Colorado State University

COLORADO WATER INSTITUTE

ANNUAL REPORT
2017 - 2018

COLORADO WATER INSTITUTE

MISSION

The Colorado Water Institute (CWI), an affiliate of Colorado State University (CSU), exists for the express purpose of focusing the water expertise of higher education on the evolving water concerns and problems being faced by Colorado citizens. CWI coordinates research efforts with local, state, and national agencies and organizations. CWI works closely with researchers, scientists, and the private sector to develop sound science that assists and informs Colorado water managers and users. CWI accomplishes this by facilitating the transfer of new water knowledge and assisting in educating the next generation of Colorado water professionals by working with all of Colorado's public institutions of higher education.
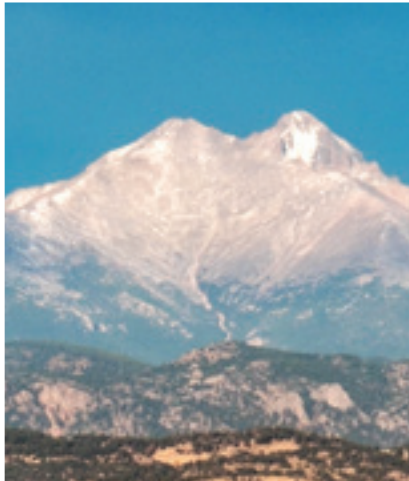
OUTREACH & TRANSFER

CWI collaborates with CSU Extension to house three water outreach specialists around the state. CWI operates several websites with up-to-date water information that have become a consistent source of knowledge for water professionals and community members alike. Publications available on these sites include: research reports and *Colorado Water*, a bimonthly newsletter containing information on current research, water faculty, outreach program updates, climate, water history, Colorado State Forest Service (CSFS) updates, and water-related events and conferences, featuring different research in each issue.

CWI outreach activities are conducted in conjunction with the CSU Water Center, CSU Extension, the Colorado Agricultural Experiment Station, the CSFS, and the Colorado Climate Center (CCC). Our primary partners include water managers, water providers, and water agencies.

TRAINING

One of CWI's primary missions is to facilitate the training and education of university students. To this end, the Institute works with the U.S. Geological Survey and the Colorado Water Conservation Board to fund student interns and research grants and manages scholarships on behalf of students. Student researchers work with faculty members and gain valuable water expertise as well as knowledge of the research process.

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MESSAGE
FROM THE DIRECTOR

The Colorado Water Institute (CWI) at CSU continues to serve its research, outreach, and training mission for Colorado through a variety of research projects and student training in cooperation with the Colorado Water Conservation Board (CWCB) and the U.S. Geological Survey (USGS). Significant efforts were dedicated over the past year toward the development of the program and architectural plans for the new Water Building at the National Western, in partnership with Denver Water. One major component of the NW Water Building is a planned Western Water Policy Institute that CWI will have a major role in helping to foster dialogue and study of water policy issues. 2018 also saw the start-up of the new Irrigation Innovation Consortium, funded by the Foundation for Food and Agricultural Research Foundation (FFAR) and industry partners, including Northern Water. CSU President Tony Frank has granted the use of CSU agricultural land in Fort Collins at the corner of Prospect and I-25 to headquarter the research and training programs of the Consortium.

Several of our research and outreach projects are highlighted in this annual report, including work in the Cache la Poudre, Arkansas, South Platte, and Colorado River Basins, and the Ogallala Aquifer. CWI staff worked hard this year to address the 2018 drought, advance water leadership, evaluate alternative transfer mechanisms, improve agricultural conservation and efficiency, and help train the next generation of water professionals. Retired State Climatologist, Nolan Doesken, worked with us on a part-time basis to continue connecting Colorado's climate to the management and understanding of our water resources.

A major development in 2018 has been the merging of the CWI and the CSU Water Center to reduce external and internal confusion and any administrative redundancies. Unlike the CSU Water Center, the CWI has a federal and state authorization, requiring us to work with faculty and students from all of Colorado's public institutions of higher education to provide water managers and users with new information to improve decision-making. Thus, CWI will continue to work with all of higher education in Colorado on the important effort of training the next generation of water managers through research project funding and internships but doing business as the Colorado Water Center. As CWI director, I am pleased to report this year that the Institute continues to benefit from a committed staff, excellent support from CSU upper administration, and the guidance of an outstanding advisory committee. This 2018 annual report contains only the highlights of our activities and impacts in service to Colorado this past year. More information on the CWI can be found at www.cwi.colostate.edu.

Reagan Waskom

Reagan Waskom

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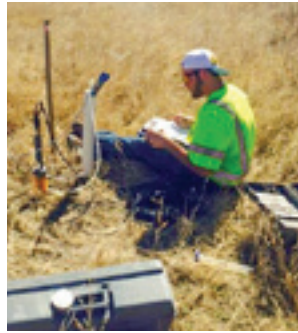
CURRENT **RESEARCH**

CWCB FY19 FUNDED PROJECTS

- Investigating Major Influences on Groundwater Levels in the LaSalle/Gilcrest Area
  Ryan Bailey, Colorado State University

- Assessing Temporal and Spatial Crop Water Consumptive Use with Unmanned Aerial Systems
  José Chávez, Colorado State University

- Update CWCB Instream Flow R2Cross Program
  Ryan Morrison, Colorado State University

- Streamflow Estimation in Colorado Ungauged Basins
  Stephanie Kampf, Ben Livneh, Gigi Richard and Aditi Bhaskar, Colorado State University and University of Colorado Boulder

- Review of Published Studies of Floodplain Storage Capacity and Changes Associated with Flooding
  Ellen Wohl, Colorado State University

- Successional Trajectories of the Riparian Forest Along the South Platte River
  Andrew Norton and Gabrielle Katz, Colorado State University

- User-Friendly Web Application for Water Data Statistical Analysis and Visualization
  Panagiotis Oikonomou, Colorado State University

EXTERNALLY FUNDED

- Hydrodynamic-Enhancement of Nitrate Attenuation by Integrating Reactive Biobarriers into Shallow, Open Water Treatment Wetlands
  Josh Sharp, Colorado School of Mines; NIWR 104G

- Assessment of Floodplain Storage Dynamics in Colorado
  Ryan Morrison, Colorado State University; NIWR 104B

- National Western Center Youth Water Project Summer 2018
  MaryLou Smith, Colorado State University; The Denver Foundation

- Irrigation Innovation Consortium
  Reagan Waskom, Colorado Water Institute; Foundation for Food and Agriculture Research

- UAS-Based Variable Rate Irrigation
  Jose Chavez, Colorado State University; Foundation for Food and Agriculture Research

- Underground Wireless Networks for Soil Moisture Sensing and Irrigation Water Management
  Jay Ham, Colorado State University; Foundation for Food and Agriculture Research

- Lysimeter Operation for Development of Colorado Crop Coefficients
  Allan Andales, Colorado State University; Colorado Division of Water Resources

- South Fork Republican Restoration Coalition: Stream Management and Restoration Planning
  MaryLou Smith, Colorado Water Institute; Republican River Water Conservation District

- Sustaining Agriculture Through Adaptive Management to Preserve the Ogallala Aquifer Under a Changing Climate
  Meagan Schipanski and Reagan Waskom, Colorado State University; USDA

USGS FUNDED STUDENT RESEARCH

- History of South Platte River Riparian Ecosystem and Channel Change
  Joshua Rogerson and Jessica Salo, University of Northern Colorado

- Streamflow Depletion on the South Platte River Due to Groundwater Pumping: Analysis via Field Work and Groundwater Modeling
  Luke Flores and Ryan Bailey, Colorado State University

- Investigating Bi-Directional Water Exchanges Across Intact and Degraded Floodplains
  Alexander Brooks and Tim Covino, Colorado State University

- Dirty Snow: Turning Qualitative Assessments into Quantitative Factors for the Effect of Dust on Snow Albedo and Melt Rate
  Caroline Duncan and Steven Fassnacht, Colorado State University

USGS INTERNSHIPS

- National Domain Water Budgets NIWR-USGS Student Internship Program
  William Farmer

- Modeling of Watershed Systems NIWR-USGS Student Internship II
  Roland Viger

- Modeling of Watershed Systems NIWR-USGS Student Internship III
  Roland Viger

CSU WATER CENTER FY19 PROJECTS

- Measuring Impacts of Forest Disturbance on Streamflow
  Paul Evangelista, Natural Resource Ecology Laboratory

- Who Changes the Rain? Linking the Social Dynamics of Pastoralism and Atmospheric Water Recycling to Enable Sustainable Development Goal Achievement
  Patrick Keys, School of Global Environmental Sustainability

- Examining Extreme Cities: Seeking Solutions for Water Management in the 21st Century
  Melinda Laituri, Ecosystem Science and Sustainability

- Development of a Novel Framework for Estimating Moisture Susceptibility Attributable to Natural Flood Hazards in the U.S.
  Ryan Morrison, Civil and Environmental Engineering

- Next Generation Soil Moisture Measurement Technology for Research, Water Management, and Environmental Monitoring
  Jay Ham, Soil and Crop Sciences

- Addressing Non-Salmonid Fish Passage in Semi-Arid Regions
  Christopher Myrick, Fish, Wildlife and Conservation Biology

- Food – Energy – Water Systems (FEWS) Justice Water Research Team: Urban and Rural Corridors in the Rio Grande-Bravo (RGB) Basin
  Stephanie Malin, Sociology

Photo by Bill Cotton

NIWR 104B / DOI-USGS Funded

STUDENT RESEARCH

For the full articles, please visit http://cwi.colostate.edu/Newsletters.aspx
and view the May/June 2018 newsletter!

Tracking Post-Flood Channel Adjustments and Reservoir Sedimentation to Inform Water Management Practices

By Johanna Eidmann and Sara Rathburn

From September 9-15, 2013, a tropical storm swept across the Colorado Front Range, producing a >200-year flood that resulted in major damage to numerous Front Range communities. Within the North St. Vrain (NSV) Watershed, the storm produced between 7.8 and 17.7 inches of precipitation. The primary goal of this research is to better understand and track continued sediment fluxes from the NSV into the Ralph Price Reservoir. To quantify the volume of sediment aggradation at the inlet and track delta progradation, we collected bathymetric surveys following the September 2013 storm. Our research indicates that the effects of extreme floods on rivers are ongoing. On the NSV, post-flood snowmelt hydrographs influence the erosion, deposition, channel change, and resulting delta deposition. Core analysis of sediments collected at the prodelta further indicate widespread sedimentation associated with the flood and continued remobilization of flood sediments in the following years. Quantifying the sediment influx into Ralph Price Reservoir provides water managers with useful information pertaining to the lasting impact of the 2013 storm and consequences of lowering the base level on reservoir storage capacity. Our findings are relevant to communities in Colorado and elsewhere that face challenges in providing water in a region where water demand often exceeds supply.

> **CWI made my research possible, and it is due to the success of this project that I was inspired to continue doing research at CSU through a PhD."** *Johanna Eidmann*

Effects of Snow Persistence on Soil Moisture and Soil Water Nitrogen Along the Colorado Front Range

By Alyssa Anenberg, Stephanie Kampf, and Jill Baron

The goal of this study was to understand how the timing of snow accumulation and melt change soil moisture and soil water nitrogen concentrations. The specific objectives were to (1) manipulate snow depths at catchments in persistent, transitional, and intermittent snow zones along Colorado's Front Range, and (2) use the results to understand how snow accumulation and melt affect soil moisture and soil water nitrogen. We monitored snow, soil moisture, and soil water nitrogen at three elevations in the Colorado Front Range. The highest elevation site, Michigan River, is located in the persistent snow zone. The middle elevation site, Dry Creek, is located in the Poudre Canyon, in the transitional snow zone. The low elevation site, Mill Creek, is located in Lory State Park, in the intermittent snow zone. Higher elevations with deep snowpacks resulted in a surge of early summer snowmelt that caused high soil moisture and flushing of soil water nitrogen. Lower elevations with smaller snowpacks experienced freeze-thaw events that released pulses of snowmelt throughout the winter and spring and generated lower soil water nitrogen supply. As monitoring continues, we hope to gain a more detailed understanding of how these factors affect the supply of soil water nitrogen in these mountain regions.

> *With this funding, I was able to purchase the supplies and equipment I needed, enabling me to further my field skills, all while enjoying Colorado's outdoors."*
> *Alyssa Anenberg*

Chloramines in Metropolitan Denver Waterways

By Daniel Clark and Sarah Schliemann

The Denver Metro Area is fully contained within the South Platte Watershed. Thus, the South Platte River can truly be classified as an urban waterway as it flows through the Denver Metro Area, highly impacted by urban runoff and stream modification. Elevated nutrient concentrations, pesticide residue, heavy metals, and halogens have been observed in the river. This diminished water quality impacts along the river through the Denver Metro. Chlorine is widely used as a disinfectant in water treatment. Denver Water currently uses chloramines in its disinfection process. Chloramines have been shown to cause adverse impacts on aquatic systems; causing mortality in invertebrates and vertebrates alike. The goal of this project was to investigate chloramine levels in the South Platte River and two of its main tributaries: Clear Creek and Sand Creek. In the Fall of 2017, 12 sample sites were identified in the northern part of the Denver Metro Area. Chloramine was present in 98% of the samples, with samples collected at sites along the South Platte River showing the highest concentrations. All the sites in this study had average chloramine concentrations that far exceeded the chronic exposure limit set by the EPA. At these levels, it is likely that invertebrate and vertebrate species are negatively impacted. This project has initiated several new investigations. We will expand our research to isolate other species of chlorine. Using this information, we will attempt to identify sources of chlorine pollution in the South Platte River and its tributaries.

> *This research project sparked my interest in water resource science, while helping me learn more about how wastewater treatment facilities affect local ecosystems and the importance of recycling water in the American West."*
> *Daniel Clark*

Effects of Water Velocity on Algal-Nutrient Interactions in Streams of the Poudre Watershed, Colorado

By Whitney Beck and LeRoy Poff

The Poudre River provides an important source of freshwater to Colorado's Front Range. There is evidence that algal biomass in Poudre Watershed streams is responsive to increases in nutrients, particularly nitrogen. If human activities continue to increase nitrogen, we are likely to see substantial increases in algal biomass. High elevation streams in the Poudre Watershed are particularly vulnerable because this research shows that they currently have high nitrogen levels and algal accumulation rates. In summer 2017, we completed field experiments in mountain streams of the Poudre Watershed to investigate how water velocity interacts with nutrient additions and aquatic insects to control algal biomass growth and accumulation. We deployed nutrient diffusing substrate experiments in fast and slow sections of five different streams. In general, nitrogen additions are likely to increase algal biomass in Poudre Watershed streams, and aquatic insects may not be able to consume algae quickly enough to compensate (especially in fast velocities). These small-scale experiments are informing the design of a larger modeling study that will inform water quality policy and stream management programs.

> *"The CWI grant will directly propel my professional career, since the grant funded my last year of field research and has directly led to three different manuscripts!"* Whitney Beck

Hydrologic Disturbance Analysis: Methods Development on the Missouri River Basin

By Leah Bensching and Ben Livneh

Stress on water resources is expected to increase for places like Colorado. We rely on remotely sensed data and models to validate our understanding of hydrology. The assumption is that these models will transform meteorological forcing data into streamflow. However, this transformation can be obscured by external forcings. A preliminary set of seven Colorado basins were selected to capture variations in size, streamflow magnitude, and external forcing influences. The analysis was then expanded for all streamflow gages in the Missouri River Basin (HUC 2 basin scale). The preliminary Missouri River Basin analysis did not reveal meaningful patterns when comparing the objective functions to the disturbance magnitude. The results do however provide insight in how to improve future analysis. Possible improvements include the following:

1. The next step would be to analyze a basin such as the Sacramento or Ohio River Basins where model simulations are expected to represent hydrologic processes.

2. Future studies should first identify basins with only one significant external forcing in order to isolate impacts.

3. Results will be more meaningful if a time series analysis is done based off changed external forcings.

4. Using an ensemble of hydrologic models will improve their role as an undisturbed proxy by identifying robust patterns across models and thereby decrease uncertainties.

> *"We found a wide array of external forcing influences (agriculture and reservoir operation) on stream flow, underscoring the complexities in analyzing streamflow to detect global change."* Leah Bensching

FY18 CWCB Projects

Grain Sorghum ©iStock

Determination of Consumptive Water Use of Grain Sorghum in the Arkansas Valley of Colorado

(2017 Season)

Allan A. Andales, *Soil and Crop Sciences, Colorado State University*

Lane H. Simmons, *Arkansas Valley Research Center, Colorado State University*

Michael E. Bartolo, *Arkansas Valley Research Center, Colorado State University*

Accurate estimates of crop consumptive water use are needed to effectively manage irrigation in the Arkansas River Basin of Colorado and to maintain compliance with the Arkansas River Compact with Kansas. Consumptive water use is normally defined as water that is lost from the crop root zone of the soil through the processes of soil surface evaporation and transpiration from crop leaves. The two processes occur simultaneously and are difficult to separate. Therefore, the term evapotranspiration (ET) is commonly used to refer to both processes. Accurate calculations of crop consumptive water use or crop evapotranspiration (ET_c) of irrigated grain sorghum (Sorghum bicolor, (L.) Moench.) are needed in the Arkansas Valley of Colorado. A locally-derived crop coefficient (K_{cr}) curve for grain sorghum is needed to convert alfalfa reference crop ET_{rs} calculated from the ASCE standardized equation to non-stressed sorghum ET_c at different stages of crop development. The objective of this study was to

measure the seasonal ET_c of grain sorghum and develop a preliminary K_{cr} curve using data collected in 2017. A precision weighing lysimeter at Rocky Ford, Colorado was used to measure daily ET_c of furrow-irrigated grain sorghum grown under local weather and environmental conditions. The mass of an undisturbed soil monolith with an actively-growing sorghum crop contained in a steel tank (3.0 m x 3.0 m area; 2.4 m deep) was continuously monitored with a calibrated load cell to determine sorghum ET_c. Grain sorghum (AG 1203 variety) was planted on the monolith and surrounding field (4 ha) on 5/23/2017. The monolith and immediate area were over-seeded on 6/2/2017 to improve crop emergence. Crop development and soil water content were monitored weekly during the growing season. Fifteen-minute average measurements of solar radiation, air temperature, wind speed, and humidity were used to calculate hourly and daily ASCE standardized ET_{rs} values. Daily K_{cr} values for grain sorghum were calculated as

Photo by Lane H. Simmons

The newly-installed linear move sprinkler system moving over the precision weighing lysimeter on March 30, 2018.

ET_c/ET_{rs}. Total season grain sorghum ET_c (6/8/2017 – 10/17/2017) was 23.7 in. Average daily ET_c was 0.18 in/d^{-1}. The seasonal grain sorghum K_{cr} curve was adequately represented ($R^2 = 0.83$) by a second order polynomial equation, with K_{cr} as a function of days after planting. Sorghum grain water use efficiency (WUE) was 1.193 kg m^{-3}. This study provided one growing season of actual grain sorghum ET_c in the Lower Arkansas Valley of Colorado that can help guide irrigation water management for sorghum in the Valley and eventually provide better sorghum ET_c estimates for Arkansas River Compact compliance.

Himes Creek Instream Flow Recommendation

Report and Expert Testimony Regarding Hydrologic and Geomorphologic Processes that Form and Maintain Habitat in Steep-Pool Channels

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Ellen Wohl, *Geosciences, Colorado State University*

The Colorado Water Conservation Board (CWCB) has received a recommendation from the United States Forest Service (USFS) San Juan National Forest for the appropriation of an Instream Flow Water Right on Himes Creek, tributary to the West Fork San Juan River located approximately 11.5 miles northwest of Pagosa Springs. Himes Creek is being recommended by the USFS because the natural environment of the stream contains a core conservation population of

pure-strain Colorado River cutthroat trout. This particular species shares a number of genetic markers with the San Juan lineage Colorado River cutthroat trout, a subspecies of Colorado River cutthroat trout that was once thought to be extinct. Colorado's Instream Flow Program requires the CWCB to appropriate the minimum amount of water necessary to preserve the natural environment to a reasonable degree. On many streams, the CWCB relies upon the R2Cross methodology to quantify the minimum amount of water necessary for appropriation. This methodology assumes that low gradient riffles are the limiting and critical habitat feature for fish. However, Himes Creek is a cold-water, high gradient step-pool mountain stream and low gradient riffles are rare or absent. Further, biologists from both USFS and Colorado Parks and Wildlife (CPW) have determined that the most limiting critical habitat feature to the Himes Creek cutthroat trout is pool habitat. Pool habitat, created through natural fluvial geomorphic processes and natural flow ranges must be maintained in order to ensure that this critical habitat feature will continue to persist over time. As a result of the forgoing information, the USFS has determined that all the unappropriated flow in Himes Creek is the minimum amount of water needed to preserve the natural environment of Himes Creek to a reasonable degree. The USFS believes that any specific methodology that could be used in an attempt to quantify the minimum amount of water required on this stream would be prone to significant error. Therefore, any withdrawal of water from Himes Creek may affect the viability of this species by reducing flow, reducing the extent and depth of pools, impacting riparian habitat, and negatively affecting the macroinvertebrate food source this species relies upon. Multiple stakeholders have expressed concerns over the lack of a specific quantification methodology to quantify the minimum amount of flow necessary to preserve the natural environment on Himes Creek. However, CWCB has relied upon subject matter experts in the past to help them understand the flow needs of natural systems and to determine minimum flows based on the available science rather than a specific hydraulic or geomorphologic model. CWCB staff therefore believes that it would be beneficial to have a subject matter expert review the USFS's recommendation and provide a report on the scientific knowledge regarding fluvial geomorphology on step-pool streams such as Himes Creek. In addition, this subject matter expert may also need to review documents and proposals, and possibly participate in the CWCB's hearing proceedings if needed.

Himes Creek in the San Juan National Forest of southern Colorado. Photo by Ellen Wohl.
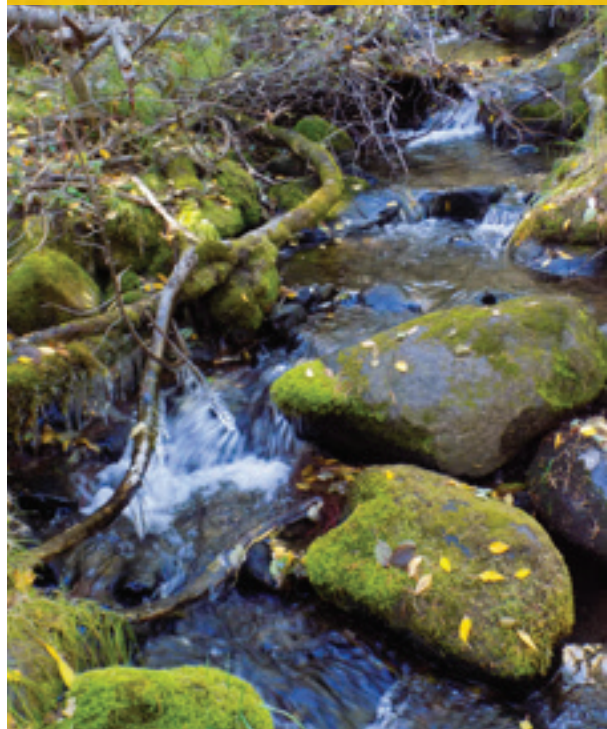
(Left and Right) CSU Graduate Student Alyssa Anenberg in the Michigan Creek Drainage. Photos by John Hammond.

Water Yield Sensitivity to Snow Loss in Colorado Headwater Streams

Stephanie Kampf, Ecosystem Science and Sustainability, Colorado State University
Abby Eurich, Ecosystem Science and Sustainability, Colorado State University
John Hammond, Ecosystem Science and Sustainability, Colorado State University
Alyssa Anenberg, Ecosystem Science and Sustainability, Colorado State University
Kira Puntenney-Desmond, Ecosystem Science and Sustainability, Colorado State University
Gigi Richard, Geosciences, Fort Lewis College

CSU Graduate Student John Hammond showing how deep the snow can be in the Loch Vale Watershed. Photo by John Hammond.
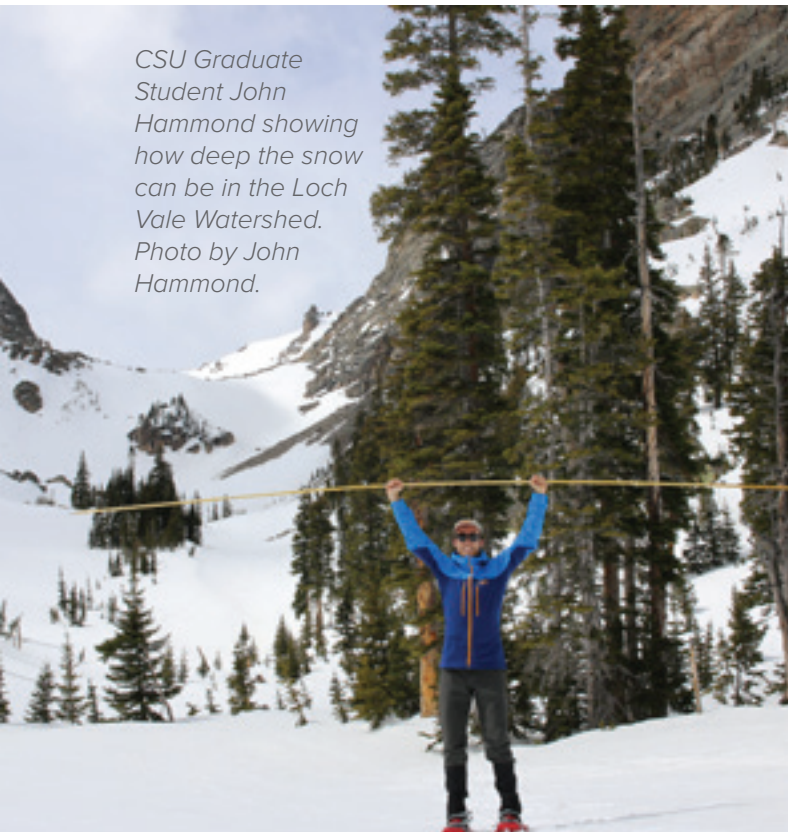
The purpose of this project is to improve the understanding of the relationship between snowpack and streamflow across Colorado. The project has two components, the first a statewide analysis of how snow and precipitation relate to mean annual water yield for watersheds throughout the state and the second, an analysis of snow, soil moisture, soil temperature, and streamflow patterns for a small watershed monitoring network designed to sample different snow zones. For the statewide analysis, we compiled streamflow data from 163 watersheds across the state and evaluated how mean annual water yield related to both mean annual precipitation and snow persistence, which is the percent of time the watershed has snow on the ground between January and June. We also determined the extent of flow modifications (diversions, reservoirs) within each watershed and flagged watersheds affected by

transbasin diversions. For natural watersheds or those that have only within-basin flow modifications, we found strong relationships between mean annual water yield and both mean annual precipitation derived from the PRISM dataset and mean annual snow persistence, derived from the MODIS satellite sensor. The relationship between snow persistence and water yield is slightly stronger and highlights how watersheds without seasonal snow cover have low mean annual water yields, typically less than 3.94 in. Water yield increases with snow persistence up to over 23.6 in within the watersheds with most persistent snow. We found that the sites in the persistent snow zone were the only catchments that produced >7.87 in annual water yield, with the highest water yields at the Front Range site (20.4 in-24.5 in) and lowest at the Grand Mesa site (11.2 in-14.37 in). The transitional snow sites produced only 0.87 in-3.3 in of annual water yield, which is lower than would be predicted by the water yield-snow persistence curve produced in the statewide analysis. The intermittent snow site on the Front Range produced 1.5 in-1.85 in of water yield, whereas the site in the Grand Valley area produced no streamflow, and the Uncompahgre site had only a few days of flow. Snow is clearly a dominant influence on water yield in Colorado, and lower snow persistence can lead to substantial reductions in water yield. However, factors such as soil freeze/thaw, melt timing, groundwater buffering, and net groundwater recharge can modify the amount of water yield a stream produces for a given amount of snow. Ongoing monitoring at the research sites, incorporating snow and soil moisture measurements in the drainage areas of existing stream gauging sites, and addition of new monitoring sites can all help improve understanding of the factors that affect water yield across the state.

Constructing and Testing a Refined Groundwater Flow Model for the LaSalle/Gilcrest Area

Ryan T. Bailey and *Chenda Deng*, *Civil and Environmental Engineering, Colorado State University*

The Gilcrest/LaSalle area is a 78 mi^2 area located northeast of Denver. In recent years, the area has experienced high groundwater levels. The source of water for the aquifer includes: infiltration and recharge from surface water irrigation, groundwater irrigation and rainfall, pumping for agricultural use and M&I use, infiltration from recharge ponds, canal seepage, groundwater lateral flow from surrounding areas, and upflux from the underlying bedrock aquifer. The principal objective for this project is to assess the impact of these individual contributions on water table elevation fluctuation through the use of a calibrated and tested MODFLOW model. This project is an extension of previous projects that constructed a refined MODFLOW model for the LaSalle/Gilcrest area, based on data used in the state's South Platte Alluvial Groundwater Flow Model. This project (1) extended the model domain spatially to include the influence of canals to the south of Gilcrest, (2) performed model calibration and testing, and (3) performed preliminary scenario analysis to determine the groundwater sources and sinks that contribute to water table fluctuation in the area. The next phase of the project includes extending the modeling period through 2017, using the following data: pumping data, recharge pond data, recharge (surface water irrigation and

groundwater irrigation), rainfall recharge, as well as canal seepage. The model will then be tested using observation data from the model domain for the extended time period (2013-2017). Furthermore, the influence of each source/sink on water table fluctuation will be quantified utilizing a quantitative sensitivity analysis scheme.
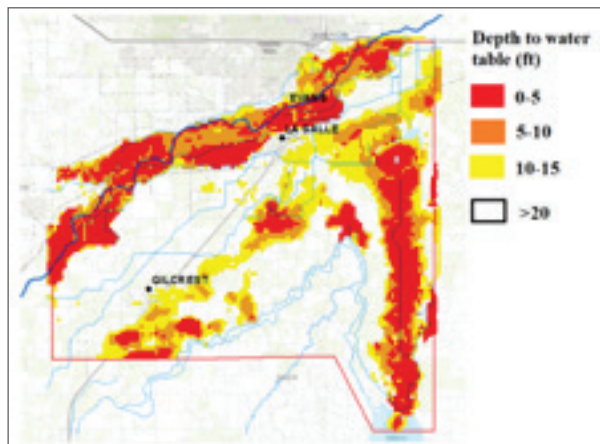
Map of the depth to water table, as simulated by the MODFLOW model developed during the project.

Snow Depth Measurement via Time Lapse Photography and Automated Image Recognition

Kevin S. J. Brown, *Ecosystem Science and Sustainability, Colorado State University*
Steven R. Fassnacht, *Ecosystem Science and Sustainability, Colorado State University*

Seasonal snow is a crucial component of water supply in Colorado and the western United States. Measurement of snow accumulation through the winter and spring

allows water managers to forecast water supply for the growing season and take actions to ease flooding and drought. The NRCS's SNOTEL network provides real-time data at a high cost per station and at single points. An evaluation of existing field measurements of snow depth taken in 2009 and 2010 was undertaken to determine if fine resolution depth measurements are justified. Fassnacht et al. (*in press*) showed that the snow depth variability can be substantial even at fine resolution. However, these data required extensive labor to collect and only represented one measurement in time. A low-cost method to measure snow variability around these stations or in underrepresented areas could improve snow forecasts by quantifying the representativeness of data from the current network. To this end, we trialed a method combining time lapse photography and computer vision techniques to find snow depth at five sites in Colorado during water year 2018. Different site configurations were trialed, and a best operating procedure was determined. The data gathered were not more accurate than current ultrasonic or laser snow depth measurement technologies. However, the low cost and versatility of this method may make it more applicable in certain situations. At the onset of this work, an analysis of existing field data provided the impetus for the use of game cameras to provide multiple snow depth measurements at a location. Previous work has manually extracted snow depth, which can be quite time consuming. Automating this process is possible using new computer vision techniques, raising the possibility of efficient, low-cost snow depth measurement via photogrammetry. In the near-term, work will continue on improving the image recognition algorithm for sites where it is currently

The Swamp Angel study plot camera up-close on February 1, 2018.

performing poorly. Further work will also examine new locations these sites could be placed to provide useful data for other research efforts. They could be used to verify remotely sensed snow data or provide estimates of SWE in underrepresented areas. Deployment of several sites in close proximity could also give insight into local-scale snow depth variability at a small time step.

Mountain Basin Hydrologic Response Study

Douglas D. Woolridge, *Civil and Environmental Engineering, Colorado State University*
**Jeffrey D. Niemann**, *Civil and Environmental Engineering, Colorado State University*

A long-standing problem for the Rocky Mountain region is that traditional meteorology and flood hydrology methods appear to significantly overestimate floods based on comparisons to paleoflood evidence and regional peak streamflow statistics. The Colorado Water Conservation Board (CWCB), Colorado Division of Water Resources (DWR), and state of New Mexico are conducting a $1.5 million study to develop improved estimates of extreme precipitation for the two-state region. Concurrently, DWR has been working to improve flood hydrology methods for the mountain region. Traditional flood hydrology methods utilize low infiltration rates to model flood runoff solely by an infiltration-excess mechanism. However, a recent but preliminary examination of the Gross Reservoir Basin suggests that saturation-excess runoff might be important for extreme precipitation events. For the September 2013 storm that produced widespread flooding along the Colorado Front Range, the rainfall rate in the Gross Reservoir Basin never exceeded 1.22 in/hr, but the storm continued for about six days. During that period, two peaks in rainfall intensity occurred approximately one day apart. Although the first peak had a higher rainfall intensity, the second peak pro-

duced much more runoff. This behavior is unexpected for infiltration-excess runoff, which would usually produce higher runoff rates for higher rainfall rates, but it is consistent with saturation-excess runoff, which depends more on the accumulated depth of rainfall. The overall objectives of this line of research are to determine whether the present Colorado Dam Safety guidelines for runoff modeling correctly specify the runoff production mechanisms for extreme precipitation events in Colorado's mountain basins and to develop updated guidelines for runoff modeling that include the appropriate runoff production mechanisms. In-situ soil moisture observations indicate that south-facing slopes often reached saturation during the September 2013 flood while north-facing slopes usually did not. They further suggest that saturation occurred first at the bottom of the soil layer and proceeded upward. These observations are consistent with saturation-excess runoff production. The

preliminary model results also indicate that saturation-excess runoff production was the primary runoff production mechanism in South Boulder Creek during the September 2013 flood. Additionally, the model results show that south-facing slopes approached saturation while the north-facing slopes did not. The results support three primary conclusions: (1) saturation-excess runoff production was the dominant runoff production mechanism during the September 2013 flood, (2) runoff production occurred primarily on SFS (and not NFS) for the September 2013 flood, and (3) a model developed using the SMA method in HEC-HMS can reproduce these observed behaviors in South Boulder Creek. These preliminary results will be tested further in the second year of the project. Specifically, models will be built for four other basins in the Colorado Front Range, and their behavior will be examined for the September 2013 event and other historical events.
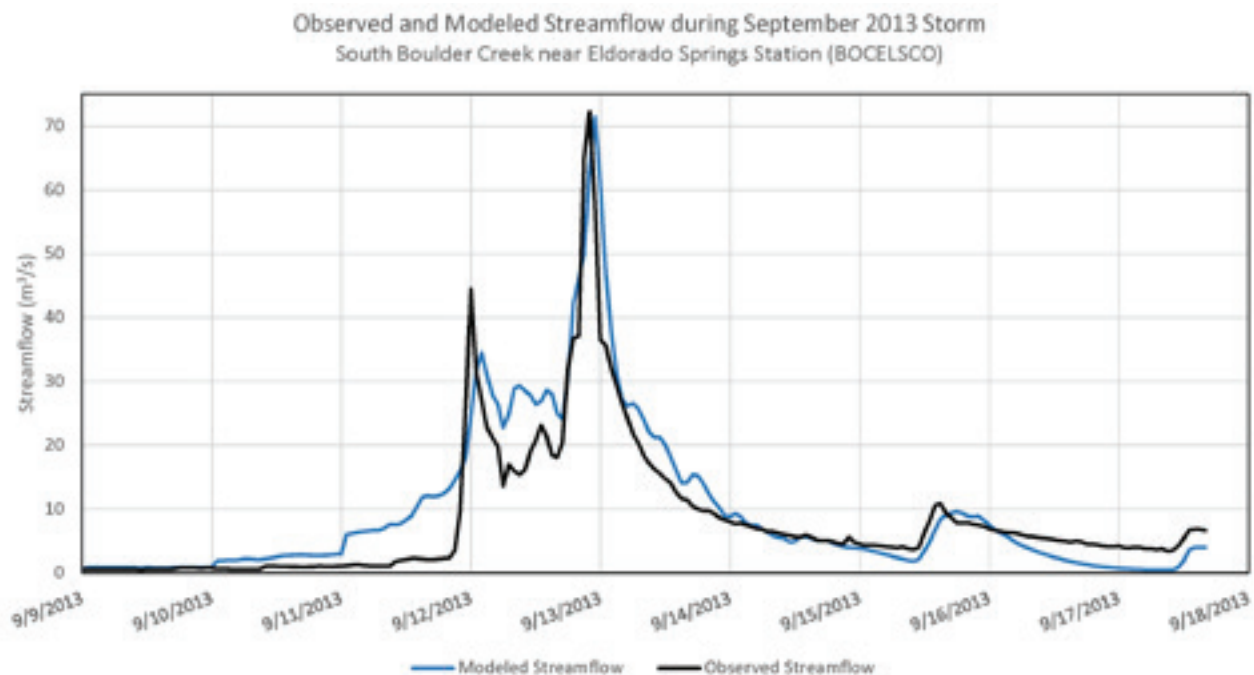

Comparison of modeled and observed streamflow. The model reproduces the main features of the observed hydrograph when runoff is produced by the saturation-excess mechanism.

Bark Beetle Impacts on Remotely Sensed Evapotranspiration in the Colorado Rocky Mountains

John F. Knowles, *Institute of Arctic and Alpine Research, University of Colorado Boulder, School of Geography and Development, University of Arizona*

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Bark beetles reached epidemic populations throughout many areas of the Southern Rocky Mountain ecoregion during the mid-2000s and represent a major ongoing forest disturbance with unknown implications for hydrological partitioning between the abiotic (evaporation) and biotic (transpiration) components of the total evapotranspiration (ET) flux. Since changes in ET are linked to both groundwater and surface water recharge processes, this scenario has the potential to affect water delivery to agricultural, industrial, and residential consumers downstream. Accordingly, this research used satellite remote sensing, eddy covariance, and hydrological modeling approaches to independently quantify the impact of bark beetles on growing season ET, the transpiration fraction of ET (T/ET), and streamflow across a range of spatial scales throughout the 144,462 km² EPA Level III Southern Rocky Mountain ecoregion. The results of this work demonstrate statistically significant post-disturbance ET reductions between 9% (remote sensing) and 28%

(eddy covariance) relative to pre-disturbance conditions. Further, commensurate decreases in transpiration and T/ET from disturbed areas suggest that the total ET flux was primarily sensitive to changes in transpiration. In the context of the water balance, the Variable Infiltration Capacity (VIC) hydrological model simulated decreased canopy interception and increased soil moisture as a result of beetle disturbance, which increased streamflow by 9%. Factoring in the number of grid cells that were disturbed, bark beetles decreased ET by 62,000 acre-feet and increased streamflow by 54,000 acre-feet between 2000 and 2013. These results will benefit water managers tasked with forecasting water re-
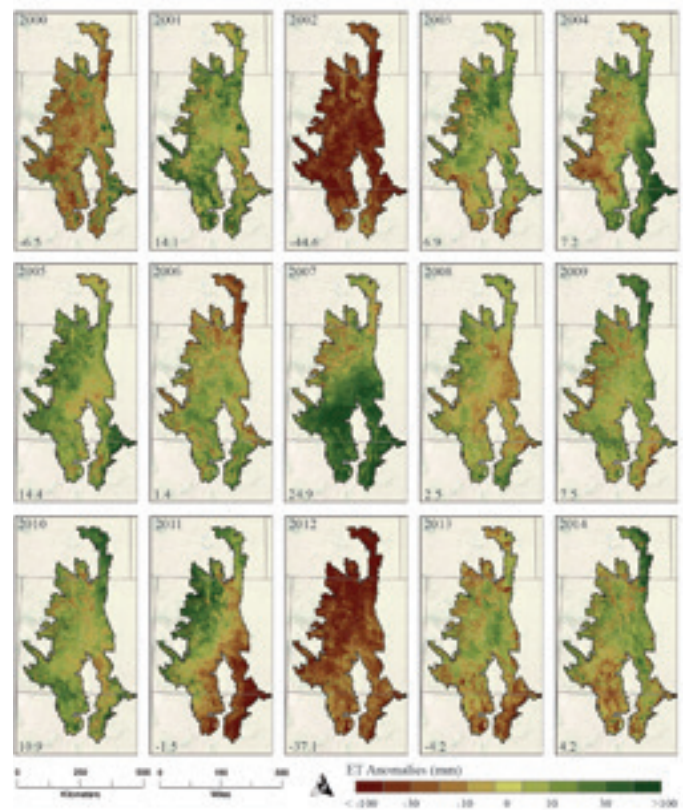
Spatial analysis of the annual difference from the 2000-2014 mean evapotranspiration (ET) throughout the EPA Level III Southern Rocky Mountain ecoregion. The annual ecoregion-integrated value (mm) is in the lower left corner of each panel. The ET was calculated from Moderate Resolution Imaging Spectroradiometer (MODIS) data at 1 km resolution.

sources from disturbed areas both now and in the future. We therefore identify future research on the effects of forest regrowth on hydrological partitioning as an important research priority. In the meantime, we recommend that water managers and/or forecasters take advantage of the multi-scale results presented herein to accurately interpret the magnitude of the beetle effect on current hydrological observations.

Hydrologic and Water Quality Data Collection in Colorado's Upper Arkansas River Basin

Timothy K. Gates *and* ***Jeffrey D. Niemann****,
Civil and Environmental Engineering,
Colorado State University*

Field data collection and analysis activities for a study region in Chaffee County in the Upper Arkansas River Basin (UARB; Gates et al., 2016) were conducted per the Scope of Work submitted to CWCB in September 2017. Locations and methods of measurements and sampling are as described in Gates et al. (2016), located at http://cwi.colostate.edu/media/publications/sr/24.pdf. Data have been entered into the Arkansas River Basin SQL Database at Colorado

Photo by Derek Adams

CSU student researcher, John Cox, measuring flow velocity in the South Fork of the Arkansas River using an Acoustic Doppler velocimeter (ADV).

State University and results reveal values for water table depth, flow rates, in-situ water quality parameters, and concentrations of selected water quality constituents which are similar in magnitude and variability to those reported in Gates et al. (2016) and in annual reports to CWI and CWCB for fiscal years 2016 and 2017. Monitoring events were conducted in November 2017 and April 2018. The average depth to the water table measured in 17 monitoring wells during the November 2017 sampling event was 6.6 m and the average electrical conductivity (EC) of the groundwater was 0.28 dS/m. During the sampling event in April 2018, depth to water table and EC were measured in 15 wells, with two additional wells found dry. Average water table depth was 5.6 m and average EC of the groundwater was 0.23 dS/m. Groundwater quality samples taken from 13 wells in April 2018 revealed average uranium (U) and total dissolved solids (TDS) concentrations of 4.2 µg/L and 216.7 mg/L, respectively. EC was measured in flows at 3 locations in the Arkansas River and at 18 locations in tributary streams in November 2017. Average EC in both the river and tributary streams was 0.12 dS/m. Acoustic Doppler Velocimeters (ADVs) were used to measure flow rates at gaging sites in eight tributaries. During the April 2018 sampling event, EC was measured in flows at 3 locations in the Arkansas River and at 19 locations in tributary streams. Average EC in the river was 0.12 dS/m and in the tributary streams was 0.13 dS/m. ADVs were used to measure flow rates at gaging sites in seven tributaries. Water quality samples collected during the April event at three locations along the Arkansas River revealed average U and TDS concentrations of 1.7 µg/L, and 100.7 mg/L, respectively. In the tributary streams, average measured U and TDS concentrations were 3.9 µg/L, and 123.3 mg/L, respectively.
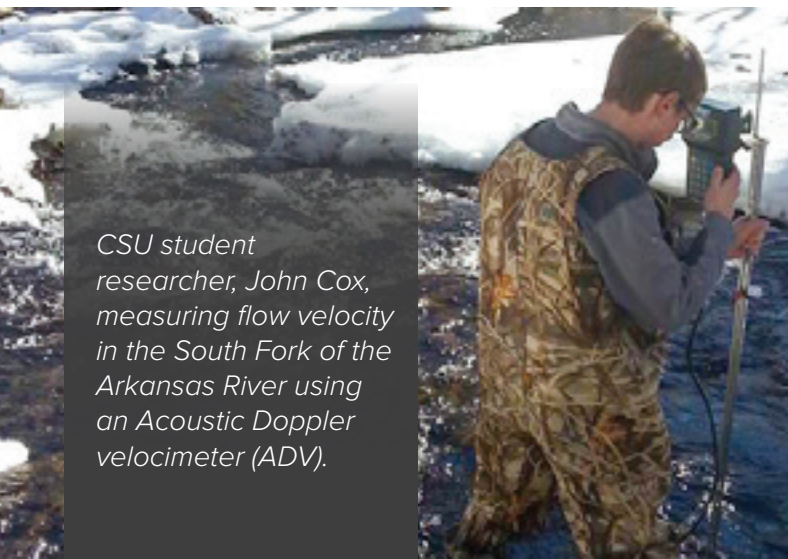
CWI STAFF UPDATES

Colorado Water Institute Igniting Dialogue for a Northern Colorado Regional Water Vision

MaryLou Smith, Policy and Collaboration Specialist, Colorado Water Institute
Julie Kallenberger, Education and Outreach Specialist, Colorado Water Institute

Water supplies in the Poudre and Thompson Basins of Northern Colorado are under intense pressure as the region's population skyrockets. Our policy dialogue the past several years with regional agricultural, urban, and environmental stakeholders have convinced us that without a clear vision about our water future, and leadership at high levels, we will not be able to sustain the desirable quality of life we presently experience.

DEVELOP A NETWORK OF KEY LEADERS TO CRAFT AN ACTIONABLE STRATEGIC VISION FOR NORTHERN COLORADO WATER

Water Literate Leaders of Northern Colorado, now in its second year, is our effort to raise the level of dialogue about water to the top decision-makers in the region. Dialogue starts with understanding, so key community leaders are offered a nine month course to become immersed in

all things water including water law and administration, domestic water providers, agricultural water users, business, recreation, environmental water concerns, economic growth, water challenges, and opportunities. Each class is made

A council member, a mayor, and environmental group representatives learn about Colorado water law at the first session of Water Literate Leaders in September 2017.

Photo by MaryLou Smith

up of just 21 members, which allows for exchange of ideas and diversity of views in a relationship rich environment. Class members are confronted with the need for tradeoffs if we are to continue providing for irrigated agriculture, open spaces, and community buffers, high quality and affordable municipal water supplies, flat water, instream recreational opportunities, and the overall health of our rivers and ecosystems. Class participants include city and town managers, city and town councilmembers, mayors, influential business and real estate leaders, community activists, and other decision makers.

Here are some comments from class members:

❝ *Seeing the various people in the room, each representing different interests* **made me wonder if there is a role for me** *in helping bring those interests together toward beneficial regional outcomes.*❞

❝ **Water is such a complex topic.** *I was relieved that this course came along just as I was elected to city council.* ❞

❝ *I am very interested in the creation of a regional water vision –* **to help Northern Colorado reach its potential**. ❞

SPARK FUELING A REGIONAL DIALOGUE
Out of the first class of Water Literate Leaders, a regional dialogue is beginning to coalesce. A few key players who are passionate about the need have begun to meet to explore the potential for such efforts as connected water facilities, ag/municipal water partnerships for economic development, and common sustainable municipal landscape development code.

One key leader said "A collaborative, cooperative, and productive regional water dialogue would be very advanta-

2018-2019 Class of Water Literate Leaders participates in dialogue with Colorado water experts in September 2018.

geous to the region and would contribute to a better future by maximizing use of available water resources. Sounds like it may be an interesting conversation. I look forward to it!"

Other notable policy and collaboration works this past year were a successful Poudre River Forum, which attracted more than 300 ag/urban/environmental stakeholders, and completion of our USDA Colorado River Basin Ag Water Conservation project with an article titled ***How Can Agriculture in the Colorado River Basin Best Address Pressures on Its Water?*** It is being published by the British publication, Scientia, which can be found at http://www.scientia.global/wp-content/uploads/CSU.pdf.

It was also another successful year for the CSU Water Sustainability Fellows program for historically underrepresented students learning about water and working with north Denver high school students in a National Western Center Youth Water Project culminating in a youth water expo attracting 150 people to Argo Park in Globeville.

Southern Colorado

Blake Osborn, *Regional Water and Extension Specialist, Colorado Water Institute & CSU Extension*

INTRODUCTION

The drought of 2018 has southern Colorado desperately hoping for a good winter snowpack. At the time of this writing, the Arkansas River is at historic lows above John Martin Reservoir with a call date of 1875, a call to 1874 has not happened in the past 20 years (including 2002 and 2012)! Similarly, the Rio Grande River call is at 1875, which is unprecedented over the last 20 years. The good water years of 2016/2017 helped limp southern Colorado through this historic drought, but reservoir levels are declining quickly. Needless to say, much of my time has been spent responding to drought situations by providing science-based information and resources to a variety of water users.

In 2018, I also continued to apply my research and outreach activities through two grant-funded projects: 1) the Lower Arkansas River Watershed Plan, and 2) the Upper Arkansas River Water Balance Study. I am working to build a "disaster response" program for CSU's outward facing institutions to help private landowners understand and respond to natural resource disasters.

PURPOSE

My research and outreach activities center on water conservation, water quality, and best management practices (BMPs). I currently have two grant-funded projects looking at agricultural water use as it relates to water quality and consumptive use. Going forward, I would like to include projects that build on my experience in forest hydrology, including post-disaster response assess-

Visiting Leprino Cheese Wastewater Facility.

ments to improve water quality and restore natural hydrologic processes.

RESULTS
LOWER ARKANSAS RIVER WATERSHED PLAN
This "9-Elements" plan follows a framework developed by the Environmental Protection Agency (EPA) and will be used by the Colorado Department of Public Health and Environment to identify and improve water quality problems below John Martin Reservoir. This watershed plan is a non-regulatory tool to improve water quality through voluntary participation of local stakeholders by implementing water quality BMPs. The plan is mostly written and final comments/edits are being solicited from participating stakeholders. The plan is scheduled to be submitted in January 2019.

Field site, Wet Mountain Valley. Photo by Blake Osborn

UPPER ARKANSAS RIVER WATER BALANCE STUDY
The Upper Arkansas River Water Balance Study is a cooperative research project with the CWI, USGS, and Upper Arkansas River Water Conservancy District. I monitor and quantify agricultural water use in the Upper Arkansas River Watershed and use the data to calibrate an irrigation scheduling tool. This study will continue through 2019 and conclude in 2020.

WATERSHED ASSESSMENT AND VULNERABILITY EVALUATIONS (WAVE)
This new initiative is a collaborative pro-

gram between the CWI, CSFS, Colorado Forest Restoration Institute, and CSU Extension. The WAVE program will capitalize on CSU's statewide reach to help private landowners respond to natural disasters, primarily wildfire recovery, using cutting-edge science and technology resources. This program will develop a series of assessment materials, using the lens of hydrology and water resources, for field-based operations such as CSU Extension and the CSFS. This program is currently looking for start-up funding.

IMPACT
Concerning the Watershed Plan, the short-term impacts from my work will increase the level of knowledge of water quality, mitigation strategies, and partnerships to implement improvements. The long-term impacts will be improved water quality and, hopefully, lasting partnerships between water users and water managers.

Regarding the Water Balance study, the preliminary data is suggesting an irrigation scheduling tool developed by CSU is a good alternative to soil moisture monitoring on high-altitude hay crops. This cost-effective alternative can help irrigators accurately estimate soil moisture and help with water conservation.

The WAVE program will provide on-the-ground assessments and resource vulnerability evaluations to help private landowners identify resource threats and pinpoint funding mechanisms to address these threats.

The Colorado River and Climate Change in the West

Brad Udall, *Senior Water and Climate Research Scientist & Scholar, Colorado Water Institute*

©iStock

INTRODUCTION AND PURPOSE

The impacts of climate change on Colorado and the Western U.S. continue to be at the center of my work and research. For example, this year will be one of the five worst runoff years on the Colorado River, and is the worst in the southwestern portions of the state. I have been especially interested in how record-setting temperatures are reducing streamflows and are leading to the aridification of the American Southwest. To this end, I perform scientific analyses, write peer-reviewed and white papers, review scientific papers, present at scientific and water manager conferences, and interact with the media.

RESULTS

Along with co-authors Mu Xiao and Dennis Lettenmaier of UCLA, in late August I published "On the causes of the Declining Colorado River Flows" in Water Resources Research (WRR), a peer-reviewed journal of the American Geophysical Union. This paper dissects the cause of the declining Colorado River flows over the last 100 years and over the last 20 using a daily model of the entire river basin. In both cases, higher temperatures were found to have caused approximately 50% of the loss of flow, and the other 50% was caused by shifting precipitation patterns from more-productive parts of the basin (Yampa, Headwaters, Gunnison, and San Juan Basins) to less productive (Utah deserts). This work builds on the peer-reviewed paper I wrote last year with co-author Jonathan Overpeck entitled "The Colorado River Hot Drought and Implications for the Future". That paper was extensively covered by the press and continues to be referenced by water managers in many meetings.

I am a lead author on the latest National Climate Assessment, scheduled to be released in early December of 2018. My work is on the American Southwest and features the Colorado River among other rivers in the southwest. Additionally, I co-authored a white paper on aridification this spring with other academics entitled, "When is Drought Not a Drought? Drought, Aridification and the 'New Normal'".

IMPACT

The new WRR article was widely covered in the press including the Arizona Republic,

OTHER WORK

In January, CWI released an entire newsletter devoted to Alternative Transfer Mechanisms (ATMs). This was based in part on my Walton Family Foundation Grant. I continue to be affiliated with the Southwest Climate Science Hub, located at the University of Arizona, which successfully rebid for another 5-year contract. We anticipate working with major Colorado River water providers. With ten other authors from around the globe, I published "The Paradox of Irrigation Efficiency" in Science Magazine in August. This article discusses how irrigation efficiency often does not save water, contrary to what many policy makers believe. We suggest five steps to make sure that IE improvements are not harmful. Within a week, the irrigation efficiency article in Science had been downloaded over 40,000 times. CSU's Climate Smart Agriculture initiative hosted a half-day workshop at the Greeley Farm Show in January. In addition, it has now finished three online courses, with three more to be finished by early 2019. Given the drought impacts in 2018, CSU Extension met in September 2018 to discuss how to better work with producers to prepare for climate impacts.

Denver Post, and Northern Colorado Public Radio. It has served to strongly reinforce the finding in my first paper last year that temperatures are strongly impacting river flows in the American Southwest. The concept of 'aridification' has widely taken hold in the press and popular discourse. Our paper on the topic was featured in numerous newspaper stories this spring.
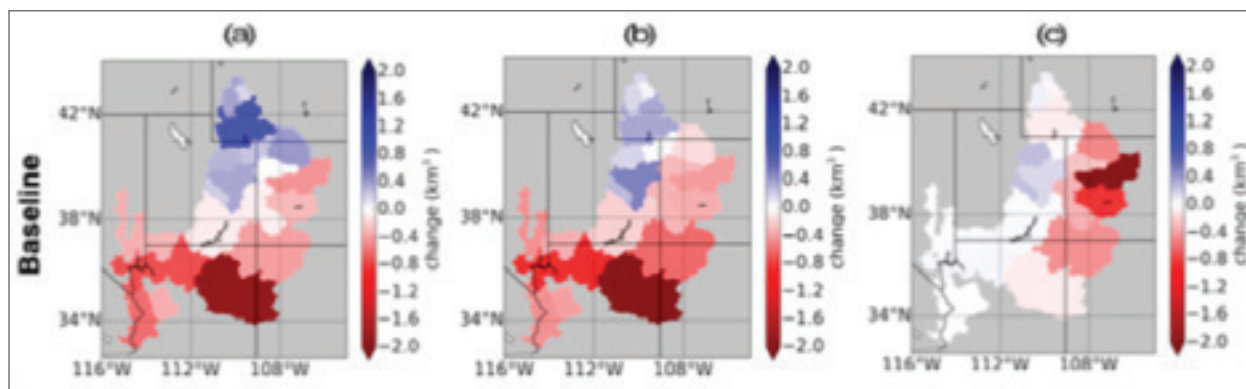
Modeled changes in (a) Colorado River precipitation, (b) evapotranspiration, and (c) runoff from 1916-2014. Note how precipitation has increased in the western portions of the Upper Colorado River Basin in (a) and how runoff has declined in all of the sub-basins in the state of Colorado in (c).

Taking infiltration measurements as part of soil health impacts of residue and tillage management. Photo by Stacey Poland.

Northeastern Colorado

Joel Schneekloth, *Regional Water Specialist, Colorado Water Institute & CSU Extension*

Drought is a constant potential risk in Colorado, oftentimes impacting water resources, reducing snowpack, as well as influencing the growing season. Additionally, Colorado also deals with issues related to the Ogallala Aquifer, such as declining water levels and the declining capacities for management strategies to maximize the economic return of water. Another growing issue for competition of water is urban growth in the Front Range of Colorado. Impacts to water availability will increase to agriculture in the future.

Agriculture in northeastern Colorado is driven by the livestock industry, with the largest concentrations of dairies and feedlots with needs for grain, silage, and hay production. Irrigation is necessary to provide reliable local supplies of feed. In recent years, stover harvest has taken place as a feedstock for feedlots. The impacts of stover harvest and silage have a potential for increased needs of water and a better understanding of the economic impacts.

- *Residue and Tillage Management*
  Harvest of residue or full tillage management have impacts on water needs. Retention of residues on the soil surface increase precipitation storage efficiency as well as reduce evaporative losses. When the residue is harvested for forage, results have shown a yield reduction of up to 15% or an increase in irrigation needs by 30 to 40% for equal yields when compared to conservation tillage or no tillage.

Increased surface residue with no till management has decreased evaporative losses during the vegetative growth stage as compared to conservation tillage or conventional tillage. Reductions have been approximately 5 to 8% of the total evapo-transpiration prior to the reproductive stage of corn. While maintaining residue on the soil surface during the winter, off season precipitation storage efficiency is increased by 50% compared to that of fall tillage or harvest of the residue. Both of these savings can contribute to decreasing irrigation needs during the growing season.

- *Limited/Deficit Irrigation Management*
  As groundwater depletions continue in the Ogallala Aquifer of eastern Colorado, irrigation management strategies that incorporate system capacity implications are needed. Work continues on a long-term database of irrigation management strategies with timing and capacity constraints and the impact on corn grain yields.
- *Soil Health*
  This issue has been of increasing interest for the potential aspect of either increasing yields or for water conservation. However, there is confusion on what soil health is and the implications on water conservation. Long-term projects are needed to document the changes in soil parameters with management practices and what the implications are for yields, water utilization, and economic impacts to producers. This project has been ongoing for 5 years with the projection of continuing indefinitely.

With management changes, economics are still the driving force as to implications of management practices of reduced tillage or the inclusion of cover crops that may or may not increase water availability or utilization in a semi-arid environment.

Measurements are being analyzed to look at soil parameters that coincide with either increased yields or water conservation.

- *Arkansas Valley Research Center (AVRC)*
  As part of increasing irrigation research in Colorado, I collaborated with AVRC and Dr. Mike Bartolo in the designing and installation of a Variable Rate Linear Irrigation system. This system is located on the field with the large lysimeter used in the Arkansas Basin Compliance. The installation of this system will allow for increased irrigation research with increased ability to precisely manage and apply water. This system also allows for more management options which can increase water use efficiency as well as salinity management.

Discussion with producers on the new VRI Linear system at the Arkansas Valley Research Center, Rocky Ford, Colorado. Photo by Bill Cotton.

Figure 1

Western Colorado

Perry Cabot, *Research Scientist and Extension Specialist, Colorado Water Institute & CSU Extension*

INTRODUCTION
The Western Region of the CWI serves the Colorado, Gunnison, Yampa/White, and San Juan/Dolores Basins, which deliver the majority of the water from or within the state. Water resources and irrigation research in the Western Region is dedicated to the optimal use of water in an area affected by competing agricultural, municipal and industrial needs, drought and climate variability, and shifting market demands.

PURPOSE
Agriculture and food production is undergoing rapid change in Western Colorado. Over the next few decades, these changes will become irreversible, due to the confluence of population growth, water shortages, and climate change. With the majority of Colorado water rights held in agriculture, the food production sector faces challenges to increase the conservation and efficiency of water use in multiple ways.

RESULTS
In partnership with CSU Extension and the CSU Agricultural Experiment Station, the CWI supports evaluation, demonstration, and deployment of practices and technologies that optimize water resources.

SUB-SURFACE DRIP IRRIGATION SYSTEM
Construction began this year on a 5.45 ac subsurface drip irrigation system that will accommodate separate control and monitoring of 66 individually addressed plots (12 beds at 30" x 120' long; 0.08 ac). This system will support research on crop water balances at varying irrigation and agricultural input (e.g., fertilizer) rates while also providing farmers a resource to learn about this valuable water-saving technology. The sub-surface dripline installation also allows this field to be managed using no-tillage and minimum-tillage practices, consistent with the goals of climate-smart agriculture and soil health.

AUTOMATED CHECK-STRUCTURE SYSTEM
While furrow irrigation is more inherently inefficient than other forms of irrigation, there are modest improvements (15-20%) possible in the efficiency of these systems. Through a partnership with Watch Technologies, the use of automated check structures is under evaluation. These tools establish communication between canal check structures and in-field soil moisture levels to control water delivery. By reducing water deliveries once optimal watering has

occurred, runoff, nutrient, and sediment losses are lowered using technology that is realistic for forage production systems.

CONSERVED CONSUMPTIVE USE EVALUATIONS

Improved measurement and verification of consumptive use (CU) could reduce costs of monitoring and increase reliability of water-sharing programs. Remote-sensing and radiometric based assessments can better represent actual CU (ACU) since they are much closer to real-time and actual conditions. These methods have been advocated as an alternative method for estimating actual CU where diversion records are too coarse to quantify CU at parcel scales, empirical models are not sufficiently specific for regional business transactions and program monitoring. A multispectral handheld radiometer device was used to measure reflectance readings at the ground-based level for selected grass hay/pastures (Figure 1). An empirical regression model was developed utilizing Normalized Difference Vegetation Index (NDVI) and actual crop coefficient data (Figure 2). The reflectance-based actual

crop coefficient (Kca) is estimated here is related to vegetation indices by an equation, such as $Kca = a \times (VI) + b$.

COLLABORATION WITH WESTERN REGION AND TRI-RIVER AREA EXTENSION

Collaboration exists with CSU Extension in the area, notably including the study of sub-optimal, optimal, and excessive irrigation of various Plant Select landscape plants. These plants were selected for their local commercial availability, aesthetic appeal, and drought tolerance. Demonstration of low-water use turf (buffalo + blue grama) have also showcased the viability and aesthetics of these options in the arid West (Figure 3).

IMPACT

Additional pressures are placed on water resources in the Western Region due to its position in the Upper Colorado River Basin as a significant signatory state in the Colorado River Compact. Despite the expansiveness of the region, these research programs represent nexus areas of water planning where the CWI focuses its resources to effect lasting impact.
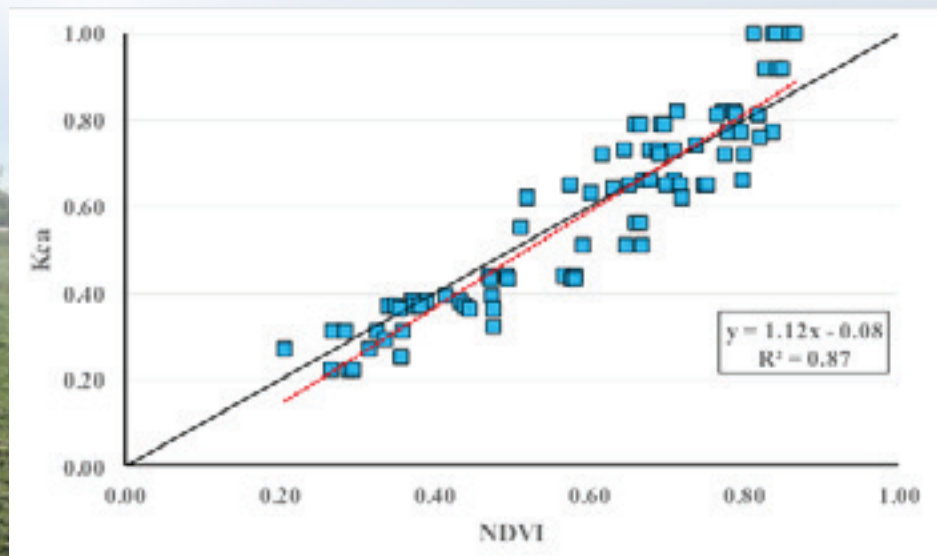
Figure 2

$$y = 1.12x - 0.08$$
$$R^2 = 0.87$$

Figure 3
Photo by Perry Cabot

YEAR IN REVIEW

GRAD592 〈〈〈〈 〈〈〈〈〈

CWI organizes and conducts a graduate level course offered in the fall at CSU. GRAD592 is taught by Jennifer Gimbel, CWI's Senior Water Policy Scholar, and hosts interested students in a variety of degree fields and academic ranks.

Described as an interdisciplinary water resources seminar, GRAD592 offers its attendees the opportunity to learn from and engage with distinguished lecturers from a variety of fields on the basis of each semester's theme.

In FY2017 and FY2018, themes included water management in Colorado and Colorado water law respectively and covered a multitude of sub-topics, including:

- **Changing a Water Right**
- **Project Development and Financing**
- **Political Process in Water Management**
- **Groundwater Law**
- **Interstate Compacts**
- **and many more!**

While offered for school credit at CSU, the course is also open to the public and welcomes anyone who wishes to educate themselves on the issues and challenges that Colorado water managers and users face.

To learn more about GRAD592 and watch previously recorded lectures, please visit **cwi.colostate.edu**

IMPACT HIGHLIGHTS
FALL 2017 & FALL 2018

31 students

14 different degree fields:

» Agricultural & Resource Economics
» Agricultural Business
» Animal Science
» Chemical Engineering
» Civil Engineering
» Earth Science
» Ecosystem Science & Sustainability
» Fish, Wildlife & Conservation Biology
» Forest Services
» Horticulture
» Political Science
» Sociology
» Soil and Crop Science
» Watershed Science

16 different organizations

17 guest speakers

COLORADO WATER >>> CWI's Bi-Monthly Newsletter

3,300+ subscribers

18 countries

V34, I6
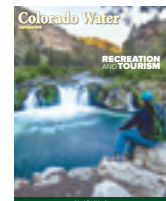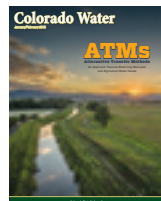November/December 2017
The Ogallala Aquifer

V35, I1
January/February 2018
Alternative Transfer Methods

V35, I2
March/April 2018
Natural Hazards

V35, I3
May/June 2018
Student Research

V35, I4
July/August 2018
Recreation and Tourism

Map ©Vecteezy

For an archive of newsletters, please visit
http://cwi.colostate.edu/Newsletters.aspx

CWI Reports

CR232

Agricultural Water Conservation in the
Colorado River Basin: Alternatives to
Permanent Fallowing Research Synthesis
and Outreach Workshops

By Brad Udall and Greg Peterson

SR32

The Economics of Irrigation in Colorado's
Lower Arkansas River Valley

*By Blake Osborn, Anthony S. Orlando, Dana L.
Hoag, Timothy K. Gates, and James C. Valliant*

For more, please visit **http://cwi.colostate.edu/Publications.aspx**

The Newly Founded
Irrigation Innovation Consortium
is Full Ahead Go in 2018

By Stephen Smith, Wade Water LLC.

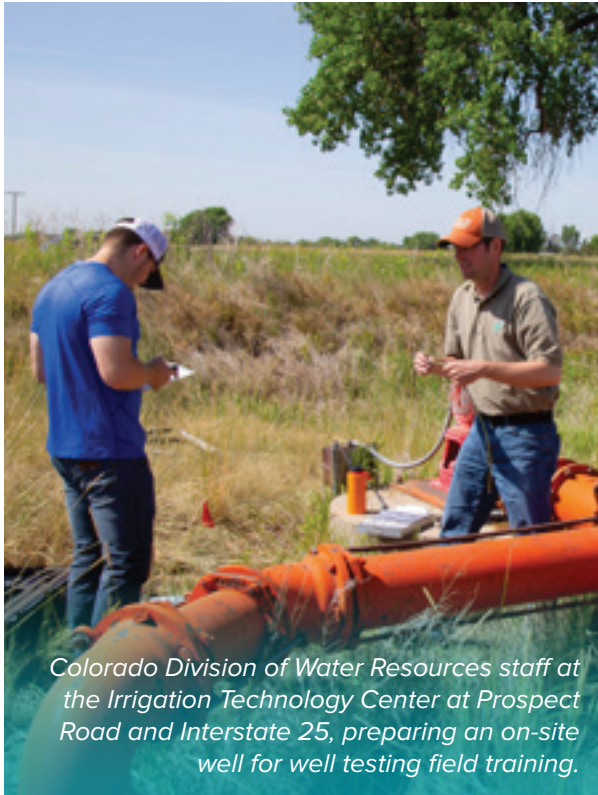*Colorado Division of Water Resources staff at the Irrigation Technology Center at Prospect Road and Interstate 25, preparing an on-site well for well testing field training.*

In April 2017, the Foundation for Food and Agriculture Research (https://foundationfar.org/) hosted a "Convening Event" in Lincoln, Nebraska. The question for the group at that time was "Is there need, and suitable industry support, for focused research, demonstration, and training in irrigation—both landscape and agriculture irrigation?" The Convening Event participants strongly affirmed the need and validity of the idea. Supporting comments from the participants in Lincoln then resulted in an intense yearlong effort to develop a proposal to form a consortium between five land-grant universities, the irrigation industry, FFAR, and others. The formative effort came to be known as the Irrigation Innovation Consortium (IIC) and the formal proposal for funding was submitted to FFAR in February 2018.

FFAR, as a 501(c)3 non-profit organization, was both founded and funded by the 2014 Farm Bill. Initial funding for FFAR was set at $200 million and FFAR has subsequently funded many significant projects in the gap or white space that exists in much of our funded agriculture research programs nationwide. Projects are funded on a 1:1 match basis with any non-federal matching dollars.

The Irrigation Innovation Consortium (http://irrigationinnovation.org/) was formally announced last April 28th in Denver with FFAR, all the universities, and participating industry partners present. Since the announcement, the 2018 research objectives under four identified research themes came together quickly under the guidance of the CWI.

Twelve additional universities are interested in joining the Consortium in phase 2. It should be noted that the Consortium is definitely not a "project" per se, but like a high technology start-up business, the Consortium is intended to be sustainable based on present and future identified needs within the irrigation industry.

The governance of the Consortium is overseen by an Executive Committee (EC) and a Director. The EC consists of representatives from FFAR, the Irrigation Association, all five of the founding universities, and irrigation industry founding members. The EC is directly advised by a Research Steering Committee (RSC), which recently met for-

FOUNDING MEMBERS

- California State University, Fresno
- Colorado State University
- Daugherty Water for Food Global Institute at the University of Nebraska Irrigation Association
- Jain Irrigation
- Kansas State Research and Extension, Kansas State University
- Lindsay Corporation
- Northern Water
- Rubicon Water
- Texas A&M AgriLife Research

mally for the first time in Fresno, California. Fresno State hosted the first meeting of the RSC. The RSC and the EC will again meet in Long Beach, California concurrently with the Irrigation Association annual meeting.

While the IIC's governance model emphasizes that strategic research direction will be set by the Executive Committee, with technical advice from the Research Steering Committee, the prioritized focus areas are set within the following areas:

- Water and Energy Efficiency
- Remote Sensing and Big Data Applications (aka IoT) for Irrigation Water Management
- System Integration and Management
- Irrigation Technology Acceleration and Technology Transfer

At its core, the IIC is a collaborative research effort intended to accelerate the development and adoption of water and energy-efficient agriculture and landscape irrigation technologies and practices through public-private partnerships. Public sector researchers and industry partners will co-develop, test, prototype and improve innovations, equipment, technology, and decision and information systems designed to equip "farms of the future" with cutting-edge technologies and optimization strategies to enhance irrigation efficiency.

Under the IIC banner, current plans in Colorado include a new Irrigation Technology Center that will be located on an irrigated farm in Fort Collins, Colorado at the interchange between Interstate 25 and Prospect Road. The farm was offered to the IIC by the CSU Research Foundation. Detailed design plans have already been commissioned. Multiple water sources at the site include Lake Canal surface supplies, Gray Lakes late season supplies, a decreed Coffin well, and leased CBT units owned by CSU. Conceptually at the present time, the site will have an on-site weather station, a lined pond for multiple water sources, VFD pump stations, a center pivot with variable rate irrigation, and subsurface drip irrigation.

Any organizations interested in joining the Irrigation Innovation Consortium are invited to contact Stephen Smith at swsmith@buenavidafarm.com

Photo by Chelsey Heiden

Upper Yampa Water Conservancy District John Fetcher Scholarship 2018-2019 Recipient

MARISSA KARPACK

By Melissa Mokry, Editor, Colorado Water Institute

The Upper Yampa Water Conservancy District John Fetcher Scholarship provides financial assistance to a committed and talented student who is pursuing a water-related career in any major at a public university within the state of Colorado.

Congratulations to this year's scholarship recipient, Marissa Karpack.

While at CSU, Karpack has been a graduate teaching assistant for undergraduate civil engineering courses. She was the 2017-2018 Walter Scott, Jr. Graduate Fellow and plans on pursuing a career in river engineering. More specifically, Karpack hopes to pursue hydraulic engineering, incorporating 2D and 3D numerical river modeling. Karpack has previously worked for the Engineers Without Borders at CSU as a Design Engineer and as the International Projects Director during her undergraduate time at the University of Washington. The ultimate goal of her education and work experience is to develop effective long-term solutions to river and floodplain issues.

RECIPIENT INFORMATION

University	**Area of Interest**
Colorado State University	Hydrology and hydraulics, emphasis on river and floodplain processes
Major	**Anticipated Graduation**
Masters of Science in Civil & Environmental Engineering	May 2019

2017-2018 CWI STAFF

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Water Resources
Specialist

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Former State
Climatologist

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Senior Web Developer

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Senior Water
Policy Scholar

Nancy Grice
Assistant to
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Specialist

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Postdoctoral Fellow

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Water Resources
Specialist

Joel Schneekloth
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Specialist

MaryLou Smith
Policy & Collaboration
Specialist

Brad Udall
Water & Climate
Research Scientist/Scholar

Reagan Waskom
Director

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Accounting

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Computer Science

■ **Emma Enebo**
Administrative Assistant
Ecosystem Science
& Sustainability

▲ **Mason Fout**
IT Intern
Computer Science

● **Anna Meiser**
Accounting Intern
Art and Art History

❯❯ **Melissa Mokry**
Editor
Journalism and Media
Communications

◆ **Emily Pantoja**
Senior Graphic Designer
Art and Art History

❯ **Elizabeth Plombon**
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Sociology

● **Courtney Reece**
Travel Coordinator
Accounting

● **Jennifer Reiher**
Administrative Assistant
Sociology

● **Hunter Scofield**
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● **Ethan Worker**
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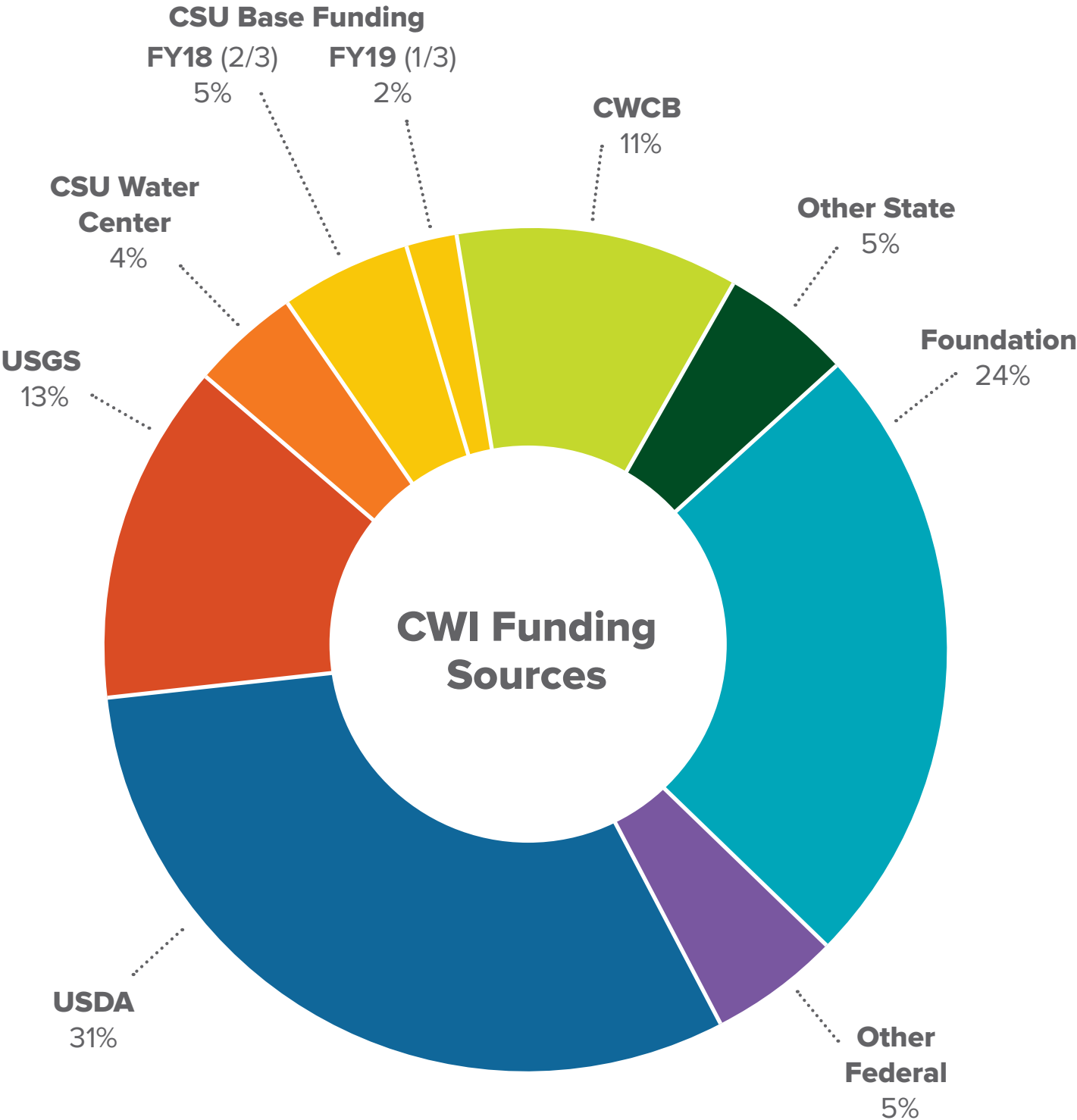Northern Colorado Water
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FINANCIAL SUMMARY

Reporting Period: November 1, 2017 - October 31, 2018

CSU Base Funding
FY18 (2/3)
5%

FY19 (1/3)
2%

CSU Water Center
4%

USGS
13%

CWCB
11%

Other State
5%

Foundation
24%

CWI Funding Sources

USDA
31%

Other Federal
5%

SUMMARY BREAKDOWN

CWI FUNDING SOURCES

CSU Base Funding *	$ 441,784
CWCB	$ 653,777
Other State	$ 277,890
Foundation	$ 1,429,517
Other Federal	$ 319,289
USDA	$ 1,852,606
USGS	$ 769,514
CSU Water Center	$ 250,415
Total	**$ 5,994,792**

ACTIVE PROJECT TYPE

Research	49
Education	2
Outreach	4
Internships	3
Training	7
Total	**65**

STUDENT DEGREE LEVEL ON PROJECTS

Undergraduate	25
Masters	18
Ph.D.	19
Total	**62**

The reporting period spans CSU fiscal years 17 and 18.
* Multiple research projects being conducted during a multi-year timeframe can cause over-lap in funding.

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