in peak streamflow and frequency of high flows and has been shown to have detrimental effects on water quality, stream morphology, and riparian ecosystem function. However, the hydrologic response to urbanization in semi-arid rangeland environments has not been well documented. Using eight years of instantaneous flow data for twenty-one watersheds ranging in size from 1 - 90 km2 with an imperviousness ranging from 1 - 47%, this study will provide a comprehensive analysis of hydrologic alteration occurring with urbanization in the semi-arid climate of Denver, CO. Additionally, innovative strategies are emerging to retain or mimic natural hydrologic characteristics in areas of new development in an effort to mitigate these impacts. West Stroh watershed in Parker, CO, is mostly undeveloped and is scheduled for residential development within the next two years. Developers have partnered with Mile High Flood District and Wright Water Engineers to incorporate development strategies designed to maintain crucial characteristics of the area's natural hydrology. Proposed plans would include preservation of existing stream channels throughout neighborhoods, directing flow from impervious surfaces to pervious areas, and incorporating a higher density of full spectrum detention structures. West Stroh watershed consists of an ephemeral network of ungauged stream channels. This research will provide a characterization of the pre-development hydrology of this watershed through time-lapse photography in conjunction with climatological data. This study seeks to inform the current Parker project in two ways. First, the anticipated effectiveness of the proposed stormwater management strategies has thus far been demonstrated through modeling. However, there is very little physical data available for this watershed to calibrate the models. The data collected should help fill this gap. Second,

monitoring throughout the development process and post-development will provide the best indicators of the effectiveness of the strategies implemented. Our data will provide important baseline information for future comparison. Overall, this research will make an important contribution to understanding the precipitation response of pre- and post-development grasslands.

Simulating the Effect of Subsurface Tile Drainage on Watershed Salinity Using SWAT

Haider Addab, Ryan T. Bailey
Department of Civil and Environmental Engineering, Colorado State University

Subsurface tile drains in areas with intensive agriculture can be a major contributor of salinity loadings to streams and rivers, as salts in soil and groundwater are transported into the tile drains. Modeling tools can be used to assess baseline conditions, quantify salt mass export, and assess management scenarios to decrease salt removal. In this study, a new developed version of the Soil and Water Assessment Tool (SWAT), the SWAT-Salt tile drain model as an updated version of SWAT-Salt which used to simulate the fate and transport of salt ions in a drained catchment and test a variety of management strategies and tile drain configurations. The new updated module consists of adding several new subroutines that are imbedded within the SWAT code and input file containing soil salinity and aquifer salinity data for the tile drained watershed. The model simulates transport of major cations and anions in groundwater, soil percolation, surface runoff, lateral flow, streams, Tile drains, and equilibrium chemistry reactions in soil layers and the aquifer. The model is applied to a 73200-ha salinity-impaired irrigated region within the Arkansas River Valley in southeastern Colorado and tested against salt loading to the tile Darin network, and in-stream salt ion concentration. The model can be a useful tool in simulating salinity transport in Tile drained watershed and investigating salinity best management practices in watersheds of varying spatial scales. In this study in-stream salt ion concentrations and salt balance have been compared within two scenarios with and without including tile drain simulation in order to study the effects of installing tile drains in large scale watersheds.

Probabilistic Downscaling of Soil Moisture Over a Large Spatial Extent

Kim Boran[1], Jeffrey D. Niemann[1], and Timothy R. Green[2]
[1]Civil and Environmental Engineering, Colorado State University
[2]Center for Agricultural Resources Research, Agricultural Research Service, USDA

Soil moisture is a key variable for many applications including agricultural production and vehicle mobility. These applications require not only accurate estimates of soil moisture but also soil moisture patterns that exhibit realistic statistical properties, such as the range of values and the spatial correlation structure in a region. Satellites such as SMAP provide soil moisture data nearly globally but at resolutions that are too coarse for such applications, so downscaling is used to infer fine resolution soil moisture patterns from the coarse resolution data and

supplemental information. Downscaling methods are often based on the deterministic dependence of soil moisture on regional topographic, vegetation, and soil characteristics. However, soil moisture patterns can also include significant stochastic variations, which most downscaling methods ignore. The Equilibrium Moisture from Topography, Vegetation, and Soil (EMT+VS) downscaling model considers the deterministic dependencies and stochastic variability, but the stochastic variability was developed by considering only small spatial extents. The objective of this research is to extend the stochastic component of the EMT+VS model to allow consideration of large regions. Airborne soil moisture data (800 m resolution) from the Soil Moisture Experiment 2004 (SMEX04) are used to analyze stochastic variations of soil moisture for a 50 km by 75 km region in Arizona. The stochastic variations are decomposed into temporally stable and unstable components, and the properties of those components are analyzed using geostatistical methods. The EMT+VS model is then generalized and shown to produce soil moisture patterns with statistical properties similar to the observations.

Community-Level Probabilistic Quantitative Flood Risk Analysis Approach

Omar M. Nofal, John W. van de Lindt
Department of Civil and Environmental Engineering, Colorado State University

Flood risk quantification with the goal of assessing and improving community resilience requires propagating uncertainties through all stages of a community-level flood damage model. Flood-related data scarcity presents several challenges to the development of high-resolution models including flood hazard, flood exposure, and building vulnerability models. The motivation behind this research was to move the current flood risk research from deterministic to fully probabilistic risk quantification. Therefore, a probabilistic multivariable flood vulnerability model was developed to account for the impact of flood depth and flood duration on the building damage. The proposed methodology depends on dividing the building into components (e.g., structural, non-structural, interior contents, etc.) and then checking the flood susceptibility of each component using a Monte Carlo framework to simulate uncertainties of the flood resistance of each component. Afterwards, a set of damage states for the whole building performance was developed to determine the level of occupancy that buildings can sustain based on flood hazard intensity and the associated consequences (damage, dislocation, etc.). This model was further extended to model the wide impact of flooding on the whole community by developing a portfolio of 15 building archetypes to enable the investigation of flood vulnerability for the different building occupancies within a community by populating the community with these archetypes. The novel contribution of this research is the development of a high-resolution community-level flood vulnerability model by transitioning from the component-level to building-level flood vulnerability analysis and using the building portfolio concept to move from the building-level to the community-level flood vulnerability. The building-level resolution of the developed methodology enables the analyst to quantify the impact of component-level and building-level flood mitigation measures on the whole community, thereby providing policymakers risk-informed decision support.

CLIMATE & METEOROLOGY

Extraction of Past Eco-Hydro-Climatological Information from Medieval Spanish Poetry

Mackenzie C. Warden[1], Jonathan E. Carlyon[2], Steven R. Fassnacht[1]
[1]Department of Ecosystem Science and Sustainability;[2]Department of Language, Literatures, and Culture, Colorado State University

This work addresses the question: can we extract past eco-hydro-climatological information from past writings by examining the correlations between humans and water in the texts. Specifically, the project uses the medieval Spanish poetry from the Romancero, a collection of Spanish narrative poems. The Romancero references the four major rivers of Spain, specifically, the Ebro, the Guadalquivir, the Tajo, and the Duero. Here the focus is on the 22 references to the Ebro River. The more than 1200-page text of poetry has been scanned and is available in portable document format, but the digital text is not directly accessible as words. Through a transmogrification process, the text is extracted from the pdf files in a semi-automated manner to account for various peculiarities related to the font and splotches due to the age of the document (see Warden et al., 2020; https://doi.org/10.25675/10217/211068). Once as digital text, it is modified from medieval Spanish to modern day Spanish, and finally translated to English. From the transmogrified poems, key terms on the hydrology, climatology, ecology, and human interactions with the Ebro River and surrounding environments were extracted. From each of these key terms, the associated descriptors were extracted. A word analysis was performed to determine the occurrence of specific key terms and also their correlation with the associated descriptors. The linkages of the different eco-hydro-climatological terms throughout each poem were evaluated to understand if and how human activity influenced natural processes. Finally, each of the underlying water metaphors were examined to illustrate how the water within the banks, the river, and the water on the landscape symbolized the protagonist in each poem.

Application of Multiplicative Random Cascades to Spatially Downscale Observed Terrestrial Water Storage Anomalies

Muhammad Ukasha[1,2], Jorge A. Ramirez[1] and Jeffrey D. Niemann[1]
[1]Department of Civil and Environmental Engineering, Colorado State University, USA
[2]Military College of Engineering, National University of Sciences and Technology, Pakistan

The Gravity Recovery and Climate Experiments (GRACE) satellite mission has been observing terrestrial water storage anomalies (TWSA) at a monthly scale since 2002. Due to their coarse spatial resolution (≥160,000 km2), TWSA have been used in numerous hydrological studies at regional scales. However, the large spatial footprint limits the use of GRACE TWSA in understanding small-scale spatial variability of terrestrial water storage and its connection with hydrologic, atmospheric, ecological and socio-economic processes. Therefore, spatial downscaling of observed TWSA is of great interest to the hydrological community. In this study, we explored the possibility of using the well-known random cascade model to downscale GRACE TWSA. Using the 0.5 degree GRACE MASCONS dataset for the southwest United States, we first

analyzed the TWSA for spatial self-similarity. Near mono-fractal behavior (i.e., simple scaling) was observed in the process of spatially upscaling the GRACE TWSA observations from 0.5 degrees to 4 degrees. Given this behavior, random cascades can be used to spatially model TWSA at scales ranging from 0.5 to 4 degrees. Assuming that a similar scaling structure is present for scales below 0.5 degrees, we used multiplicative random cascades to downscale TWSA from the large-scale (4 degree) to the small-scale (1/16th degree). Downscaling was performed using two variants of the random cascade (uniformly distributed cascade and beta log-normally distributed cascade). For each variant, 1000 realizations were performed to downscale TWSA. By considering the realization for which the Euclidean distance between the modeled and observed TWSA images is minimized at 0.5 degrees, we found that a random cascade based on the uniform distribution better models the TWSA at small scales.

Using High-Density Observations to Track Heavy Rainfall Rates and Mesoscale Rotation in Tropical Storm Imelda (2019)

Allie Mazurek, Russ Schumacher, and Erik Nielsen
Department of Atmospheric Science, Colorado State University

Landfalling tropical cyclones (TCs) can deliver multiple hazards to coastal communities, including tornadoes, flash flooding, storm surge, and violent winds. These phenomena often take place in the same locations simultaneously, which can pose challenges to communication and recovery efforts. This research seeks to better understand two of these concurrent and collocated hazards (flash flooding and tornadoes) through a close examination of heavy precipitation and storm-scale rotation. For this analysis, Tropical Storm Imelda, which impacted the Texas and southwest Louisiana coasts in September 2019, is assessed. Radar observations and mesoscale analyses reveal the most extreme rainfall occurred in association with training convection on the south side of the remnant TC over an approximately 18-hourlong period. Several locations reported one-hour precipitation rates well over 100 mm during this period, which contributed to storm totals in excess of 1000 mm at some locations. Two high-density networks consisting of nearly 250 gauges in east Texas provided rainfall data every five minutes, allowing for a somewhat rare opportunity to assess exceptional rainfall rates on very fine spatial and temporal scales. Storm-scale rotation near several rain gauge sites of interest was subjectively identified and tracked using WSR-88D radar relative velocity data. The radar-derived rotation and gauge precipitation were then examined together over time to statistically examine rainfall rates with and without the presence of stormscale rotation. In addition to this analysis, rotation tracks and hourly quantitative precipitation estimates from the Multi-Radar Multi-Sensor (MRMS) system were used to further examine the relationship between embedded rotation aloft and precipitation at the surface over time and across space. These findings suggest that there was some positive relationship between storm-scale rotation and surface precipitation rates in Tropical Storm Imelda. This finding is consistent with observed continental precipitation systems (e.g. Nielsen and Schumacher, MWR 2020) and numerical modeling simulations (e.g. Nielsen and Schumacher JAS 2018), which showed that low-level mesoscale rotation tended to enhance surface precipitation by dynamically lifting otherwise unstable parcels. By further diagnosing the processes associated with local extreme rainfall in landfalling

TCs, these findings have the potential to be translated into improvements in short-term flash flood forecasting.

STATISTICAL & STOCHASTIC HYDROLOGY

Trend and Change Point Analysis of Hydrological Variables in the Lower Mississippi River Basin

Meena Raju[1], John J. Ramirez-Avila, Ing, PH
[1]Watersheds and Water Quality Research Lab, Richard A. Rula School of Civil and Environmental Engineering, Mississippi State University

*Recent climatic changes are influencing the natural flow regime of river basins worldwide. This condition has important implications for agricultural water demands, urban water supply, stream function and health, and many others environmental issues. Long-term trend and change point analysis of hydrologic variables provides practical information for better management of water resources. Streamflow and rainfall trends and annual change-point have been analyzed for the Lower Mississippi River Basin (LMRB). Trends for monthly, seasonal, and annual time series were determined in sixteen (16) streamflow and twenty-six (26) precipitation stations for a total of fifty-one (51) water years (1969 - 2019), using the Modified Mann-Kendall tests. The Pettitt's test was used to determine change-point analysis of annual maximum, annual mean streamflow and annual precipitation. Results showed mixed significant increasing and decreasing trends at the stations. Decreasing trends outnumbered increasing trends for mean streamflow at 63%, 25% and 6% of the stations at monthly, seasonal, and annual time series, respectively. Similarly, precipitation trends for monthly depth, monthly maxima, and monthly number of rainy days indicated significant decreasing trends at 27%, 31% and 58% of the stations, respectively. Mean seasonal streamflows trended to decline in all seasons, with the autumn season experiencing the most significant decline (i.e. - 8.8*106 m3 per year). Increasing trends of mean seasonal rainfall depth outnumbered decreasing trends in spring and summer. However, the magnitude of decreasing trends in spring denoted a most significant decline (. - 0.09*106 m3 per year). Results of the seasonal trends infer that during the growing season in the region (May to August), streamflow experiences a decline though there is an increasing trend in rainfall. Change-point analysis of annual maximum, annual mean streamflow and annual precipitation revealed that statistically significant decreasing shifts occurred in 2001, 1998 and 1995, respectively. This work provides a better understanding of long-term streamflow and precipitation trends in an agriculturally dominant area that could facilitate decision making regarding river basin water resources management.*

Connecting Irrigation Return Flow and Hydrologic Data to Riparian Greenness Using Bayesian Linear Regression

Matthew R. Lurtz, Ryan R. Morrison and Timothy K. Gates
Department of Civil and Environmental Engineering, Colorado State University

Previous studies that focus on riparian evapotranspiration in semi-arid irrigated river valleys have proposed that changes in water use are related to energy demand, water availability and anthropogenic forcing (e.g., irrigation methodology and pastoral practices). This work examines riparian water use on the Arkansas River in Colorado, USA using independent temporal and spatial analyses to test hypotheses about socio-hydro-ecological system connections that previous research has only speculated. In our temporal approach, we quantify monthly riparian greenness by means of the Landsat normalized difference vegetation index (NDVI) and regress it on cumulative precipitation, temperature, river discharge and canal discharge as a proxy for irrigation-perturbed return flow. In the spatial analysis, a simplified version of temporally integrated NDVI is used as a response variable to test the predictability of variables that describe river confluence type, irrigation methodology and other floodplain activities. Information criterion and mean square prediction error show a model's predictive abilities given the data. Accounting for autocorrelation increased the predictability of the linear models and improved inference in the independent approaches. Posterior density intervals (α=0.05) for linear trend coefficient values indicate growth at distinct subregions (e.g., areal segments of riparian vegetation along the Arkansas River) in our study area. The spatial approach indicates that subregions of riparian vegetation that intersect with perennial tributaries have noticeably higher cumulative densities of aboveground biomass compared to subregions influenced by adjacent land use changes. Identifying the temporal and spatial dependencies of a hydrosocial system in an irrigated alluvial-aquifer setting can highlight temporal lag between cause-and-effect, storage and attenuation, and distinguish areas that are suitable for restoration.

Compound Coastal-Riverine Flooding Along the U.S. Coasts: The Effects of Sea Level Rise and River Flow Change

Mahshid Ghanbari[1], Mazdak Arabi[1], Shih-Chieh Kao[2], Jayantha Obeysekera[3], and William Sweet[4]
[1]Department of Civil and Environmental Engineering, Colorado State University, Ft Collins, CO
[2]Climate Change Science Institute, Oak Ridge National Laboratory, Oak Ridge, TN
[3]Sea Level Solutions Center, Florida International University, Miami, Florida
[4]Center for Operational Oceanographic Products and Services, National Oceanic and Atmospheric Administration, Silver Spring, Maryland

The co-occurrence of coastal and riverine flooding leads to compound events with substantial impacts on human life, property, and infrastructure safety in low-lying coastal areas. Climate change could increase the level of compound flood hazard through higher extreme sea levels (SLs) and river flows. In this study, a bivariate flood hazard assessment method is proposed to estimate compound coastal-riverine frequency under current and future climate conditions. A copula-based approach is used to estimate the joint return period (JRP) of compound floods by

incorporating sea level rise (SLR) and changes in extreme river flows into the marginal distributions of flood drivers. Specifically, the changes in JRP of compound major coastal-riverine flooding, defined based on flood impact thresholds, are explored by mid-century. Subsequently, the compound flood risk is assessed in terms of probability of occurrence of at least one compound major coastal-riverine flooding for a given design life. The proposed compound flood hazard assessment is conducted at 26 paired tidal-riverine stations along the Contiguous United States coast with long-term observed data and defined flood impact thresholds. We show that the northeast Atlantic and western part of the Gulf coasts are experiencing the highest compound major coastal-riverine flood probability under current conditions. However, future SLR scenarios show emerging high compound major flooding probability along the southeast Atlantic coast. The impact of changes in extreme river flows is found to be negligible in most of the locations except the southeast Atlantic coast. However, even in this region, its impact is considerably less than that of SLR.

Analysis of Uncertainty in Using GEFS to Drive the NWM

Carolien Mossel[1,2], Kelly Mahoney[3], Andrea Thorstensen[4], Mimi Hughes[3], Rob Cifelli[3]
[1]NOAA Center for Earth System Science and Remote Sensing Technologies, City University of New York
[2]Earth and Atmospheric Science Department, The City College of New York, CUNY
[3]NOAA Earth System Research Laboratory, Physical Sciences Division, Boulder, CO
[4]Department of Atmospheric & Hydrologic Sciences, St. Cloud State University

The National Water Model (NWM) was run with downscaled GEFS meteorological forcings for the 2016-2017 wet season (October-March) in California to create 11 ensemble members. To evaluate the performance of these model runs, we chose to study 7 streamflow sites within Sonoma county, California, a rain-dominated area which includes the Russian, Navarro, and Napa Valley River basins. The uncertainty in the model when forced with the downscaled GEFS meteorological inputs was compared to USGS observations, as well as a deterministic NLDAS-driven NWM run. For the purpose of our analysis, we focused on the middle 80% of the ensemble envelope, with a 5-day lead time. The seasonal hydrographs were systematically trimmed into high flow events. Normalized bias was the primary method used to analyze the uncertainty for each high flow event. We found that for some high flow events, the spread in bias trended towards overestimating discharge across the streamflow system. Preliminary results indicate that the normalized bias at the 90th percentile of ensemble members had a greater variation between events, while the normalized bias of the 10th percentile stayed relatively more stable. Some stations had their own trends in biases as well. We also found that model behavior in the beginning of the season was different than late season, as there were periods where the NWM predicted a high flow event that did not coincide with any event from the observations. This could be due to many different reasons, especially those related to soil moisture and the seasonal changes, as well as the meteorological forcings used to drive the model. These results indicate that the NWM may benefit from further evaluation and correction of biases, as well as a better understanding of how well the meteorological forcings affect the model outputs. *NOAA disclaimer: The National Oceanic and Atmospheric Administration – Cooperative Science Center for Earth System Sciences and Remote Sensing Technologies (NOAA-CESSRST) under the Cooperative Agreement Grant #: NA16SEC4810008. The authors* *would like to thank The City College of New York, NOAA-CESSRST program and NOAA Office of Education, Educational Partnership Program for full fellowship support for Carolien Mossel.*

URBAN WATER SYSTEMS

A Review on the State Of 'One Water' in Different Cities Across the World

Donya Dezfooli, Mazdak Arabi
Department of Civil and Environmental Engineering, Colorado State University

Urban areas across the world are plagued by various challenges including growing population, extreme events along with climate change, aging and inadequate infrastructures, sea-level rise, combined sewer overflows, water supply limitations, and reliance on imported water. Moreover, the linear approach which was once considered the best practice is obtained unsustainable due to neglecting the effects of greenhouse emissions and waste. Taking these issues into consideration, new ways of water resources management which are more in line with holistic urban water management have been developed. This shifted approach which is known as "One Water" not only delivers regenerative and resilient water systems but also provides several co-benefits to link human and natural systems. In this study, the state of the One Water approach was investigated in various cities across the United States and the world. The results indicate that cities have implemented several strategies to achieve this holistic approach. Major strategies include stormwater management and rainwater harvesting, water reclamation and reuse, water conservation, and desalination. The cities are making efforts to take the whole water cycle into account, leading to more co-benefits such as livability, air quality, and greenhouse reduction, regulating the air temperature, water quality, and groundwater regeneration. Further investigations reveal that cities encounter several barriers that inhibit the One Water transition. Social and institutional barriers, the issue of path dependence, and lock-in are the most important impediments. The institutionally siloed approach to water management and the absence of drivers for integration impede organizations to collaborate with each other and apply this holistic approach. However, different actions including public education on water issues, public engagement and awareness, adequate funding, collaboration among water service sectors, data management, and technology can be conducted by water associations to facilitate the shift towards the One Water approach and remove existing barriers.

Correlation of Urban Water-Demand with Municipal Land-Use Categories and Development of a Web-Tool to Assist Water and Land-Use Planners

Galen Macpherson
Department of Civil and Environmental Engineering, Colorado State University

This study builds upon and further develops the understanding of the relationships between municipal land-use categories and urban water demand to construct a tool named Polaris, capable of translating future spatial changes in land-use codes to the consequential impacts on urban water demand. Historical water-demand datasets provided by water utilities across the front range of Colorado, municipal land-use, zoning, and comprehensive plan data, and demographic information are geospatially integrated in GIS software, and trend analyses are performed utilizing statistical computing tool R. Trends in water-demand are compared inter-municipally by a developed set of generalized land-use categories to account for high variability in specific municipal land-use codes. The study has found that the indoor vs. outdoor proportion of water-demand has evolved over time, water-demand normalized by household is decreasing, and municipal land-use codes can serve as a predictor of water-demand. The tool, expected to be released in summer 2021, provides enhanced decision-making support to water and land-use planners.

Local Forecast Accuracy and the Implications to Smart Irrigation Technology

Ryan Bridges, Sonali Chokshi, Christina Lilligren, Sam Myer, Steven R. Fassnacht
Department of Ecosystem Science and Sustainability

A significant amount of water is needed to take care of the average Fort Collins lawn. During the summer months, residential water use more than doubles, and up to 58% of the total water demanded goes to outdoor purposes at the same time. In 2018 and 2019, the City of Fort Collins noticed this excessive water usage and offered rebates to residents for smart irrigation controllers to reduce outdoor water use. However, studies have shown for low-water users, water consumption actually increased after residents implemented a smart irrigation controller. As the City of Fort Collins continues to grow, the demand for water will increase, thus, by making irrigation systems more efficient, residents can greatly reduce their overall water consumption. The goal of this research is to determine the accuracy of weather forecasts to determine when to water the lawn, in order to reduce water usage. To do this, we gathered five-day forecasts from the National Weather Service for Fort Collins from November 2019 to the present to compare to actual meteorological data. The focus is temperature, precipitation, wind, and cloud cover forecasts. Our analyses show that the forecasted and actual temperatures vary greatly, with forecasted temperatures tending to underestimate both minimum and maximum daily temperatures. These forecasts are being implemented in modeling evapotranspiration, using a modified Penman-Monteith equation.

Insights from a Synthesis of Municipal Stormwater Control Measure Inventories Across 23 United States Cities

Benjamin Choat
Civil and Environmental Engineering, Colorado State University
Amber Pulido
Center of Watershed Sciences, University of California, Davis
Aditi Bhaskar
Civil and Environmental Engineering, Colorado State University
Rebecca Hale
Biological Sciences, Idaho State University
Harry Zhang
The Water Research Foundation
Thomas Meixner
Hydrology and Atmospheric Sciences, University of Arizona
Lauren McPhillips
Civil and Environmental Engineering, Penn State University
Kristina Hopkins
United States Geological Survey
Jennifer Cherrier
Earth and Environmental Sciences, CUNY-Brooklyn College
Chingwen Cheng
The Design School, Arizona State University

It has become clear that site-scale management of urban stormwater does not equate to watershed-scale success. As the call to move towards a watershed-based approach to managing urban hydrology grows louder there are essential steps that must be taken to allow for practical implementation. This work addressed one of the biggest steps - making it easier for cities wishing to pursue newer approaches to stormwater management to learn from those that have come before them. Our goals were first, to tackle the challenge of inconsistent language and data management approaches regarding municipal inventories of stormwater control measures (SCMs; physical structures used to control storm runoff), and then to investigate which physical, climatic, regulatory, and socioeconomic factors are most correlated with assemblages of SCMs appearing in city inventories. To meet those goals we collected SCM data from 23 United States cities, synthesized the data, and performed statistical analysis to understand which factors may be driving implementation of individual SCMs and SCM assemblages. The number of different terms used by municipalities to label their SCMs was overwhelming with nearly 400 terms being listed. We used an existing classification scheme to reclassify those into 7 coarse categories and 30 finer categories of SCMs and explored other function-based classifications. Then we applied redundancy analysis, multiple linear regression, and other statistical methods to understand which factors are driving the relative abundance of the different SCM types. Physical watershed variables such as depth to water table and impervious percentage were the most statistically important in explaining variation of SCM assemblages between cities. Diversity of implemented SCMs was greater in cities with combined sewers as swales and strips and filters were implemented more frequently and basins less frequently than in cities without combined sewers, suggesting federal regulation may be driving adoption of more diverse SCM assemblages. This work resulted in a database of SCMs that is readily available to other researchers, a record keeping approach that will enable knowledge to be more easily shared and highlighted important factors that cities may consider when looking to companion cities for new knowledge and insights related to stormwater management.

Assessing the Performance Validity of the CLASIC Tool for the Characterization of Urban Hydrologic Components Compared to a Full SWMM Model

Mahshid Mohammadzadeh, Mazdak Arabi, Sybil Sharvelle, Tyler Dell
Department of Civil and Environmental Engineering, Colorado State University

Urban development has caused an increase in impervious surfaces and removal of vegetated land in the US and across the world. As a result, stormwater runoff has significantly increased in urban areas causing many social, economic, and environmental problems, such as loss and damage to properties and contamination of water resources. Understanding the impacts of urban development on water resources made municipalities upgrade their stormwater infrastructures, therefore they need a robust tool to assist them in planning for new sustainable infrastructures. However, existing models are complex and require extensive data for quantifying their parameters. The CLASIC tool is a simplified web-based model that has been developed to help the stormwater managers build different scenarios, using BMPs, and compare their costs and co-benefits to find the best stormwater infrastructure alternatives. CLASIC also provides reports of the hydrologic budgets and reduction of pollutants. To evaluate the abilities of the CLASIC tool, this study aims to assess the performance validity of this tool for the characterization of urban hydrologic components compared to a full SWMM model. First, a full SWMM model was built for Spring Creek watershed, in the City of Fort Collins. The model was then calibrated using the gauged data at two locations for a period of 9 years. Second, the same model was built within the CLASIC tool to compare with the full SWMM model. Finally, the performance of the models in terms of simulating the hydrologic responses was compared. The results from CLASIC showed a good agreement with the SWMM model.

Spatial Location and Type Ranking of Green Stormwater Infrastructure Practices Combining Site Based Assessments with Fully Integrated Hydrologic/Hydraulic Model Results

Jessica Seersma[1], Venkatesh Merwade[2], Siddharth Saksena[3]
[1]Department of Civil & Environmental Engineering, Colorado State University
[2]Department of Civil Engineering, Purdue University
[3]Department of Civil & Environmental Engineering, Virginia Tech University

The effectiveness of urban green stormwater infrastructure (GSI) practices is a function of site-specific characteristics, spatial location, and type. Additionally, the effectiveness is impacted by the hydrologic, pipe and groundwater hydraulic, and atmospheric interactions of the system that it is connected with. Implementation of multiple GSI practices can be used to satisfy MS4 permit requirements and meet other objectives within an urban area including but not limited to; urban flooding, erosion, and water quality. Evaluating the differences in impact and performance of GSI practices at each site is helpful in determining strategic placement and type that will best satisfy overall city scale objectives. An evaluation of the performance of several types of green stormwater infrastructure for each block within a subsection of Minneapolis, MN adjacent to the Mississippi River was performed using the Community-Enabled Lifecycle Analysis of Stormwater Infrastructure Center (CLASIC) tool. The corresponding changes in infiltration,

runoff volume, and pollutant loadings along with cost for each location for each type of green stormwater infrastructure practice were determined. A preliminary feasibility analysis was performed to qualitatively assess the likelihood and ease of implementation of green stormwater infrastructure practices at each location. The fully integrated Inter-Connected Channel and Pond Routing Model (ICPR) was used to determine locations and the extent of local flooding with consideration to the stormwater network infrastructure and the groundwater-surface water interactions. Discrete Compromise Programming (DCP) was then used to compare and rank the performance of the various green stormwater infrastructure practices at each location using the results from CLASIC, the feasibility analysis, and ICPR. Further research will include evaluating additional impacts/benefits of the GSI practices, and evaluation of the overall system impacts through implementation of these practices in the ICPR model.

Changes in Water Delivery to Agricultural and Municipal Sectors Under Current Institutions in Response to Climate Change, Population Growth and Rapid Urbanization

Ahmed Gharib[1], Mazdak Arabi[1], Dale Manning[2], Christopher Goemans[2]
[1]Civil and Environmental Engineering Department; [2]Agricultural and Resource Economics Department, Colorado State University

Water delivery sustainability is subjected to great fluctuations in the future due to physical and human activities. Regions with high rapid urbanization rate like South Platte River Basin -SRPB- are more worried about sufficient extra water supplies to reduce the gap between the current available water supply and the projected water demands. This study focuses on SPRB with objectives to estimate the changes in water delivery to agricultural and municipal sectors under current institutions in response to climate change, population growth and rapid urbanization. 75 aggregated users were selected to represent the current water users of the agricultural and municipal sectors in the study region. Water demand models were used to estimate the water demands of each user under the historical conditions and proposed future scenarios which considered combination of climate change scenarios and population growth scenarios with their associated land use change, while water supply estimates were obtained from different study. These estimates in addition to reservoirs' capacities and current institutions were supplied to WEAP -a water allocation model- with a half monthly timestep to simulate the amount of water delivered and the estimated shortage of each user at each timestep if any. The expected outputs from this study will show initially how much shortage exists in the future under the current institutions and technology levels, what is the effect of advancing technology in both agricultural and municipal sectors on decreasing water shortage, and what is the amount of agriculture acres or how many users should go out of production to overcome the shortage to the other users.

WATER QUALITY

Improving Natural Water Quality through Wastewater Reuse

Anthony L. Pimentel, Bryan, Liu, Karl Linden
Department of Civil, Architectural, and Environmental Engineering, College of Engineering and Applied Science, University of Colorado Boulder

Wastewater reuse is a growing application in many areas of the world as water scarcity is becoming a major issue due to climate change and exponential population growth. In Colorado, water reuse is becoming more viable because of drought and increased water demand. However, chemical contamination from industrial and domestic waste are a main concern of direct potable reuse project because of their ability to pass through conventional water treatment processes. Chemicals contaminants are well known to harm aquatic wildlife and can cause chronic illness if ingested at high concentrations. Membrane filtration can be applied in these settings to physically separate larger contaminants, but membrane fouling can reduce water quality and membrane lifetime. Advanced Oxidation Processes (AOPs) and ceramic membrane filtration can work together in water treatment processes to enhance chemical removal. This study investigated the synergistic effects of ceramic microfiltration and ozonation compared with other AOPs in secondary wastewater effluent. Ozone may be able to react with metal oxide-based membranes to catalyze its decomposition into hydroxyl radicals, strong non-selective oxidants which can degrade micropollutants rapidly. Oxidation of micropollutants, anthropogenic trace organic contaminants, were studied by measuring total organic carbon (TOC) and ultraviolet absorption (UVA254) reduction. Ozonation with ceramic microfiltration was compared to other AOPs such as UV with hydrogen peroxide (UV/H2O2). We investigated hydroxyl radical production via catalytic ozonation, which can remove micropollutants in addition to degrading bio-foulants on the membrane surface. These bio foulants physically block membrane pores and lead to an increased transmembrane pressure (TMP) needed to push water through the membrane, as well as irreversible membrane fouling. Less membrane fouling leads to less frequent backwashing and chemical cleaning of the membranes, thus lowering operating costs and extending the lifetime of the membranes for water utilities. The study found that ozonation coupled with ceramic microfiltration was the most efficient in reducing TOC (~35-40%) and UVA254 (~60-70%). Overall, advancing technologies in wastewater reuse shows that potable reuse is becoming more viable and can enhance water availability while protecting natural water quality.

Addressing Sediment and Phosphorus Impairment in Beaver Creek, WI

Catherine Schumak
Soil and Crop Sciences, Colorado State University

Suspended solids and sediments are two of the greatest pollutants of streams and waterbodies due to their innate impact and ability to transport nutrients and pesticides. Section 303(d) of the 1972 Clean Water Act mandates that states keep a list of impaired waters. This baseline study investigated sediment and nutrient movement from May to November 2017 through Beaver Creek, an impaired stream for Total Phosphorus (TP), located in Beaver Dam, WI.

Objectives included 1) analyzing water quality from upstream to downstream and across time at five sites through monthly grab samples, 2) comparing baseflow and stormflow water quality between monthly grab samples and monthly storm samples collected by a Teledyne ISCO 6712 Standard Portable Sampler installed at the furthest downstream site, and 3) measuring legacy phosphorus in deposited sediment through sediment cores. Water samples were analyzed for Total Solids (TS), Total Suspended Solids (TSS), Total Phosphorus (TP), and Dissolved Reactive Phosphorus (DRP). Sediment cores were analyzed for TP. Results indicated high levels of suspended solids and phosphorus in both the water and deposited sediment. TSS, TP, and DRP concentrations were significantly higher during storm events and during June and July. Both TP and DRP concentrations in baseflow and stormflow were consistently higher than the Wisconsin Department of Natural Resources (WDNR) TP standard. Sediment cores contained substantial caches of phosphorus, with greater concentrations found in the upper 2.5 cm. Understanding patterns and sources of sediment and nutrient contributions within agricultural tributaries such as Beaver Creek can lead to more targeted management strategies.

Quantifying Temporal and Spatial Distribution of Microplastics in a Northern Colorado Watershed

Jan Sitterson[1], David Barnard[2]
[1]Department of Civil and Environmental Engineering, Colorado State University; [2]United Stated Department of Agriculture

Microplastics (plastic particles smaller than 5.0 mm) are an emerging global contaminant, yet little is known about their abundance and impacts in freshwater systems. Recently, there has been an increased interest in understanding the fate, transport, and impacts of microplastics in our catchments and waterways. Studies have reported microplastics in remote areas such as arctic ice floes and alpine snowpack, however, little is known about the distribution of microplastics in source water systems, suggesting the need to understand spatiotemporal gradients of microplastics in relation to hydrologic status and anthropogenic impacts in the semi-arid western United States. In northern Colorado, the Cache la Poudre River is a key water source for several municipalities and large swaths of agricultural land, and, like most western US rivers, water in the Poudre originates from melting seasonal snowpack. Much of the Poudre is under limited human impact, with almost half of the river designated as a Wild and Scenic river. For this remote watershed, primary sources of microplastics can be ruled out, leading secondary introduction as the main source of microplastics. Yet, we still need to understand the abundance and distribution of microplastics in the Poudre watershed. Thus, the objectives of this research are to 1) differentiate the microplastic size distribution and seasonality within the watershed, and 2) assess microplastic abundance from remote headwater streams to city waterways in relation to anthropogenic impacts. We will meet our objectives using a combination of field sampling approaches coupled with lab analysis protocols over a one-year period. In addition, this project will benefit from close collaboration with the U.S Department of Agriculture–Agricultural Research Service (USDA-ARS) and the City of Fort Collins. Quantifying the temporal and spatial distribution of these secondary microplastics in this freshwater system will aid the study of microplastic contamination and transport to larger bodies of water.

Salt Mobilization and Transport in Upland Catchments of the Lower Arkansas River Basin

Carly Zimmer and Ryan Bailey
Department of Civil and Environmental Engineering, Colorado State University

Salt loading can significantly alter water quality in large river basins. The mobilization and transport of salt in high-desert regions hinder the sustainability of crop production. The primary objective of this study is to identify major environmental factors that control the mobilization of salts in natural upland catchments to nearby streams. A variety of field measurements were used to perform this assessment. Electrical conductivity data loggers and rain gauges were placed along a tributary of the Arkansas River, the Purgatoire River, to quantify in-stream salt loading at two different points along the river. Water samples were routinely taken at each site to be used to create a linear relationship between electric conductivity and specific salt ions. These equations were used to estimate individual salt ion quantities through time. Further, total salt load was calculated daily for the tributary over 16 months. This information was used to estimate the percent of salt in the Arkansas River originating from the Purgatoire River. Historic electric conductivity data was reviewed and compared to current data to examine the variation in salt load over time. A salt mass balance was calculated by comparing total salt load from the upstream site and the designated outlet site. This information was used to analyze major salt transport factors. Additionally, soil samples were collected from within the drainage basin to better understand salt location and concentration. Salt intensity maps were created throughout the basin based on land cover, slope, and precipitation concentration. Further research will be conducted to create an ArcGIS Soil and Water Assessment Tool (SWAT) model to predict salt transport through time given a variety of environmental factors using the observed data from the implemented field monitoring network organized through this research. Results can be used in the Arkansas River Basin and other high-desert basins worldwide to assess salt contribution of natural upland catchments to river valleys as compared to contributions from largely irrigated basins.