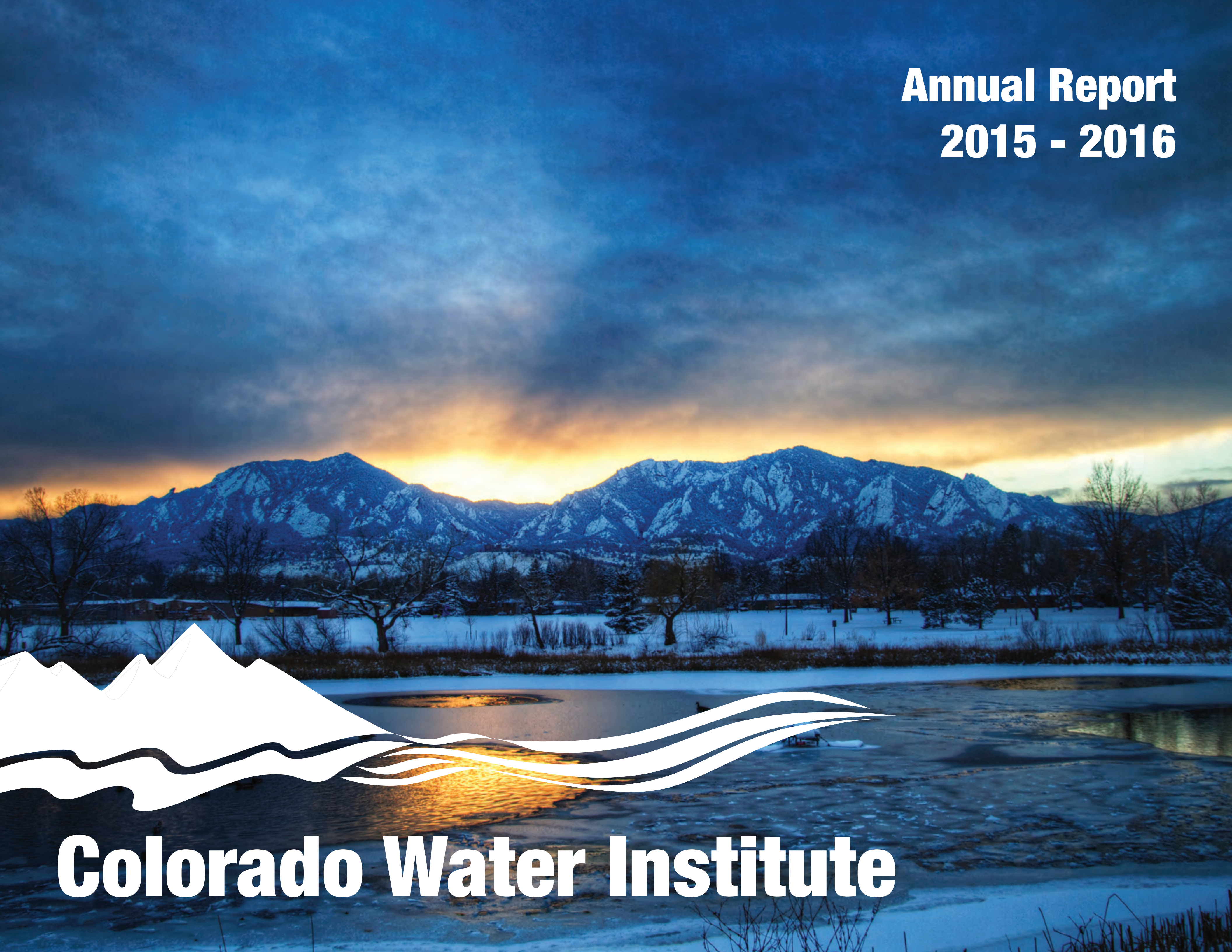


Annual Report 2015 - 2016

Colorado Water Institute

Contents

Message from the Director

CWI continued to serve its research, outreach, and training mission in 2016 through funding research projects and student internships in cooperation with the Colorado Water Conservation Board and the U.S. Geological Survey. Several of our projects are highlighted in this annual report, including our work on the Cache la Poudre and Colorado rivers. CWI staff worked to provide clarity on Colorado's approach to the so-called "use it or lose it" provision of our laws, rain water harvesting and alternatives to agricultural buy and dry. Additional work on hydraulic fracturing in the South Platte and agricultural conservation in the Ogallala put CWI in the middle of currently controversial water topics in Colorado. Through the work of outstanding past leaders such as Robert Ward, Neil Grigg, and Norm Evans, the institute has worked with faculty and students from all of Colorado's institutions of higher education to produce many important projects that provide water managers with new information to improve decision-making for the past five years. While the societal context of water management continues to evolve, we confront the same water management, quality, and quantity problems as Colorado seeks to cope with limited water supplies punctuated with periodic drought and flood. CWI will continue to support the training of the next generation of water managers through research project funding and internships. As CWI director, I am pleased to report this year that the institute continues to benefit from a committed staff, excellent support from Colorado State University upper administration, and the guidance of an outstanding advisory committee. This 2016 annual report contains only the highlights of our activities in service to Colorado this past year. More information on our activities can be found at www.cwi.colostate.edu.

Colorado Water Institute

Colorado Water Research

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 private industry 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 Colorado institutions of higher education.

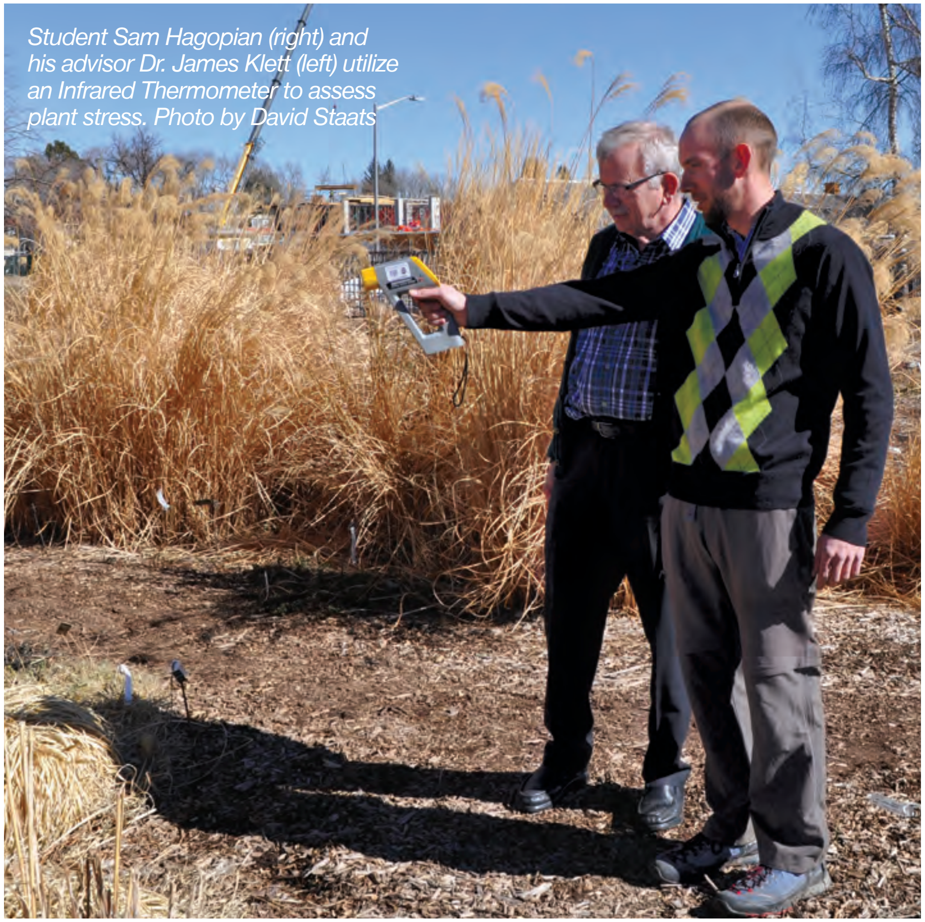
Outreach/Information Transfer

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 updates, and water-related events and conferences, featuring a different research theme each issue.

CWI outreach activities are conducted in conjunction with the CSU Water Center, CSU Extension, the Colorado Agricultural Experiment Station, the Colorado State Forest Service, and the Colorado Climate Center. 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 place student interns in positions and also funds student research grants and manages scholarships on behalf of students. Student researchers funded by CWI work with faculty members and gain valuable water expertise as well as knowledge of the research process.



Student Sam Hagopian (right) and his advisor Dr. James Klett (left) utilize an Infrared Thermometer to assess plant stress. Photo by David Staats

CWI Websites

- cwi.colostate.edu/southplatte/
- cwi.colostate.edu/ThePoudreRunsThroughIt/
- crbagwater.colostate.edu/index.shtml
- agwaterconservation.colostate.edu/

Selected Current Projects

FACULTY RESEARCH

- *Developing a Refined Groundwater Flow Model for the LaSalle/Gilcrest Area*
  Ryan Bailey, Colorado State University; CWCB
- *Quantifying Pumping-Induced Streamflow Depletion in the South Platte River Corridor*
  Ryan Bailey, Colorado State University; CWCB
- *Data Collection and Analysis in Support of Improved Water management in the Arkansas River Basin, Phase 3*
  Timothy Gates, Colorado State University; CWCB
- *Aquifer Storage and Recovery – Fountain Formation in Northern Colorado*
  Tom Sale, Colorado State University; CWCB
- *Colorado Irrigation Center Design and Concept Development*
  Jose Chavez, Colorado State University; CWCB
- *Enhanced Open Data for Colorado's Water Resources*
  Steve Malers, Colorado State University; CWCB
- *Agronomic Responces to Partial and Full Season Fallowing of Alfalafa and Grass Hayfields*
  Perry Cabot, Colorado State University; CWCB
- *Determination of Consumptive Water Use of Winter Wheat in the Arkansas Valley (Year 2)*
  Allan Andales, Colorado State University; CWCB
- *WOOD: Windows Of Opportunity for Debris Retention in Response to 2013 Front Range Flooding*
  Ellen Wohl, Colorado State University; CWI
- *Economic Impact Analysis of Decreased Crop Production Due to Reduced Groundwater Irrigation in the San Luis Valley*
  Reagan Waskom and James Pritchett, Colorado State University; San Luis Valley
- *Alternatives to Permanent Fallowing Research Synthesis and Workshops*
  Brad Udall, Colorado State University; Walton Family Foundation
- *Investigating the Beneficial Links Between Oil and Gas Production and Agriculture Using Water as the Common Currency*
  Reagan Waskom and Kenneth Carlson, Colorado State University; CU-Boulder/ NSF
- *Enhancing Decision-Making by Agricultural Producers in Colorado with Weather Variability: Reducing Enterprise Risk and Increasing Resilience*
  Lou Swanson and Brad Udall, Colorado State University; USDA-ARS
- *Moving Forward on Agricultural Water Conservation in the Colorado River Basin*
  Reagan Waskom, Colorado State University; USDA-NIFA
- *Climate Risk Informed Decision Analysis (CRIDA)*
  Reagan Waskom, Colorado State University; NIWR 104S/ DOI-USGS
- *Application of Remotely Sensed Data for Improved Regional and National Hydrologic Simulations - Year 2*
  Reagan Waskom and Terri Hogue, Colorado State University; NIWR 104S/ DOI-USGS
- *USGS Sedimentary Transport Internship*
  Allen Gellis; NIWR 104S/ DOI-USGS
- *ICIWaRM Research Workshops and Advisory Committee*
  Reagan Waskom, Colorado State University; DOI-USGS-Geological Survey
- *WEBB-Water, Energy, and Biogeochemical Budgets NIWR-USGS Student Internship Program*
  Reagan Waskom, Colorado State University; DOI-USGS-Geological Survey
- *MOWS - Modeling of Watershed Systems NIWR-USGS Student Internship II*
  Steve Regan; NIWR 104S/ DOI-USGS
- *Trace Organic Contaminants (TOrCs) in Urban Stormwater and Performance of Urban Bioretention Systems: a Field and Modeling Study*
  Christopher Higgins, Colorado State University; NIWR 104G/ DOI-USGS

Selected Current Projects

STUDENT RESEARCH

- *Investigating relationships between drought management strategies and factors contributing to their selection in analysis of adaptive capacity of South Platte River Basin water providers*
  Dennis Ojima and Amber Childress-Runyon, Colorado State University; NIWR 104B/ DOI-USGS
- *Watershed monitoring across the snow transition zone: an east slope-west slope comparison*
  Stephanie, Kampf and John Hammond, Colorado State University; NIWR 104B/ DOI-USGS
- *Changes in water, sediment and organic carbon storage in active and abandoned beaver meadows*
  Ellen Wohl and DeAnna Laurel, Colorado State University; NIWR 104B/ DOI-USGS
- *Evaluating wood jam stability in rivers*
  Ellen Wohl and Daniel Scott, Colorado State University; NIWR 104B/ DOI-USGS
- *Channel restoration monitoring of the Upper Colorado River, Rocky Mountain National Park, CO*
  Sara Rathburn and Matthew Sparacino, Colorado State University; NIWR 104B/ DOI-USGS
- *Water sampling and the effects of plastic absorption on heavy metals*
  Randi Brazeau and Haley Sir, Metro State University, Denver; NIWR 104B/ DOI-USGS
- *Microbial community responses to metals contamination: mechanisms of metals exposure and bioaccumulation in a stream food web*
  Brian Wolff and William Clements, Colorado State University; NIWR 104B/ DOI-USGS
- *Comparing fine scale snow depth measurements at rocky and flat surfaces using lidar and photogrammetry derived digital elevation models*
  Steven Fassnacht and Roy Gilbert, Colorado State University; NIWR 104B/ DOI-USGS

CSU WATER CENTER RESEARCH

- *New Frontiers in the Nexus of Food, Energy, and Water Systems: Exploring Food Crop Uptake of Contaminants from Oil & Gas Wastewater*
  Jens Blotevogel, Colorado State University; CSU Water Center
- *Evaluating alternative water and nutrient management strategies as climate-smart agricultural options for Colorado and beyond*
  Steven Fonte, Colorado State University; CSU Water Center
- *Investigation of the Effects of Whitewater Parks on Native Fishes in Colorado: A Novel Two-Dimensional Modeling Approach*
  Christopher Myrick, Colorado State University; CSU Water Center
- *Evaluating the Energy Cost of Groundwater Production in the Denver Basin Sandstone Aquifers*
  Michael Ronayne, Colorado State University; CSU Water Center
- *One Health Surveillance of Antimicrobial Resistant Bacteria in Fort Collins, CO*
  Elizabeth Ryan, Colorado State University; CSU Water Center
- *Toward a Quantitative Estimate of Organic Carbon Storage in River Corridors of the United States*
  Ellen Wohl, Colorado State University; CSU Water Center
- *CSU Subsurface Water Storage Workshop/Symposium*
  Tom Sale, Colorado State University; CSU Water Center

Student Research

NIWR 104B/ DOI-USGS Funded

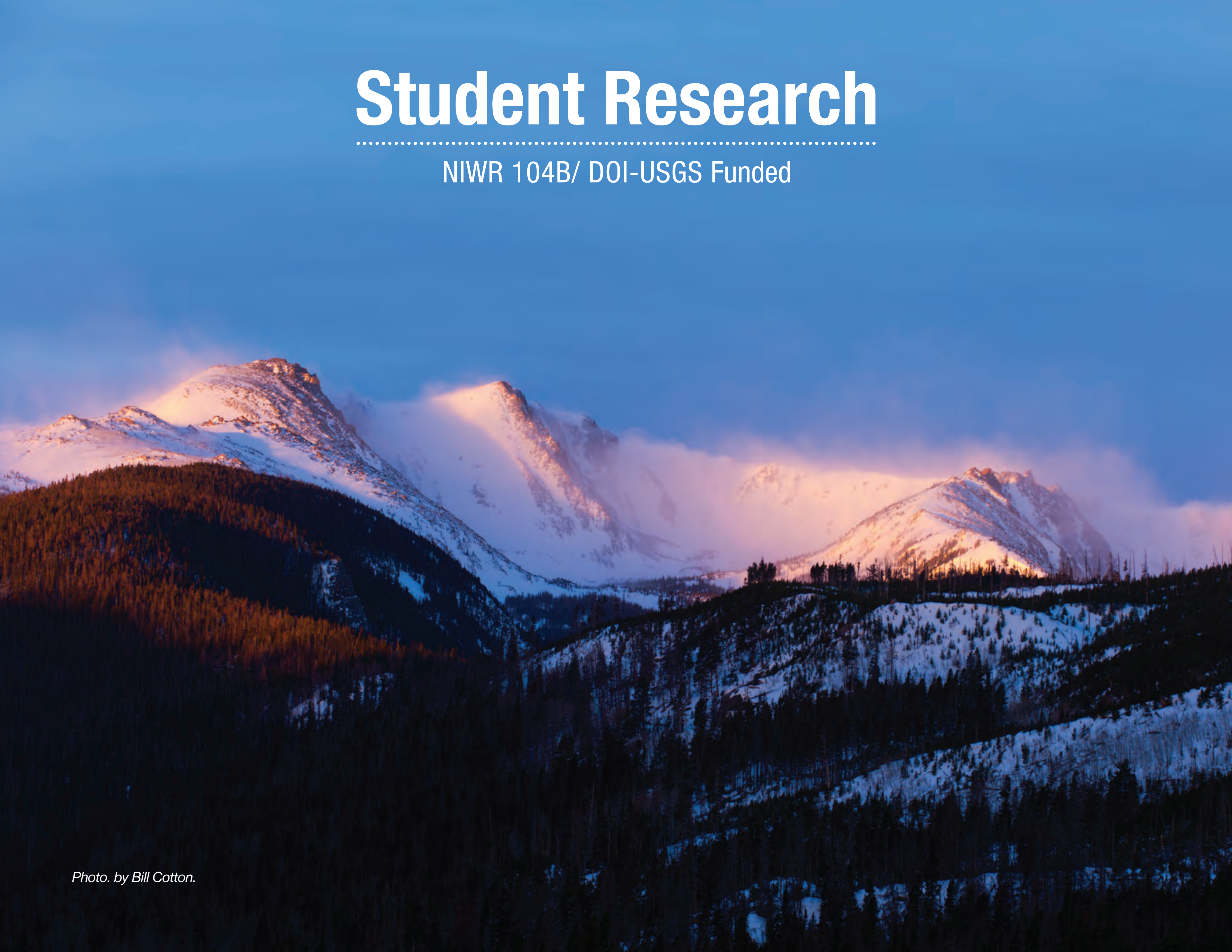


Photo. by Bill Cotton.

Snowpack Accumulation Patterns Across the Southern Rocky Mountains

Benjamin C. VonThaden, MS Candidate, Watershed Science, Colorado State University
Dr. Steven R. Fassnacht, Ecosystem Science and Sustainability, Colorado State University

Understanding patterns and variability in spatial snow distribution is critical in determining the timing, magnitude, and inter-annual consistency of snowmelt runoff and are crucial inputs to snowmelt hydrology models. Year-to-year patterns are known to exist in snowpack properties. This study used variogram analysis with snow water equivalent (SWE) data at 90 long-term Natural Resources Conservation Service Snow Telemetry (SNOTEL) stations located across the Southern Rocky Mountains to examine the consistency and spatial extent of snowpack accumulation patterns. The following objectives were addressed: (1) determine how SWE varies for individual dates in the accumulation season, (2) determine the consistency of snowpack accumulation patterns over time for all pairs of SNOTEL stations, (3) if the patterns are consistent, determine the spatial extent of this consistency, and (4) define if subsets of stations pairs can better explain spatial accumulation patterns.

Variograms were constructed through pair-wise analysis in which each long-term SNOTEL station was compared among all other 89 SNOTEL stations for the period of record. Initially two variograms were constructed from individual day SWE values based on: (1) four dates in separate accumulation years from a high, low and two average accumulation years, and (2) four dates in the same accumulation year. The individual day SWE variograms were used to examine how SWE varies for individual dates in the accumulation season.

Starting with one SNOTEL pair, the first step was to identify the concurrent period of accumulation for the first year on record. This concurrent period of accumulation begins when both SNOTEL stations have begun accumulating and ends as soon as one of the SNOTEL stations reaches its maximum annual SWE. The SNOTEL station with the larger maximum mean SWE is set as the independent variable and the other is set as the dependent. The relative accumulation slope is computed from SWE values on the same day for the entire accumulation season. Next, the variance is computed for all station pairs within a range of lag distances, herein using 20 kilometer intervals, and the variogram is plotted. Additionally, the data were subset into SNOTEL station pairs based on their latitude and by the land cover type.

The relative accumulation rate in the Southern Rocky Mountains was found to be constant up until 100 kilometers, after which it displays a steeper but constant (almost linear) increase. Beyond 340 kilometers the relative accumulation rate shows a steeper (cubic) increase. The location-based variogram showed the most variability in relative accumulation rates to occur in the south zone station pairs. While the land cover-based variogram exhibited scale breaks around 140 kilometers for all three land cover types, land cover showed little effect on relative accumulation rates. This approach provides a new method to analyze snowpack accumulation. The scale breaks can be used to inform snow accumulation modeling and sampling strategies at larger scales, as well as inform the placement and spacing of future snowpack measurement stations.

Benjamin Von Thaden and Dr. Steven Fassnacht measure snow depths and record GPS coordinates during the 2014 Little South Fork of the Cache la Poudre Snow Survey. Photos by Bill Cotton

Spatiotemporal Assessment of Groundwater Resources in the South Platte Basin, Colorado

Christopher J. Ruybal, PhD Candidate, Civil and Environmental Engineering, Colorado School of Mines
Dr. John E. McCray, Civil and Environmental Engineering, Colorado School of Mines
Dr. Terri S. Hogue, Civil and Environmental Engineering, Colorado School of Mines

In recent years, the water-energy nexus emerged in the crosshairs of public debate. Until the downturn in June 2014, oil and gas production reached historic levels due to hydraulic fracturing and directional drilling, helping drive production in low-permeability, unconventional reservoirs. While much attention has centered on issues of groundwater contamination from hydraulic fracturing operations, less has focused on competition for water resources. The growing need for water among urban users, agriculture, industry, and increased energy development presents challenges in over-appropriated and water-limited systems. Colorado is recognized as one of the top ten oil and gas producing states. Lack of rigorous water accounting has limited the ability to fully understand any additional stresses that oil and gas operations may place on aquifers. The overarching goal of this research is to evaluate the potential impacts of oil and gas production on groundwater resources within the South Platte Basin to better manage current and future water resources within the region. Specifically, objectives included: (1) identifying areas that are experiencing significant energy development and competition for groundwater, and (2) utilize ground-based and satellite data to improve understanding of regional aquifer stresses and variability.

Christopher Ruybal (left) and his advisor, Dr. John McCray (right) assessing the impacts of oil and gas production on groundwater within the South Platte Basin.

Initial analysis of regional aquifer stress was performed using water level measurements from traditional groundwater observation wells. Furthermore, the Gravity Recovery and Climate Experiment Satellites (GRACE) was utilized to measure monthly spatial and temporal changes in the Earth's gravity field. By measuring changes in gravity, water storage changes in surface waters, snow, ice, soil moisture, and groundwater can be inferred. In addition, a Mann-Kendall Test of trend was applied to each aquifer series to evaluate whether a significant increase or decrease trend existed from 1995–2015. Monthly GRACE derived groundwater storage anomalies (km3) for a grid pixel centered over the Denver Basin Aquifer System were compared to 277 ground-based observation wells. Comparison of GRACE with the U.S. Drought Monitor, shows a correlation between groundwater response during wet and dry periods associated with the variable climate. In early 2011, approximately 80% of the South Platte Basin was characterized as being in moderate drought, and by 2012 to mid-2013, the entire basin ranged from moderate to exceptional drought. The drought severity is consistent with GRACE derived groundwater depletions and trends during this drought period.

This work indicates the importance of good temporal and spatial data that are needed to investigate groundwater storage changes. To evaluate the potential impacts of oil and gas production on groundwater resources within the South Platte Basin and to better manage current and future water resources in the region, ongoing work includes the following: (1) obtaining aquifer properties for each observation well to enable estimates of water storage changes from ground-based data, (2) evaluating the limits of GRACE when applied to smaller scale basins and providing a comparison to observational well data, (3) evaluating depletion rates before and after the increase in energy development, and (4) developing a high resolution groundwater model of the region, using spatiotemporal data to assess recharge regimes under current and future climate and land use.

Shaping Water Access and Allocation: A Relation Analysis of Water Use for Oil and Gas Development in Colorado

Karie Boone, PhD Candidate, Geosciences, Colorado State University
Dr. Melinda Laituri, Ecosystem Science and Sustainability, Colorado State University

The state of Colorado's Division of Water Resources considers water use for oil and gas (OG) extraction activities as short-term and an insignificant percentage of Colorado's overall water consumption. The Statewide Water Supply Plan makes no mention of concern about OG water uses; and OG activities are not represented at the Basin Roundtables, a state initiated water governance mechanism mandated to integrate bottom-up, local decision-making into the State's Water Plan. The quantity and sourcing of water for OG operations are not accurately documented or fully understood by state agencies. At the same time, the number of active OG wells in the state has gone from 22,500 in 2002 to almost 54,000 in 2016. Changing water use is particularly important on the South Platte River in Weld County and the Colorado River in Garfield County since they contain the largest percentage of active wells. A comparative case study was conducted for this study, spanning the U.S. Continental Divide to investigate divergent influence and change of OG water use in Garfield and Weld counties. More specifically, a mixed-methods approach was used to integrate historical institutional analysis, document analysis of water rights, in-depth interviews, and geographic information systems (GIS).

Water rights have evolved differently across Weld and Garfield counties and within the South Platte and Colorado River Basins. Thus, OG operators in these two counties acquire water through distinct access mechanisms. The South Platte River Basin flows through Weld County, out towards eastern Colorado and Nebraska. The river supplies the greatest concentration of irrigated agricultural lands in Colorado. OG began in the early 2000s and Weld County is the top producing county. The South Platte River is over-appropriated and OG operators are nevertheless able to access water for OG development. On the western side of the Continental Divide, Garfield County is the second largest producing county after Weld County and located on the main stem of the Colorado River Basin (CRB). OG operators lease small amounts of CRB water from private entities, however, the predominant trend is for OG companies to own their own water rights. Many of these rights remain 'conditional,'

Karie Boone (left) conducting an interview for her research project. Photo by Karie Boone.

meaning they have reserved a place in the priority list, have proven intent to divert the water by taking a justifiable first step toward development but do not immediately need to put the water toward a beneficial use. The different access and allocation mechanisms across the two counties represent divergent interpretations of the same institution of prior appropriation rooted in unique contexts and histories.

This research project has provided the opportunity to get to know a diversity of water users, understand their interests, concerns, and vision for the future of water access and allocation in Colorado. Participating communities share a lot in common, while at the same time work through points of contention and historical grudges. Despite the diversity and challenges, there remains a common mission to do what is necessary to keep water for agriculture alive in Colorado.

Floating Wetland Systems: Managing Aquatic Plants as a Selenium Sequestration Strategy

Craig D. Moore, BS Student, Environmental Science and Technology, Colorado Mesa University
Dr. Gigi Richard, Geosciences, and Director for the Water Center, Colorado Mesa University
Dr. Perry E. Cabot, Research Scientist and Extension Specialist, Colorado Water Institute

Student Craig Moore. Photo by Nicholas Harshman

Excessive concentrations of selenium (Se) in natural water systems is of growing concern in western Colorado. At elevated levels, Se is a bio-accumulative toxin to aquatic wildlife. Percolation of irrigation water through the local Se laden soils has been described within the Department of the Interior's Programmatic Biological Opinion (PBO) for the Aspinall unit as inhibiting recovery of four local endangered fish species and concentrations in the Gunnison River at Whitewater exceed the state chronic standard (4.6 ppb). Approximately 8,000 pounds per year of Se needs to be eliminated from the current Se load to the Upper Colorado Basin in order to meet the water quality standard acceptable for local endangered fish species. The purpose of this project is to demonstrate that a consortium of halophytic plant species in a managed floating wetland system is capable of improving water quality by sequestering Se in their root tissue and leaf and stem (referred to collectively as "shoot") tissue under field conditions.

Four species of wetland plants were selected for their demonstrated or predicted ability to take up and accumulate Se from an aquatic system, for salinity tolerance, and for regional availability. Twenty replicates of each of the following species were purchased from AlpineEco Nursery in Denver, Colorado: Nebraska Sedge (Carex nebrascensis), Common Spikerush (Eleocharis palistrus), Baltic Rush (Juncus balticus), and Panicled Bulrush (Scirpus microcarpus).

The study site was a gravel pit pond located adjacent to the Colorado River in Mesa County, Colorado. A constructed floating wetland was installed in July, 2015 and extracted in October, 2015. Following removal, measurements were taken for root depth and stand height. Plants were dried for at least 48 hours at approximately 80° C and separated into their constituent root and shoot (leaf and stem) systems, after which the mass of the separated aliquots were recorded. The samples were then grounded using a laboratory blender and subsequently underwent chemical analysis for Se at ACZ Labs in Steamboat Springs, Colorado using the Environmental Protection Agency's method M6020 ICP-MS. Two additional replicates of each species were designated as reference samples. These individuals were grown in greenhouse conditions and also analyzed for Se concentration. The species specific reference concentration was subtracted from each treatment concentration to obtain the Se concentration accumulated from the study site by each treatment replicate. The average Se concentration of each replicate was determined by subtracting the reference concentration from the final concentration after the field season.

The study documented that Panicled Bulrush outperformed the other three species in terms of plant growth, Se sequestration, and total biomass. On the basis of this study, Panicled Bulrush is the best candidate for Se phytoremediation under a larger deployment. Positive results among Common Spikerush and Baltic Rush suggest that these species may also be candidates for further testing. Total Se removal capability is determined by a plant species' ability to accumulate Se in its tissues as well as its ability to volatilize Se. The findings justify future inquiry into the volatilization potential of the Panicled Bulrush.

Impact of Limited Irrigation on Health and Growth of Three Ornamental Grass Species

Sam Hagopian, MS Horticulture and Landscape Architecture, Colorado State University
Dr. James Klett, Horticulture and Landscape Architecture, Colorado State University

Water is one of the most valuable resourceS in the world, and water availability is slowly decreasing. Much of the information available about standard landscape watering procedures is not research based, and is instead based on general observations and age old practices. To improve the research, finding exact water use of specific landscape species is extremely valuable in terms of water savings for homeowners and industry personnel. It is important to find precise irrigation needs of a few species of ornamental grasses, and research the limits to which these plants can survive around those needs. As ornamental grasses become more important components of urban landscapes, it is imperative that their water needs are better understood and landscape characteristics are scientifically researched. The purpose of this study was to assess ornamental quality and plant stress of three ornamental grass species under four different irrigation regimes, quantify a feasible irrigation standard at which ornamental grasses should be watered, and identify the pattern of water use within the soil profile to understand rooting behavior of these grasses.

Two studies were performed--the water use study and lysimeter study. All measurements for both studies were taken throughout the 2014-2015 growing seasons. The water use study examined three species of ornamental grasses: Panicum Virgatum 'Rotstrahlbusch' (Rotstrahlbusch Switchgrass), Schizachyrium Scoparium 'Blaze' (Blaze Little Bluestem), and Calamgrostis Brachytricha (Korean Feather Reed Grass). The study consisted of four treatments; 0%, 25%, 50%, and 100% Bluegrass ET (ETo). Two generalized categories of data were collected, plant stress, and ornamental quality. The lysimeter study examined one species of ornamental grass: Schizachyrium Scoparium 'Blaze', which were placed in a pot-in-pot system. The three treatments applied were 25%, 50%, and 100% of actual plant ET (ETs). In addition, four dry down periods were conducted each year. This consisted of providing each treatment with its relative level of irrigation, and then allowing plants to dry down to critical stress levels (periods of drought).

The most important conclusion comes from coupling the concepts of ET and water potential. The ET data generated indicates that as the growing season progresses, plants receiving less water are using less water and are also significantly more stressed. Additionally, the longer a period of drought they experience, the more dramatic these levels of stress are. When combining the results of both studies, plants grown in the 25% treatment are as aesthetically pleasing and physiologically healthy as those in the 100% treatment. However, if these plants are ever subject to periods of drought they are much more likely to succumb to physiological stress than those in the 100% treatment. This implies that ornamental grasses put on a deficit irrigation schedule must be constantly watered to ensure health and aesthetics. In order to recommend this practice to growers, landscapers, homeowners, and municipalities, a weekly water budget was created. The amount of water to apply on a weekly basis is 0.25 inches (including precipitation). It is important to note that years with significantly more drought will have higher water demands.

Sam Hagopian (left) and his advisor Dr. James Klett (right). Photo by David Staats.

Combined Influences of Hydrologic Connectivity and Nutrient Uptake on System-Scale Retention

Pam Wegener, MS Candidate, Watershed Science, Ecosystem Science and Sustainability, Colorado State University
Melissa Miller, BS Student, Watershed Science, Ecosystem Science and Sustainability, Colorado State University
Dr. Tim Covino, Ecosystem Science and Sustainability, Colorado State University

From May-September 2015, researchers conducted fieldwork at North Saint Vrain Creek in Rocky Mountain National Park, Colorado. The purpose of this study was to better understand how the strength of hydrologic connectivity (exchange of water, sediment, and nutrients) between the river and the floodplain influenced stream ecosystem metabolism, or the rate in which organisms produce and consume energy in fluvial systems. An experiment was designed to test the hydrologic mechanisms that optimize stream ecosystem metabolism in the Wild Basin Watershed, an 88-km2 watershed in Rocky Mountain National Park, Colorado.

In March 2015, a network of instrumentation was set up in the main channel at the inflows and outflows of the unconfined and confined segments and in six side-channels and seven ponds in the floodplain. In order to compare the relative water and DOC retention/transport potentials for the unconfined versus the confined segment, streamflow and DOC data were needed at the inflows and outflows of each segment. Empirical relationships between stage and streamflow were created to transform continuous (15 minutes) stage to continuous flow at each site. Weekly measurements of flow were gathered using the standard U.S, Geological Survey velocity-area method. Daily water fluxes and balances from flow data were calculated along with unconfined and confined segment water balances as the difference between water fluxes at the outflow and inflow of each segment. A similar approach was used to calculate unconfined and confined segment DOC fluxes and balances.The timing and magnitude of normalized stage fluctuations between floodplain side-channels/ponds and the main channel were compared to evaluate the strength of lateral hydrologic connectivity across flow regimes. The relative connectivity values for each of the floodplain water-bodies were averaged to categorize periods of "high" and "low" connectivity. The ecosystem metabolism rates were calculated at the outflows of the unconfined and confined segments and two floodplain surface water-bodies – a side-channel and a pond – using an open-channel, single-station, diurnal DO change approach.

The strength of lateral hydrologic connectivity was strongly related to stream ecosystem metabolism at the confined and unconfined segments, and in the floodplain water-bodies where DO was monitored. The floodplain water-bodies had higher metabolism rates following hydrologic disconnection with the main channel. Metabolism rates measured at the outflow of the confined segment were consistently lower than rates measured at the outflow of the unconfined segment. The confined segment did not develop floodplain surface water-bodies with high variability in processing rates as a function of streamflow. Lastly, it is believed that metabolism rates at the outflow of the unconfined segment were optimized at the trade-off between high processing efficiencies in floodplain water-bodies and sufficient levels of hydrologic exchange between those water-bodies and the main channel. It is suggested that intermittent river-floodplain hydrologic connectivity can optimize stream ecosystem metabolism, and as such, is an important mechanism to consider in wetland construction/mitigation practices that seek to optimize nutrient and organic matter processing and associated stream ecosystem health.

(From left to right) Pam Wegener, Melissa Miller, and Dr. Tim Covino conducting field work.
Photos by Kim Hudson.

Nutrient Retention and Productivity in Rocky Mountain Streams Under Alternative Stable States 2014-2015

Adam Herdrich, MS Student, Graduate Degree Program in Ecology, Colorado State University, Cooperative Fish and Wildlife Research Unit
Dr. Dana L. Winkelman, U.S. Geological Survey, Colorado Cooperative Fish and Wildlife Research Unit, Colorado State University
David Walters, U.S. Geological Survey, Fort Collins Science Center

Much of the Intermountain West was deforested following European-American colonization in the 19th century. Logging, especially in riparian areas, has significantly reduced the input of large wood to mountain streams throughout this area. Tie-driving, snag removal, and beaver trapping have further reduced physical habitat complexity, such as channel spanning logjams in streams. Many mountain streams in the Intermountain West have shifted to an alternative stable state, where logjam density is low and both wood retention and logjam formation is greatly reduced. This research study focused on utilizing the small amount of true old growth forest (> 350 years old) still remaining in the Colorado Front Range to study patterns in trout density, growth, and diet among two streams (North St. Vrain and Glacier Creek) with varying riparian forest stand ages (~120 and >350 years old) and logjam densities. Data on fish density and growth rates was collected. Diet samples at both sites was also collected to investigate any differences in diet composition between the two sites.

Trout biomass estimates were approximately four times higher at the high wood site, on the square meter scale, and approximately nine times higher on the valley scale. Average growth rates were almost identical for the two sites; however, Brook Trout in Glacier Creek reach an estimated larger overall length. Diets differed between the high and low wood site during the summer, but were more similar during the fall. Brook Trout biomass was significantly higher at the high wood site at both the square meter and valley scale. At the high wood site, the high volume of large wood forced the creation of multiple parallel stream channels, creating additional aquatic habitat that is not present at the low wood site. The similarity of growth rates between the two sites suggests there is a higher availability of prey resources at the high wood site that allows fish to maintain high growth rates despite higher densities. Diet data indicate the invertebrate taxa differed significantly between the high and low wood sites during the summer season. Most likely, Brook Trout are keying in on the increased production of smaller benthic invertebrate species.

In this research study, the small amount of true old growth forest (> 350 years old) still remaining in the Colorado Front Range was utilized to understand how mountain headwater streams in the Intermountain west functioned pre-European colonization. Trout biomass was significantly greater in the high wood site. Average growth rates, however, were very similar among sites in spite of the large differences in population densities, suggesting a higher availability of prey resources afforded by the higher habitat complexity at the high wood site. While diet data showed that trout at both sites are consuming different insects to support population densities and growth rates. Ultimately, the ecosystem-level approach provided the opportunity to examine how legacy effects are influencing mountain stream communities through both fluvial geomorphic processes (e.g., influence of logjams on the physical habitat template) and food web dynamics.

Adam Herdrich collecting samples during field work. Photo by Pam Sponholtz.

What's New?

Marble, CO
Photo by Daniel Hoherd

Climate Smart Ag Efforts Gain Momentum

Jim Beers, Communications Coordinator, Vice President for Engagement

Colorado State University's expanding Climate Smart Agriculture initiatives deepened its international focus as a four-member group from Fort Collins traveled to Rome earlier this summer for the Global Alliance for Climate Smart Agriculture at the United Nations Food and Agriculture Organization office. The GACSA forum focused on the three pillars of CSA: productivity, adaptation, and mitigation.

The CSU delegation, which included Office of Engagement Vice President Lou Swanson, Vice President for Research Alan Rudolph, Department of Soil and Crop Sciences Professor Rajiv Khosla, and Ecosystem Science and Sustainability Professor Dennis Ojima, further reinforced the university's leadership in the area of climate smart agriculture.

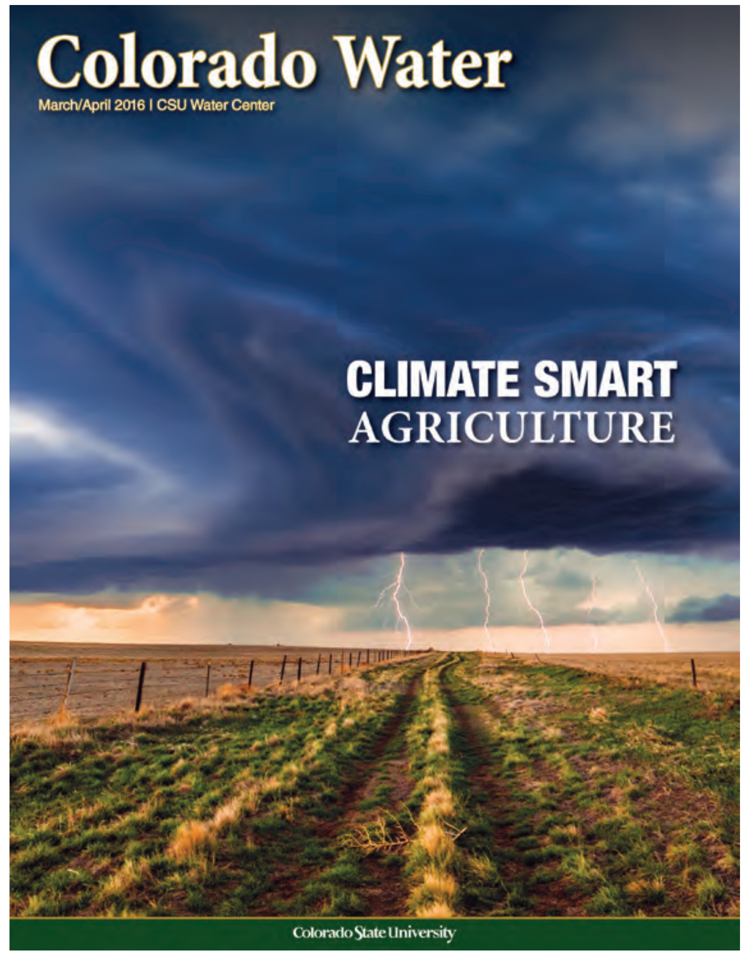
"Colorado State had the largest presence among U.S. universities at the Rome forum," Swanson said. "We are a founding member of GACSA, and are working in a number of areas across campus, around the state and globally to further develop effective socioeconomic and ecological programs that address challenges associated with changing weather patterns, especially in terms of producer adaptability and resiliency. We do so by co-creating programs and developing applied research in conjunction with Colorado's farming and ranching communities."

CSU's Climate Smart Agriculture effort brings together an impressive number of partners from across campus including the Office of the Vice President for Research, Colorado Water Institute, CSU Extension, CSU Online, School of Global Environment Sustainability, College of Agricultural Sciences, Department of Atmospheric Sciences, Colorado Climate Center, and Natural Resource Ecology Laboratory, among others. The university also works on climate smart ag issues with universities in China, Ethiopia and Kenya.

CSA Campus Initiatives

The Rome meeting comes on the heels of two very successful on-campus events held recently. Earlier this summer, the Focus on Climate Smart Agriculture forum drew over 120 participants from campus, the agriculture industry and business interests around Colorado to the Lory Student Center. Two weeks later, U.S. Department of Agriculture Secretary Tom Vilsack came to CSU for a roundtable discussion on CSA with researchers and industry representatives. And the momentum will continue.

"We plan to offer educational modules and programs and planning and risk management tools for Colorado agriculture," said Swanson. "The goals of these initiatives are to reduce the vulnerability of agriculture to a changing climate, including extreme weather events, and to assist our producers in being more nimble and economically resilient in national and global markets. It will be a work in progress, and one that CSU will address head-on."



The spring 2016 issue of Colorado Water is dedicated to Climate Smart Agriculture. This magazine is available online at http://www.coopext.colostate.edu/comptrain/docs/ColoradoWater.pdf.

U.S. Secretary of Agriculture Tom Vilsack Visits CSU

Lou Swanson, Vice President for Engagement and Director of Extension, Colorado State University

With Climate Smart Agriculture (CSA) practices, farmers and ranchers constantly adjust to weather variability to assure their economic and ecological resilience.

CSA is a major U.S. Department of Agriculture initiative, and U.S. Secretary of Agriculture Tom Vilsack visited the CSU campus on May 20, 2016 to discuss CSA initiatives at CSU, a follow-up to a daylong forum held on campus May 5, 2016.

Vilsack shared his assessment of global climate change and the challenges confronting global food production and distribution. He applauded CSU's engagement with Colorado producers as well as U.S. Department of Agriculture's (USDA) Northern Great Plains Climate Hub.

United States Secretary of Agriculture, Tom Vilsack. Photo by Joe A. Mendoza.

John Fetcher Scholarship Award

Name: Carter Stoudt

University: Colorado State University

Major: Environmental and Natural Resource Economics

Graduation: Fall of 2016

Area of Interest: Carter would like to increase water efficiency in the agricultural industry

Four States Irrigation Council is a collaborative forum for the discussion of interstate irrigation-related issues and problems. Each year in January, individuals from Colorado, Kansas, Nebraska, and Wyoming gather in Fort Collins.

The Four States Irrigation Council awarded a scholarship for the 2015-2016 academic year to a recipient interested in a career in a water resources related field or irrigation in Colorado, Kansas, Nebraska, or Wyoming. This year the award was given to Carter Stoudt, a student at Colorado State University who is majoring in Environmental and Natural Resource Economics with a minor in the sustainable water interdisciplinary program.

Carter originally was intrigued by agriculture when he moved to the rural town of Cedaredge, Colorado in 2009. He was taught what farming was really like and how essential agriculture can be to a small town. When he came to Colorado State University, he found his niche in the Department of Agricultural and Resource Economics. With the help of his devoted advisors, he found a major that combines his love for agriculture, water use, and mathematics.

First Norm Evans Endowed Lecture Featured Mike Connor

Lindsey Middleton, Communications Specialist, North Central Climate Science Center

On March 9, 2016 the Colorado Water Institute (CWI) and CSU Water Center held the first annual Norm Evans Endowed Lecture. This lecture series, sponsored by Ken and Ruth Wright, honors Norm Evans and his legacy as a leader in the water community and focuses on water management, education, and policy.

The 2016 guest lecturer was Mike Connor, Deputy Secretary of the Interior, whose responsibilities as Chief Operating Officer of the Department of the Interior (DOI) include water policy relations and land consolidation

Ken Wright gave an introduction about Norm Evans and the significance of the lecture series, and Brad Udall, Senior Water and Climate Scientist/Scholar for the CWI, introduced Connor, noting Connor's two-plus decades of public service. Connor focused his discussion on the DOI's goals, achievements, and shortcomings in its involvement in water issues.

Connor explained that for nearly eight years the DOI has operated under President Barack Obama, who has taken an interest in water issues. As part of the President's Climate Action Plan, the federal government is currently investing funding and efforts into the resiliency and sustainability of water resources.

Historically, water resource issues in the West have echoed the U.S.'s changing political and social climate. From a period of growth and development to progressive scientific and technological discovery and an increased environmental awareness, governmental involvement in water changed as new priorities took precedence and new policies came into play.

The Bureau of Reclamation was established in 1902 with goals that included addressing water shortages in the West and hydrologic variability. The long-standing focus on development helped populations in the West thrive, but the effects were not always positive. Along with policy shifts in the 1960s and 1970s that placed more focus on environmental impacts, the Bureau of Reclamation funding and priorities began to change. Connor gave a budget comparison between 1971, when 90 percent of the budget funded the construction, operation, and maintenance of water facilities, and the recently approved fiscal year 2017 budget, which includes 25 percent for environmental purposes (such as river restoration) and 10 percent dedicated to conservation research and planning. "Our goal is to diverge from litigation driven initiatives and move toward more strategic and collaborative approaches to water management," said Connor.

Despite these efforts, Connor acknowledged that the agency's efforts may not be sufficient to address challenges in the West, and particularly climate change. He noted that climate change will impact streamflows, wildfires, and many other aspects related to western water resources.

Norm Evans was a director of the Colorado Water Institute from 1967-1988, took part in ensuring the preservation of historical landmarks.

The Norm Evans Endowed Lecture Series is a contribution to science, education, and public service in the name of Evans to honor his scientific approach to the handling and use of water and his work for the Fort Collins community. Ken and Ruth Wright, whose own legacy in water includes decades of scientific contributions and leadership, hope the series will "keep up the Evans spirit and a desire for teaching and learning."

From left to right: Mike Conner; Jean Evans; Norm Evans; Ruth Wright; and Ken Wright. Photo by Kim Hudson

CWI Staff Updates

Delores River Valley
Photo by Carol M. Highsmith

Starting Young: Students Learning How to Collaborate about Water

MaryLou Smith, Policy and Collaboration Specialist, Colorado Water Institute

Many students at Colorado's institutes of higher learning are engaged in engineering, agriculture, and natural resources—learning how to conduct research to find answers to difficult water resources questions. Colorado Water Institute (CWI) is deeply engaged in connecting students to those research opportunities.

Increasingly, we are also engaged in helping students learn how to address water policy questions—such as "how can water users collaborate to address the 'wicked problems' created by increased competition for limited (and decreasing) water supplies?"

The term "wicked problem" refers to a problem that is difficult or impossible to solve—and instead has to be managed. Martin Carcasson and Leah Sprain from CSU's Center for Public Deliberation have written that wicked problems "have no technical solution, but due to inherent underlying competing values and tensions, call for ongoing communicative processes of broad engagement that helps communities and organizations develop mutual understanding across perspectives." Students recognize that they will be called on to address society's wicked problems—and they are clamoring for opportunities to gain understanding of the problems as well as the social skills to tackle them.

With funding from the U.S. Department of Agriculture (USDA), as part of its Moving Forward on Agricultural Water Conservation in the Colorado River Basin project, CWI has given students a taste of the problems as well as an introduction to and practice in applying the social skills.

High School Students

"Contemporary Challenges of Rivers" was the theme of a summer course for 45 selected Colorado high school students. CWI designed and orchestrated a role play in which the students were given the opportunity to try negotiating an actual case that is currently in play on the Cache la Poudre River. This required students to understand the background of the conflict and to consider trade-offs between agricultural, urban, and environmental interests. Interestingly, on their own, students came up with some of the bargaining points under consideration in the real life situation.

Sociology Graduate Students

"How to Facilitate Water Stakeholder Collaboration" was the title of a six-part summer series in which five graduate students in sociology and related fields were introduced to prevalent water conflicts and the variety of approaches being employed to facilitate their resolution. Included were opportunities for dialogue with a number of practitioners, including a prominent Denver attorney and engineer who rely on both fields to work in arbitration and mediation of water conflict, and a retired sociology professor who observed and wrote about the intricate multi-year, multi-state negotiations leading to the Platte River Habitat Recovery Program. The students reported that their favorite part of the series was hearing about and discussing the "in the trenches" experiences of CWI staff as they work with water stakeholders around

Students majoring in agriculture meet with students majoring in natural resources to learn together about current issues of water conflict and how to collaborate to address them.

Colorado Water Sustainability Fellows and their advisors pose in front of a Mexican mandala, created from corn, beans, rice and flowers to exemplify a sustainable approach to life on the globe. The setting was a statewide workshop at which the students weighed in on the challenge of getting Colorado River Water to the delta of Mexico.

Colorado and the Colorado River Basin. All of these students are currently using what they learned in their water-related social research, primarily as they conduct interviews pertaining to oil and gas, groundwater/surface water interaction, and environmental justice.

Agriculture and Natural Resources Undergraduate Students

One of the graduate students who completed the "How to Facilitate Water Stakeholder Collaboration" course took what she learned and applied it right away. Hannah Love, a Doctoral Candidate in Sociology, assisted in the design and teaching of three separate non-credit short courses in which agriculture and natural resources students were brought together to collaboratively address water issues affecting both sectors. Historically, agricultural producers and environmentalists have disagreed over water resource issues. Breaking down polarization and increasing collaboration for multi-sector water solutions is a primary goal of CWI's U.S. Department of Agriculture's (USDA) project on agricultural conservation. This non-credit class, offered to three different groups of students during three semesters, proved to be successful. One student said "I learned there's more to the hydrologic cycle than just equations; people are affected too." Another said "It changed my view of people in general – which affects my viewpoint of society as a whole. Although we have different backgrounds and beliefs, we all want what is best for the whole."

First Generation Latino Undergraduate Students

The Community for Excellence (C4E) at CSU is a suite of programs designed to help students who have traditionally been underrepresented in institutions of higher education to gain access to college and successfully complete their degrees. One of the programs is called Access, and serves undocumented students, most of who came to the U.S. as children and until recently could not attend Colorado colleges and universities except as "foreign students" paying steep out of state tuition. More than 100 such students are now enrolled at CSU, receiving mentoring from counselors such as Elias Quinones, who was the first in his family to go to college, subsequently earning a Master's degree in Social Work from UNC. CWI is working with Quinones, and with Paul Hellmund, a visiting fellow with CSU's School of Global Environmental Sustainability (SOGES) to offer eight Access students an opportunity to learn about water issues and be exposed to water careers they might want to pursue. With partial funding from the Mattie Collier Fund at the Community Foundation of Northern Colorado, these students were accepted to become Colorado Water Sustainability Fellows, receiving small stipends and an opportunity to apply for paid summer internships related to water careers. They are learning about the "wicked problems" inherent in water issues, and have accepted the challenge of offering proposals for how those involved in Colorado and Colorado River Basin water issues can increase the ethnic diversity of voices weighing in on these issues. Plans are underway for them to attend important water conferences such as the Upper Colorado River Basin Symposium at Colorado Mesa University and the annual convention of the Colorado Water Congress. These opportunities are good for the students, but also for those involved in water decision making, who can benefit from hearing from a broader range of community voices.

Students Bring Wider Perspectives

Through all of these activities that engage students in the societal impacts of water issues, CWI is learning that the younger generation has a more open attitude toward collaboration than that of many of their older counterparts. Increasingly, we hear students reflecting that the issues are too complex to be solved by "splitting up the pie." Students want more opportunities to delve deep into "wicked problems" and try their hand at carving out a future where water is understood and valued by a much wider diversity of people and where solutions take into account the needs of all—agriculture, the environment, and city dwellers.

Southern Colorado Update

Blake Osborn, Regional Water Specialist, CWI and CSU Extension


Twin Lakes Reservoir, a water resource for the Upper Arkansas River Basin
Photo by Ken Lund

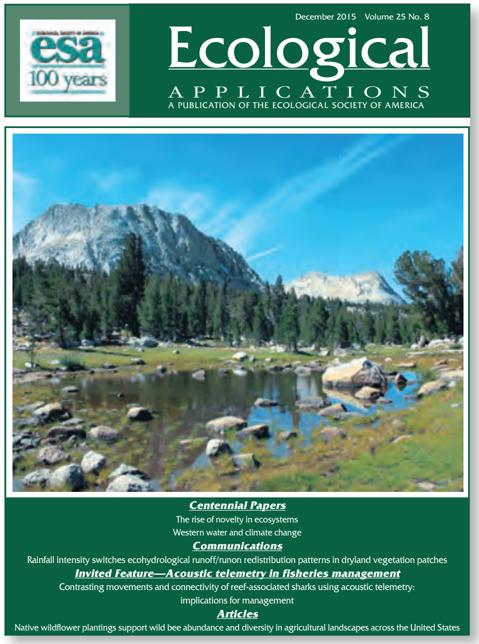
Although drought is never far from anyone's mind in southern Colorado, this year's strong El Niño precipitation boosted snowpack amounts and stored water from 2015 storms helped keep drought out of people's vocabulary. For the most part, the 2016 water year will be considered above average in terms of water supplies. With that in mind, much of the discussion over the past year has centered on water quality topics such as selenium and nutrient management. I have been working closely with Dr. Timothy Gates from the Department of Civil and Environmental Engineering at CSU, to implement research projects that address water quality concerns in the Arkansas River basin. For example, I will be taking the lead on the Lower Arkansas River Watershed Plan, which will accumulate scientific data from observations and models to create strategies to improve water quality. Other research and outreach activities are as follows:

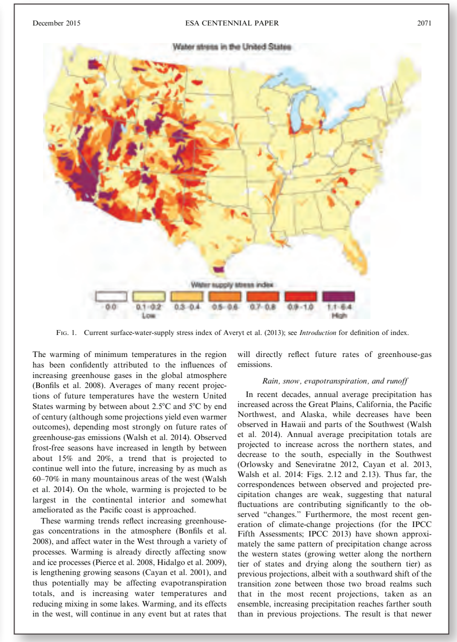
- **Lower Arkansas River Watershed Plan**: I believe the Colorado Water Institute (CWI) is the perfect entity to take on this watershed plan as we have credibility as a research organization with extensive stakeholder contacts, as well as extensive scientific research data characterizing the watershed with a particular focus on water quality.
- **Upper Rio Grande Watershed Assessment Project Technical Advisory Committee**: I am excited to work with technical hydrologists to assist and guide the development of the Upper Rio Grande Watershed Assessment (URGWA). The URGWA is a continuation of the Rio Grande Headwaters Restoration Project which has been, in my view, a near-perfect example of watershed planning and stakeholder involvement.
- **Groundwater and Surface Water Interactions and Potential for Underground Storage**: Initiated by the Upper Arkansas Water Conservancy District, and working alongside the U.S. Geological Survey (USGS), I will be working with sprinkler irrigators in the Upper Arkansas Basin to monitor soil moisture, formulate an agricultural water balance, and calibrate an irrigation scheduling tool for high mountain hay crops.
- **Distribution of Water and Salinity under Subsurface Drip Irrigation**: This project focuses on understanding the subsurface distribution of water and salt under drip irrigation systems. This project is a collaboration with Dr. Mike Bartolo at the Arkansas Valley Research Center and is in its second year.

In 2016, I worked to cultivate stronger partnerships between the CWI and local water stakeholders through participation in several water organizations including: The Arkansas River Basin Water Forum, Arkansas River Management Action Committee, Public Education Participation and Outreach (PEPO), Lower Arkansas River Salinity Workgroup, and the Arkansas River Watershed Collaborative. It is clear, the need for research and outreach about water is growing in southern Colorado. The CWI is in a great position to fill many of the research and outreach gaps, but as water issues evolve so too will the need for more research and education. I have had many conversations with people expressing great optimism and creativity towards meeting the water needs of southern Colorado. I look forward to continuing these discussions, sprouting new project ideas, and improving the water landscape of southern Colorado.

Listening to a Wisconsin Dairy farmer's involvement in water quality improvement projects. Photo by Eric Wardle, CSU.

Activities at the Intersection of Climate Change and Agriculture





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

Alternatives to Permanent Fallowing Report

Along with CWI Researcher Greg Peterson, I wrote four chapters in a soon-to-be released report on how to procure water for municipal and environmental purposes without permanent fallowing. The chapters cover deficit irrigation (especially alfalfa), crop switching, rotational fallowing, and related but different concepts of irrigation efficiency and water conservation. After peer review, the chapters will be released. We will hold workshops in Colorado, Arizona, and Washington D.C. to present our findings and to obtain additional feedback on the effort. In addition, I will present our findings as part of a panel at the November 29th meeting of the Interbasin Compact Committee. The effort was funded by the Walton Family Foundation.

Climate-Smart Agriculture Initiative

The CWI with the support from the Vice President for Engagement Lou Swanson and Colorado State University's President Tony Frank has begun an initiative on climate- smart agriculture. Our goal is to reduce the vulnerability of Colorado agriculture to a changing climate, including extreme weather events and to assist our producers in being more successful in national and global markets. On May 5th at the Lory Student Center we hosted an event with over 200 attendees to discuss ongoing CSU work in the field and to obtain input on where the initiative should go. Highlights included a number of presentations from CSU faculty and several panel discussions with important agricultural producers. An entire edition of the CWI Newsletter was focused on the topic with ten short articles ranging from basic climate science, to current Colorado climate trends and even reasons for optimism. CWI along with other CSU faculty are pursuing a series of short online courses on this topic to held in late 2016 or early 2017. The U.S. Department of Agriculture (USDA) North Central Climate Hub, based at CSU, is also a partner in this effort.

Western Water and Climate Change Efforts

I continue to research the effects on the ongoing drought in the Colorado River with a special focus on how temperatures are reducing runoff. With co-authors Mike Dettinger of the U.S. Geological Survey (USGS) and Aris Georgakakos of the Georgia Institute of Technology, I wrote an article in the peer-reviewed journal Ecological Applications on climate change and western water supplies. In the article, we reviewed how climate change will impact the hydrology of water supplies in the western U.S. and also projected those impacts into the human and ecological realms. In addition, we provided case studies on how four key basins in the West (the Klamath, Sacramento-San Joaquin, Colorado and Rio Grande) will be impacted by climate change. This work was an extension of the U.S. National Climate Assessment released in 2014.

Talks and Other Activities

During the course of the year, I gave a variety of talks on climate change. I spoke at the Federal Reserve Bank of Kansas on water and agriculture, the University of Arizona's Extension Forum, the Water Education Foundation in California, and at the National Academy of Sciences in Washington D.C. On behalf of CWI, I attended the annual meeting of the National Institutes of Water Research in Washington D.C. in February. I also spoke to producers in Imperial Valley of California about the future of Colorado River water supplies and at the Family Farm Alliance Annual Meeting in Nevada. In October, I provided an opening keynote talk at the annual South Platte Forum. I also attended an U.S. Department of Agriculture (USDA) "Cattle and Climate" workshop in Colorado and a workshop on research directions for climate change and agriculture. Finally, it was a great honor and pleasure for me to introduce Deputy Secretary of Interior Mike Connor when he spoke at CSU in March.

Brad Udall

Water Management Issues and Outreach in Northeastern Colorado

Joel Schneekloth, Regional Water Specialist, CWI and CSU Extension

Approximately 40% of Colorado's irrigated landscape is located the northeastern portion of the state. In addition, this area contains a large portion of the state's population and water has always been a major issue within this region. The transferring of water rights from agricultural to municipality use is a major concern and could result in a loss of irrigated land by 2050.

The Republican River Basin's water supply is the Ogallala Aquifer, which has experienced a decline in its supply since the 1970s. As a result, there has been a loss in well capacity, as well as difficulties in management. It is essential that producers are able to make sound economic and management decisions.

Agricultural Water Management

Irrigation and water management have been the crux of decision making by producers. Without good research available to producers, management changes/decisions are much more difficult. Research on issues that producers will face is important to help with decision making 10-15 years into the future.

- **Drought Genetics** – Improvements in technology are continuing within the agricultural industry. Research with these genetics has shown some promise for corn under stress. Further research is being conducted to determine the potential of genetics in limiting irrigation at the end of the season.
- **Residue and Water Management** –In recent years, producers have utilized residue harvest as an income source during years of high forage prices. Current research is looking at implications of water management in these systems, as well as nutrient and tillage management. Long term data is needed to determine the impacts of residue harvest and tillage management on irrigation management and soil health.
- **Limited/Deficit Irrigation Management** – In addition to output declines or water limited for irrigation, producers have to make decisions on how to manage the water for irrigation scheduling or crop management. Research is being conducted on the response of corn to irrigation strategies of timing limited quantities of irrigation availability with crop rotations.
- **Irrigation Scheduling Technology** – Remote sensing has the potential to be helpful for irrigation management, however, there is limited data available. Working with the U.S. Department of Agriculture-Agricultural Research Service (USDA-ARS) Water Management Unit, we are looking at thermal imaging as a potential scheduling tool.
- **Ogallala CAP grant** – One of the major new grants is the Ogallala CAP (NIFA). It includes researchers from six states that overlay the Ogallala Aquifer. The major aspect of this grant is to look at policy and management impacts on the Ogallala Aquifer within this region. It will also look at ways to sustain the aquifer as well as the transition from irrigated to dryland or range in areas where sustainability is not achievable.

Extension

- Central Plains Irrigation Association - The Central Plains Irrigation Association strives to provide producers with current research within the High Plains Region of Colorado, Kansas, and Nebraska. The Central Plains Irrigation Association is a consortium of industry and universities in Colorado, Kansas, and Nebraska. The 2016 annual meeting was held in Nebraska. In 2017, Colorado will host the annual meeting.
    - » South Platte Roundtable -The roundtable structure was developed for individual basins to solve water issues. Membership of these roundtables are made up of agricultural, municipal, environmental, and recreational interests within the basin. Over the past 11 years, the South Platte Roundtable has had discussions on the future issues within the basin and the potential to resolve the water gap created by growth within the Colorado Front Range. The past three years have involved the development of the "Basin Implementation Plan"
        - As part of the Educational Outreach committee of the South Platte Roundtable, we have been developing approaches to educate residents' water issues within the South Platte Basin.
- Field Days – As a member of the Central Plains Research Station, we host an annual field day to highlight research findings. Irrigation management is a key component of this event.

Continued research and outreach are major components of my program for producers and policy makers within the region. Without factual and accurate data, management and policy decisions are difficult to make.


Impact of Residue and Tillage
Management on Infiltration
Year 2

Collaboration on Agricultural and Water Use Issues in Western Colorado

Perry Cabot, Research Scientist and Extension Specialist, Colorado Water Institute

The Western Region is home to only 10% of the state population, while its numerous major rivers—the Colorado, Gunnison, Yampa, White, San Juan, Animas and Dolores—deliver roughly 90% of the water from or within the state. These two realities are set unavoidably between the economic power of the Lower Colorado basin states (Arizona, California, Nevada) downriver and the Colorado Front Range through massive transbasin diversions. These circumstances, along with the persistent threat of drought and climate change, shape the wide-ranging narratives of water users, basin roundtables, and the general public on the Western Slope. Diverse as it is, certain common threads run through the discourse on water planning, and the CWI works to focus its resources on strategies that offer the best opportunities for collaboration and impact.

Pilot System Conservation Program (SCPP)

The Pilot System Conservation Program (SCPP) for the Upper Colorado River Basin created an opportunity to integrate research needs and actual strategy, related to drought contingency planning through voluntary, temporary, and compensated foregone diversions. The CWI has continued its partnership with the Water Bank Work Group (WBWG) to understand the impacts to cropping systems that could endure shorter irrigation seasons as part of enrollment in the SCPP or similar programs. Though there is not currently a water bank operating in Colorado, the WBWG is working with agricultural water users to understand how water sharing agreements could be implemented to alleviate Reservoir Interim Guidelines or Colorado River Compact challenges. The deliverables of the CWI work have been focused on the direct field impacts to potential farmer-participants. A major study funded by the WBWG and the CWCB on split-season irrigation is documenting a range of conserved consumptive use amounts and agronomic impacts that may arise from foregone diversions. This study, entitled "Monitoring Consumptive Use and Agronomic Sustainability for Split-Season Irrigation of Alfalfa and Grass Hayfields under the Auspices of a Western Slope Water Bank," is entering its final year in 2017. Preliminary results demonstrate that alfalfa and grass hay fields are resilient yet still impacted under irrigation curtailment imposed partially during the cropping season. The scenarios simulated under these studies will provide guidance to agricultural water users who need metrics for pricing their participation water sharing programs. A detailed interim report on this study will be finalized before January 2017.

Resource Conservation Partnership Program (RCPP) Support.

The RCPP is a locally coordinated, comprehensive effort coordinated through the Colorado River District to maximize agricultural water use efficiency through modernization of irrigation water. The RCPP impact area includes the Bostwick Park WCD, Crawford WCD, North Fork WCD and the Uncompahgre Project. Working with the farmer-led focus group No Chico Brush (NCB), the CWI is completing the third year of collaborative projects entitled "No Chico Brush Agricultural Water Research Project" and "A Farmer-Led Initiative to Quantify and Demonstrate Irrigation Efficiencies at Farm-Scales through Instrumented Water Budgeting," funded under the Gunnison Basin WSRA and CWCB ATM programs, respectively. Dominant agriculture in the RCPP are irrigated alfalfa, grass hay, pasture and corn for feed. The relatively low profitability of the cropping systems affects farmer decisions to invest in irrigation improvements, but the No Chico Brush group argues that these improvements will secure agriculture for longer terms. Results from 2014 – 2016 demonstrate that – across cropping systems and water uses – improved irrigation systems allow farmers to apply (and divert) less water to achieve roughly the same (or better) yield. Farmers are quick to point out that improved irrigation systems are costly, and do not lead to immediate profits. The No Chico Brush group sees the role of the CWI research as being important to the evaluation that many farmers must make when considering the likelihood of their tenure as producers against their willingness to devote time and resources to these improvements.

Remote Sensing as a Tool for Evaluating CU. A project entitled "Using remote sensing assessments to document historical and current conserved consumptive use (CCU) on alfalfa and grass hayfields managed under reduced and full irrigation regimes" was completed with funding under the CWI Research Grant Program. This project was based on the need for reasonable accuracy in quantifying CU and CCU for water resources planning, water sharing and water regulation. This need was deemed particularly relevant to the Western Slope, where the majority of irrigated grass hay fields and pastures that might participate in water sharing arrangements are scattered over hundreds of thousands of acres. The successful operation of broad water-sharing programs will benefit from remote-sensing approaches, which can cost-effectively monitor and track agricultural CU and CCU across an area as large and administratively decentralized as the Western Slope. The results of this project are available within a technical report published through the CWI.

Alternative Crops and Alternative Fuels.

Working with CSU Extension and the Agricultural Experiment Station, a mobile oilseed press was constructed and is expected to be one of many aspects of a portfolio of investments in climate smart agriculture. Additionally, the CWI worked with other CSU faculty to submit a proposal to the National Institute of Food and Agriculture entitled, "Incentivizing transitions to organic farming under programs that compensate producers for reduced water diversion in the Upper Colorado Basin." The concept of the proposal was to utilize water sharing arrangements to incentivize farmers in transitioning portions of their farms to include fields that can be certified for organic production. Though not funded, this concept will continue to be pursued through other partnerships, as there is distinct support for this idea among some Gunnison Basin producers.

Extension and Engagement.

The CWI works regularly with Extension agents and other specialists in the Western Region. Workshops and presentations are provided in coordination with Extension offices and other partners on the Western Slope. Among the engagement events in which we participate are Master Gardner Programs for lawn irrigation scheduling and numerous public events to promote irrigation efficient technologies.

2015-2016 Colorado Water Institute Staff

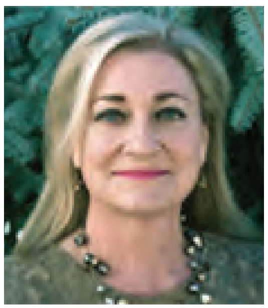

Jessica Bennett
Student Intern


Perry Cabot
Water Resources Specialist


Cameron Castells
Student Intern


Shelby Cronk
Student Intern


Derek Drummond
Senior Web Developer


Nancy Grice
Assistant to the Director


Britton Hart
Student Intern


Mitchell Hawkins
Student Intern

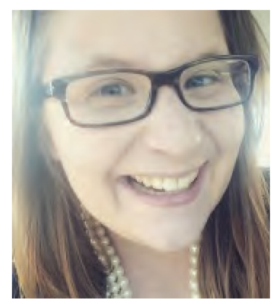

Kim Hudson
Student Intern


Julie Kallenberger
Education and Outreach Specialist

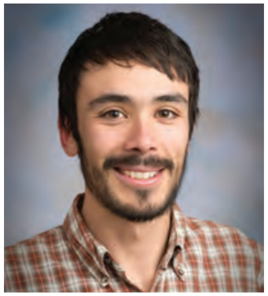

Gracie Ludens
Student Intern


Kayla Mees
Student Intern


Lindsey Middleton
Editor


Melissa Mokry
Editor


Panagiotis Oikonomou
Student Intern



Blake Osborn
Water Resources Specialist

Emily Pantoja
Student Intern

Greg Peterson
Program Aide

Beth Plombon
Student Intern

Johnathan Pryor
Student Intern

Courtney Reece
Student Intern

Joel Schneekloth
Water Resources Specialist

MaryLou Smith
Policy & Collaboration Specialist

Andy Tatro
Senior Web Developer

Brad Udall
Water & Climate Research Scientist/Scholar

Reagan Waskom
Director

Financial/Academic Summary

CWI Funding Sources

(November 1, 2015 - October 31, 2016)

CSU Base Funding	$	76,242
CWCB	$	349,592
Other State	$	10,000
Non-Profit	$	235,291
Other Federal	$	199,018
USDA	$	749,000
USGS	$	671,449
Total	$	2,690,592

*Multiple research projects being conducted during a multi-year timeframe can cause overlap in funding.

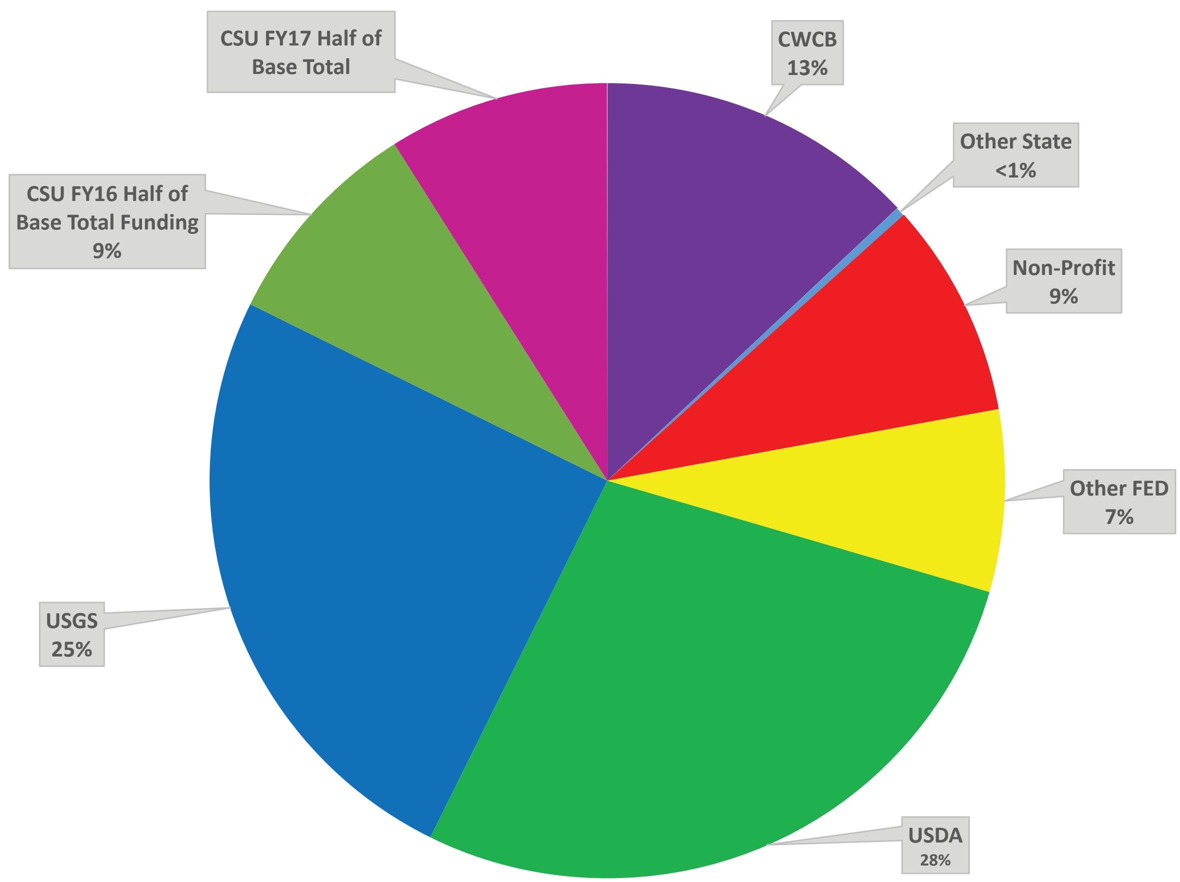
Active Project Type

Research	22
Education	2
Outreach	2
Internships	3
Training	1
Total	30

Student Degree Level on Projects

Undergraduates	18
Masters	4
Ph.D.	9
Total	31

CWI Funding Sources



Colorado Water Institute Advisory Board

Name	Organization	Telephone	Email
Jim Broderick	Southeastern Colorado Water Conservancy District	(719) 948-2400	jwb@secwcd.com
Don Brown	Colorado Department of Agriculture	(303) 869-9004	don.brown@state.co.us
James Eklund	Colorado Water Conservation Board	(303) 866-3441	james.eklund@state.co.us
Eugene Kelly	CSU Agricultural Experiment Station	(970) 491-6881	eugene.kelly@colostate.edu
Ken Knox	Noble Energy, Inc.	(303) 228-4000	Ken.Knox@nblenergy.com
Eric Kuhn	Colorado River Water Conservation District	(970) 945-8522	ekuhn@crwcd.org
Mike Lester	Colorado State Forest Service	(970) 491-7290	mike.lester@colostate.edu
David Mau	USGS, Colorado Water Science Center	(303) 236-6900	dpmau@usgs.gov
Patrick Pfaltzgraff	Colorado Department of Public Health and Environment	(303) 692-3509	patrick.j.pfaltzgraff@state.co.us
Chris Piper	Denver Water	(303) 601-4814	chris.piper@denverwater.org
John Porter	Southwestern Water Conservation District	(970) 565-8333	dolores333@bajabb.com
Robert Randall	Colorado Department of Natural Resources	(303) 866-3311	robert.randall@state.co.us
David Robbins	Hill and Robbins	(303) 296-8100	davidrobbins@hillandrobbins.com
Travis Smith	San Luis Valley Irrigation District	(719) 754-2254	slvid@centurytel.net
Jerry Sonnenberg	State of Colorado	(303) 866-6360	senatorsonnenberg@gmail.com
John Stulp	State of Colorado	(303) 866-3441	john.stulp@state.co.us
Louis Swanson	Cooperative Extension	(970) 491-2785	louis.swanson@colostate.edu
Eric Wilkinson	Northern Colorado Water Conservancy District	(970) 622-2201	ewilkinson@ncwcd.org
Dick Wolfe	State of Colorado - Division of Water Resources	(303) 866-3581	dick.wolfe@state.co.us

Colorado State University

Leadville, CO
Photo by Mark Byzewski

Contact the Colorado Water Institute

1033 Campus Delivery, Fort Collins, CO 80523-1033 • (970) 491-6308 • cwi@colostate.edu • http://cwi.colostate.edu