Colorado Water

May/June 2016 | CSU Water Center

STUDENT RESEARCH 2016







Colorado State University

Director's LETTER

This issue of *Colorado Water* newsletter features reports on student projects funded by the Colorado Water Institute. This annual student issue always causes me to contemplate our water future. Water science, management and administration keeps changing; mainly in small increments, but nonetheless we keep moving forward. As a current example, beginning August 10 of this year we can now have legal rain barrels at urban homes. Admittedly, rain barrels are a minor step in our overall water management, but they represent another increment of change. Likewise, each student we train in water resources represents another step towards the future of Colorado water.

One perceived barrier to change that frequently gets held up as evidence of stagnation in Colorado water is the so-called "use it or lose it" provisions in our law. The colloquial term "use it or lose it" is commonly associated with the incorrect belief that by maximizing the amount of water diverted, regardless of the need, one can enhance or preserve the magnitude of a water right in a future transfer or protect it from some other reduction. Efforts towards conservation or efficiency raise a similar concern: that in reducing the amount of water diverted, some portion of the water right may be lost. Because of this, "use it or lose it" is seen as a barrier to implementing water conservation and efficiency improvements. Generally, in a water right transfer case the true measure of the water right is its actual historical, beneficial consumptive use. In the case of an irrigation right, this is the documented annual crop evapotranspiration that can be shown to have been met by the water right, for a representative period of years.

While engaged in research and outreach activities related to agricultural water conservation, the Colorado Water Institute realized the concern about "use it or lose it" is a stumbling block to modernizing irrigation systems. In an effort to better understand how the term "use it or lose it" is currently construed and under what circumstances it is used accurately or erroneously, CWI and the State Engineer convened a 20 member stakeholder group composed of legal and engineering experts. Over the course of several meetings, the group analyzed Colorado statute and administration and agreed on major points that could be made in educational materials to clarify what the law has to say about "use it or lose it." Various Colorado statutes address the topic, some specific to abandonment of a water right if it is not used, and others having to do with quantification of a water right in a change case. A water right can be determined to be abandoned due to non-use for a period of ten years or more, but only if it's due to an actual intent of the water right owner to permanently forego the beneficial use of this water. This is the real basis for the term "use it or lose it." Water that is diverted above the amount necessary for application to a beneficial use (including necessary transit loss) is considered waste. Increased diversions for the sole purpose of maintaining a record of a larger diversion are considered waste and will either be curtailed, or will not be considered as a part of the water right's beneficial use.

CWI Special Report #25, *How Diversion and Beneficial Use of Water Affect the Value and Measure of a Water Right* (http://cwi.colostate.edu/publications/SR/25.pdf), was derived from the work of those meetings. The stakeholder group concurred that a better understanding of the law would allay some fear in the agricultural community, though they also pointed out that additional clarification (through statute, administrative practices or rulings) might be needed for greater assurance. So, on we go into the future of water management - one student, one topic, one project at a time. We move slowly and deliberately because so much is at stake.

Reagan Waskom
Director, Colorado Water Institute

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Colorado Water Institute

Features— Student Research 2016

In Every Issue

Idaho Springs, CO
Photo by John B. Kalla

On the cover: the Maroon Bells
Photo by Dhaval Shreyas

Student photos on the cover listed clockwise beginning with the upper right photo: Adam Herdrich (Photo by Pam Sponholtz); Christopher Ruybal (Photo by Deidre O. Keating); Karie Boone (Photo by Emily Pantoja); Craig Moore (Photo by Craig Moore); Sam Hagopian (Photo by David Staats); Melissa Miller and Pam Wegener (Photo by Kim Hudson); and Ben Von Thaden (Photo by Bill Cotton).

Snowpack Accumulation Patterns Across the Southern Rocky Mountains

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

Photo by Bill Cotton

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.

SYNOPSIS

This research project focused on assessing the spatial distribution of snowpack within the Southern Rocky Mountains. The spatial extent was determined for 90 Snowpack Telemetry (SNOTEL) sites, through a variogram analysis, utilizing snow water equivalent data.

Introduction

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. Relatively few studies have attempted to quantify such patterns, and no studies were found that quantify snowpack patterns at the modeling scale (the scale of the Southern Rocky Mountains). 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. This work used the hypothesis that there is a physical distance between SNOTEL stations beyond which snow accumulation patterns in the Southern Rocky Mountains are less correlated. To examine this hypothesis, 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.

Study Area

The Southern Rocky Mountains span from

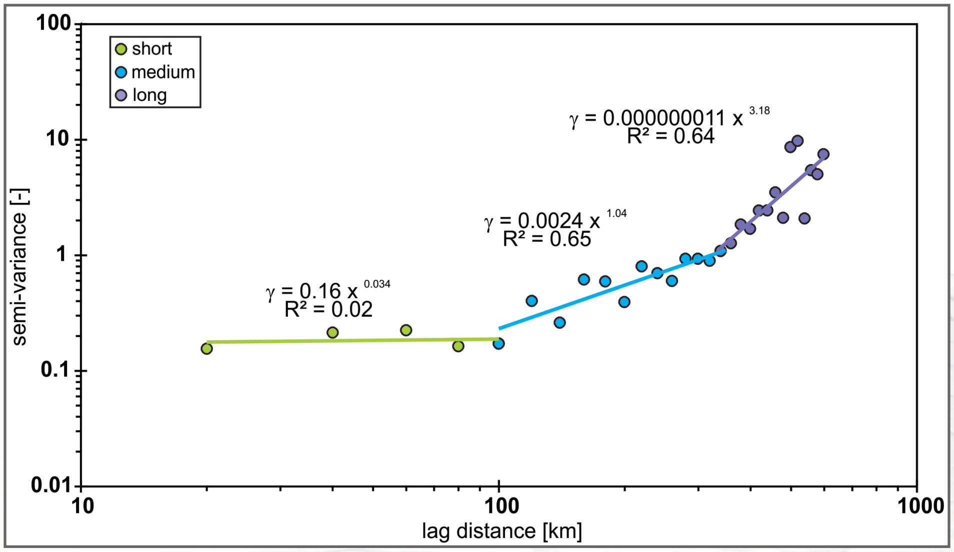

Figure 1. Variogram plot of all station pairs on log-log axes with the power functions fitted to data bins of three lag sections, separated by scale breaks.

the Laramie Range in southern Wyoming, through Colorado, and into northern New Mexico near Santa Fe. Most of the long term SNOTEL stations in the Southern Rocky Mountains are at elevations from 2,300-3,500 meters. The SNOTEL station with the deepest mean peak SWE is Tower (1,324 mm) located on Buffalo Pass near Steamboat Springs, Colorado, while the station with the shallowest mean peak SWE is Copeland Lake (144 mm) located in Rocky Mountain National Park near Allenspark, Colorado. The largest distance between SNOTEL pairs is 757 km. Many of the stations started operating in the late 1970s; 32 years of daily data, starting in 1982 were used in this analysis.

Methods

Variograms are plots of the variance of all data from stations within a range of distances apart from one another versus that distance, called the lag-distance. These 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. The main feature of interest in the variograms are the scale breaks. A scale break occurs at a lag distance where a substantial change in the driving process exists and occurs when there is a notable change (increase in this case) in variance beyond a given lag distance. 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.

Results

For the individual day SWE variograms, no scale breaks were found, although consistent patterns in the SWE variance were found through the extent on all four dates on both variograms. Further, the amount of variability in SWE variance was found to be a function of the magnitude of SWE: the higher the average SWE across all stations, the higher the variance.

Three power functions were fitted to the entire relative accumulative data dividing it by two scale breaks occurring at approximately 100 and 340 kilometers (*Figure 1*). Note, that the variogram is in log-log space in order to easily display all of the data, and the fitted functions are power functions that appear linear in log-log space and aid in visualizing scale breaks.

The first subset analysis divided station pairs into north and south zones about the parallel 38°45'N. This approach was chosen based on previous studies that found a snowpack-based divide in the climatology measured at SNOTEL stations within the study region. No scale breaks were found in this variogram, although the south zone stations exhibited a greater increase in variance with distance, i.e., steeper relative accumulation slope than that of the north zone stations. This illustrates the differing climatologies in the north and south zones. The second subset analysis divided station pairs by land cover type at each station in the pair (evergreen, non-evergreen, or a mixture of both types), and exhibited scale breaks in all three land cover pairings at approximately 140 kilometers.

Conclusion

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.

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

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Dr. John E. McCray, Civil and Environmental Engineering, Colorado School of Mines
and Dr. Terri S. Hogue, Civil and Environmental Engineering, Colorado School of Mines

SYNOPSIS

For this study, ground-based and satellite data were used to conduct a spatiotemporal assessment of groundwater resources within the South Platte Basin to evaluate potential impacts from energy development.

Introduction

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. This historic production continues to generate controversy and discussion regarding environmental, public health, and social concerns.

While much attention has centered on issues of groundwater contamination from hydraulic fracturing operations, less has focused on the added competition for water resources. The growing need for water among urban users, agriculture, industry, ecosystems, and now 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. Within the Niobrara Shale and Codell Sandstone, the Wattenberg Field has emerged as the sweet spot for crude oil and natural gas liquids (Figure 1).

A recent Ceres report found that 97% of oil and gas wells drilled in Colorado are in areas classified as experiencing high or extremely high water stress. A recent study by Ella Walker and colleagues at the Center for a Sustainable WE^{2}ST at the Colorado School of Mines identified that while state-wide water demands for hydraulic fracturing in Colorado are relatively low, accounting for 0.24% of the state's consumptive water use, local use is much more significant, accounting for nearly 7% of the consumptive use for the city of Greeley in 2014. Water use for the same period within the South Platte Basin averaged around 11,100 m^3 (~9 AF) for horizontal wells and 1,100 m^3 (~0.9 AF) for vertical wells.

Water sourcing options for oil and gas production are similar to any other water user. Surface and tributary groundwater sources are the most challenging sourcing options due to over-appropriation and users needing to obtain a water right, develop augmentation plans for water taken out of priority, and legally change the beneficial use of the water right. Because energy development demands are short-term, more enticing options include: leasing water from agriculture, municipalities, water well users of non-tributary groundwater, or drilling new wells to utilize non-tributary groundwater. Municipalities such as Erie, Fort Lupton, Aurora, Greeley, and Longmont, Colorado already lease excess water to oil and gas companies.

Objectives

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.

Methods

Ground-based data

Initial analysis of regional aquifer stress was performed using water level measurements from traditional groundwater observation wells. Within the South Platte Basin, the principal aquifer systems include the South Platte Alluvial Aquifer and the Denver Basin Aquifer System. These systems consist of four vertically sequenced

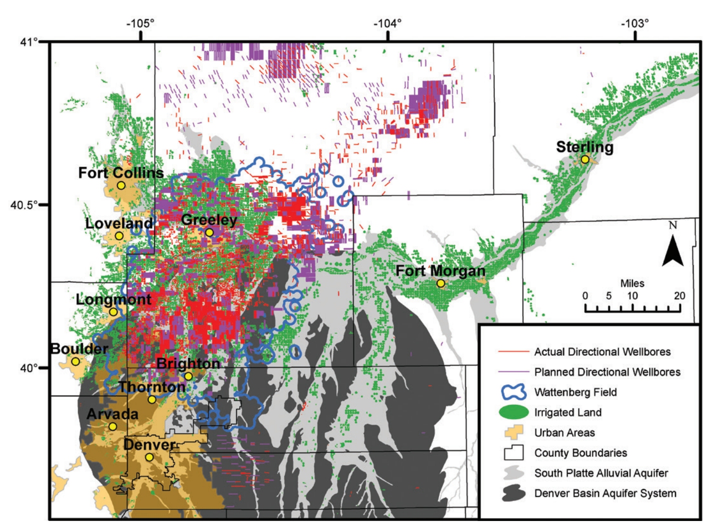

Figure 1. Map showing actual and future drilling operations in relation to principal aquifer systems, urban areas, and irrigated land within the South Platte Basin.

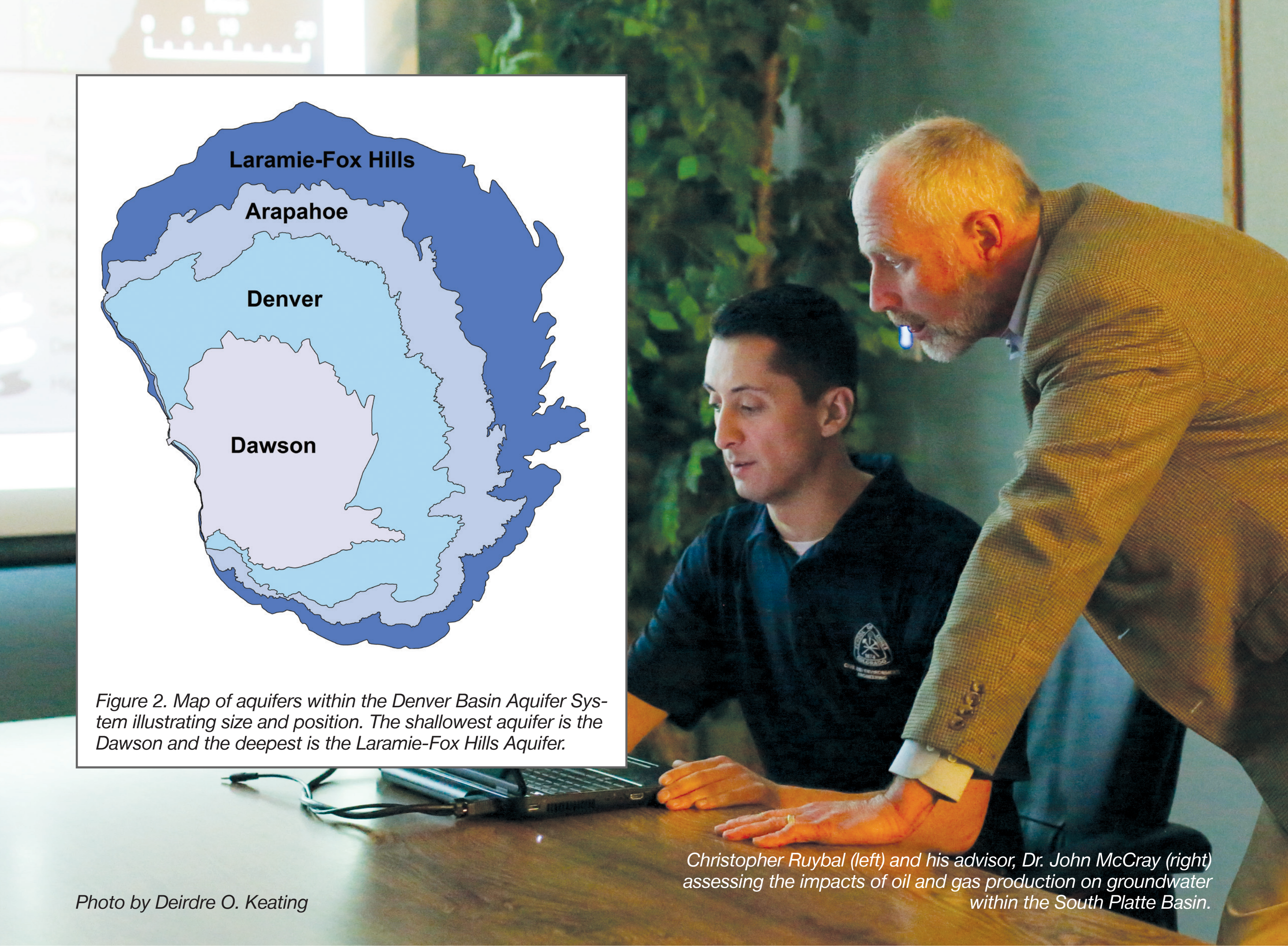

Figure 2. Map of aquifers within the Denver Basin Aquifer System illustrating size and position. The shallowest aquifer is the Dawson and the deepest is the Laramie-Fox Hills Aquifer.

Photo by Deirdre O. Keating

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.

aquifers in different geologic formations that encompass approximately 6,700 square miles, as seen in Figures 1 and 2. Approximately 9,726 observation wells were identified using data from the Colorado Division of Water Resources. However, 94% of the wells identified had only one groundwater level measurement in time, likely when the well was installed. 8,408 well logs did not identify the aquifer for the screened interval. A smaller subset of observation wells with data from the past 20 years were selected. This included: 64 wells within the Laramie-Fox Hills Aquifer, 165 within the Arapahoe Aquifer, 80 within the Denver Aquifer, 54 within the Dawson Aquifer, and 178 within the South Platte Alluvial Aquifer.

Satellite-based data

In 2002, NASA launched the Gravity Recovery and Climate Experiment Satellites (GRACE) with German partners 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. Auxiliary datasets from remote sensing satellites and land surface or global hydrologic models can be used to determine individual components of soil moisture, snow water equivalent, and surface waters. These components are then subtracted from the GRACE terrestrial water storage signal, where the residual is attributed to groundwater storage changes. GRACE data from three processing centers (University of Texas at Austin Center for Space Research, GeoForschungsZentrum Potsdam, and NASA Jet Propulsion Laboratory) were processed to scale the data and create an ensemble of averages of the three data centers. Values were then converted from equivalent water height in centimeters to cubic kilometers using the area of GRACE grid pixels.

Preliminary Results and Discussion

Most groundwater wells are irregularly sampled, once per year, leading to large gaps in the data that limit the understanding of spatial and temporal changes occurring. For example, the Laramie-Fox Hills Aquifer for a given year may have only one well observation measurement per 100 square miles. Long-term trends in groundwater levels throughout the various aquifers of the Denver Basin Aquifer system are highly variable (Figure 3). A Mann-Kendall Test of trend was applied to each aquifer series (moving average of median water level) to evaluate whether a significant increase or decrease trend existed from 1995–2015. Results of the trend test indicate that both the Laramie-Fox Hills and Dawson Aquifers have significant decreasing trends ($p<0.05$) for the 20-year time series. Similarly, both the Arapahoe and Denver Aquifers have significant increasing trends ($p<0.05$) with time.

Long-term changes in groundwater may reflect changes in recharge rates due to anthropogenic effects or variations in climate. Although seasonality was removed using a moving average (Figure 3), seasonal fluctuations in water level elevations are also common due to variation in precipitation, evapotranspiration, groundwater pumping, and irrigation. Water level differences between the aquifers may indicate vertical water movement throughout confining units and may be influenced by the relative amounts of groundwater pumping each aquifer receives. The upper portion of the Laramie-Fox Hills Aquifer though is relatively impermeable, and may prevent downward vertical movement of water from the above aquifers. The decreasing trend in this system may be a result of groundwater usage exceeding mountain block recharge rates to the aquifer.

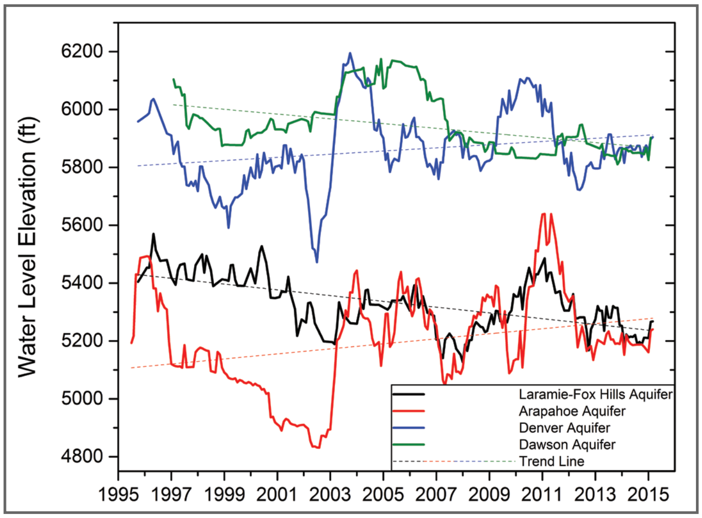

Figure 3. Moving average of median water level elevations for aquifers of the Denver Basin Aquifer System from 1995 – 2015.

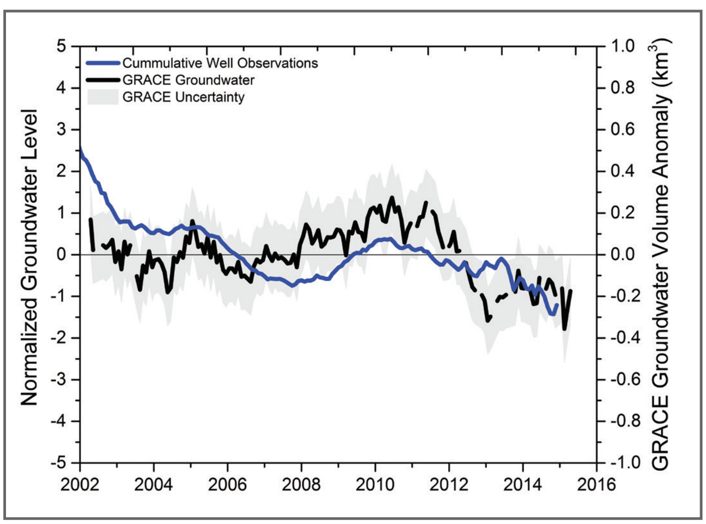

Figure 4. Comparison between well observations and GRACE derived groundwater storage anomalies (with seasonality removed) for Denver Basin Aquifer System.

For water resources planning, reliable temporal data are needed to enable predictions of groundwater storage changes (either from models or trend analysis). Given the relative temporal sparseness of current well data, it is hypothesized that monthly GRACE data can improve the current uncertainty associated with groundwater quantity analysis along the Colorado Front Range. Monthly GRACE derived groundwater storage anomalies (km^3) for a grid pixel centered over the Denver Basin Aquifer System were compared to 277 ground-based observation wells (Figure 4). Each observational well was normalized for comparison to GRACE since at the time, the aquifer properties (i.e. specific storage, specific yield, aquifer thickness) were unknown and needed to convert a head measurement into a volumetric change.

Comparison of the water levels for the cumulative well observations for all aquifers are consistent with the increasing and decreasing patterns detected by the GRACE satellites. The response of each aquifer contributes to the observed GRACE signal. Long-term depletion rates over the Denver Basin Aquifer System from the GRACE signal amount to 0.008 km^3/year (~6,500 AF/year). Previous U.S. Geological Survey (USGS) reports identify depletion rates in the Denver Basin bedrock aquifers from 2002–2008 as 0.007 km^3/year. For comparison, the GRACE determined depletion rate from 2002–2008 was 0.007 km^3/year, matching the reported values from the USGS.

Comparison of GRACE with the U.S. Drought Monitor, which reports on the extent and magnitude of drought, 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.

Early results indicate that the satellite based data may be useful for managing and understanding groundwater resources over the South Platte Basin, and can help reduce uncertainty due to missing spatial and temporal groundwater level data. Significant long-term trends exist for each of the four aquifers of the Denver Basin Aquifer System, which are likely due to a combination of natural and anthropogenic effects.

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

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Dr. Melinda Laituri, Ecosystem Science and Sustainability, Colorado State University

Photo by Karie Boone

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

SYNOPSIS

This study focused on identifying how increased water use for oil and gas shapes and is shaped by the institutions of water rights in order to inform adaptive policy-making and institutions.

Introduction

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. These are the predominant entities responsible for guiding water policy, and while Colorado's institutions were built on the premise of mining interests, the contemporary pace and scale of energy extraction represents a new phenomenon that has not been critically examined. Indeed, 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 with 22,724 and 11,067 OG wells respectively. Throughout its lifecycle, each well uses between 3-8 million gallons, or between 9-24 acre feet of water. To meet the increasing demand for OG use, water suppliers, right holders, and Colorado's diverse community of users are innovating ways to navigate the rules governing water access and allocation to find flexibility in the State's water institutions.

With financial support from the National Institutes for Water Resources and the Colorado Water Institute, this research study examined how OG water users are able to find flexibility in the system when other uses have not, who is impacted by this type of flexibility, how, and what it means for access by other users. What does differential access look like if it exists and what does its presence illuminate about the system of prior appropriation? A comparative

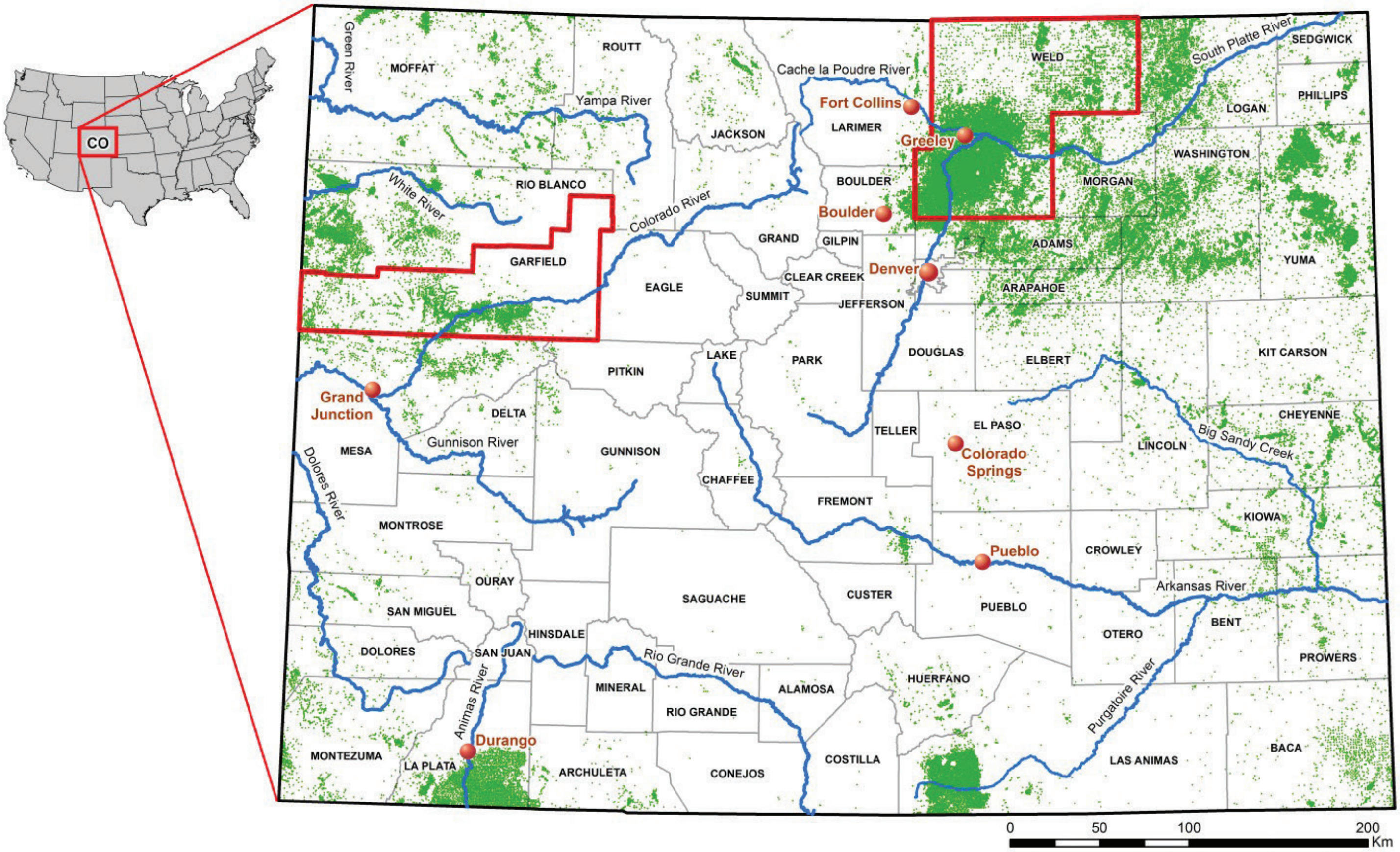


Figure 1. Map of Colorado with oil and gas development highlighted in green and the counties of study outlined in red (Oikonomou et al., 2016)

case study was conducted, spanning the U.S. Continental Divide to investigate divergent influence and change of OG water use in Garfield and Weld counties to examine these questions (Figure 1). These regions are of particular importance since they are located above Colorado's most productive OG fields, the Piceance and Denver-Julesburg Basins respectively. These regions have differing shale geologies, land tenure (private versus publically owned), divergent regional histories, and water sourcing strategies related to OG extraction. Identifying how increased water use for OG shapes and is shaped by the institutions of water rights both historically and in new ways will inform adaptive policy-making and institutions.

Methods

A comparative case study methodology provided the necessary in-depth examination of the 'how' and the 'why' of social and political change processes, an important step in building our understanding of water access and allocation mechanisms. State water institutions, policy, and local level decision-making comprise the ideal space to examine the actions and daily experiences of institutional decision-making on individual actors while compiling data that offers insights into larger scale changes in Colorado's water governance. A mixed-methods approach was used to integrate historical institutional analysis, document analysis of water rights, in-depth interviews, and geographic information systems (GIS). The historical institutionalist method traced the development of water rights and national energy policy as it related to OG development.

Then, an analysis of water rights for OG development was based on identifying current water sourcing strategies in Weld and Garfield counties. Data were gathered from published research and from a document analysis of primary source formal water court agreements including Substitute Water Supply Plans (SWSPs) and Water Right Decrees. The analysis of legal documents collected from government databases were evaluated in three phases. First, a literature review identified strategic search terms to locate the relevant water right decrees and short-term lease agreements (SWSPs) from the Colorado Division of Water Resources (DWR) online databases Laserfiche (http://dwrweblink.state.co.us/) and HydroBase (http://water.state.co.us/DataMaps/Pages/default.aspx). Search terms fit into categories of energy company, water provider, transport names, county, water uses, and key terms including oil and gas.

The second phase applied a Boolean search logic to locate the relevant water rights and SWSPs in the government databases from 2000-2014, a time frame including the height of OG production and the subsequent decrease of drilling activities and water use. Boolean searches consisted of combinations of county name, energy company, water organization name, and keywords such as 'natural gas' and 'oil'. Records returned from searches were organized using a common naming convention for systematic document and folder organization. Phase three entailed the document analysis using coding for applicant and water right holder name, diversion location, appropriation date, water source, decreed use(s) and volume, and proposed new use(s).

Then, interviews with farmers and ranchers, water managers, and OG company representatives shed light on how access and allocation is or is not flexible for multiple uses and/or sites of differential water access. In this case, utilizing qualitative interview methods provided the means to gain a better understanding of local definitions, perceptions and behaviors on the core topics of water access and allocation related to OG development, or how this institutional change is experienced by people on the ground.

Trends in Oil and Gas Water Access and Allocation in Weld and Garfield Counties

Water rights have evolved differently across Weld and Garfield counties and within the South Platte and Colorado River Basins (Figure 1). 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, with 85% of water used to irrigate 831,000 total acres, representing 24% of the state's irrigated acres. OG began in the early 2000s and Weld County is the top producing county with 22,108 active OG wells. Operators purchase water rights from agriculture and have short-term leasing arrangements including SWSPs from a variety of private entities. These entities include: water haulers, municipalities and increasingly from stakeholder-driven irrigation and reservoir companies, particularly those leasing water diverted from the Colorado River Basin through the Colorado Big Thompson (CBT) project. CBT water is diverted from western Colorado, under the Continental Divide and into the South Platte River Basin, flowing across the Eastern Plains in Colorado. CBT water is legally multi-use (i.e., municipal, industrial, irrigation) and considered more flexible since water can be leased to diverse use types without long and costly water court change of use cases. The South Platte River is over-appropriated, meaning that there are more legally sanctioned water uses then there is water, 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 with 11,000 active wells and located on the main stem of the Colorado River Basin (CRB). The main stem of the CRB has 268,000 or 8% of the state's irrigated acres of farm and ranch lands. OG operators lease small amounts of CRB water from private entities such as ranchers and conservancy districts, however, the predominant trend is for OG companies to own their own water rights. These rights were acquired from agriculturalists starting in the 1940s in anticipation of a federally funded oil shale boom. Many of these rights remain 'conditional', 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. A conditional right holder intends to make beneficial use of the water for some sort of future development, in this case OG extraction. 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.

Conclusion: Reflection on Research Experience

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. Colorado's water community has been generous for their time to interview and respond to questions about water rights and OG activities. 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.

Colorado's water institutions and rights change and adapt relationally with changing uses on the South Platte and Colorado Rivers, generating contemporary water accessibility for the state's diverse users. To understand these processes, social complexity is defined and integrated through a relational examination of historic policy outcomes, their influence on contemporary water allocation and access, changing water use for OG, and the physical nature of water as continually evolving and shaping one another. This integration links the hydrological and social impacts, while further enriching our understanding of how adaptive water governance is iteratively shaped through this same relational process.

In sum, issues of water access related to OG development have been identified piecemeal through individual conversation and in newspaper articles demonstrating the real concerns of farmers, environmental groups, and state legislators. No substantive studies have examined the tradeoffs of water access for the state's diverse users. While water quantity for extraction is still contested, a sufficient amount of data has been gathered from this research study, specifically from the Division of Water Resources' database to identify changes in water rights precipitated by increased OG production. If differential access is occurring, water policy should account for it and ensure all users have access to beneficial uses, particularly as the state moves toward more flexible water administration mechanisms. At the same time, formal policy often has divergent impacts on groups of people. This research examines these potential impacts and tradeoffs and will propose policy alternatives. The data analysis is still continuing so stay tuned for comprehensive research findings this fall!

Photo by Emily Pantoja

Karie Boone (right) with advisor, Dr. Melinda Laituri (left), discussing water use within the oil and gas industries in Weld and Garfield Counties.

Photo by Nicholas Harshman

Craig Moore (above) and his advisor, Dr. Gigi Richard (below) setting up the study area.

Photo by Craig Moore

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

SYNOPSIS

High levels of selenium (Se) can be toxic to aquatic wildlife. The purpose of this research study was to determine if four different wetland plants had the potential to improve water quality through sequestering Se into the root, leaf, and stem tissues.

Introduction

Excessive concentrations of selenium (Se) in natural water systems is of growing concern in western Colorado. A non-metal chemical element, Se is an essential human micronutrient in small doses. However, at elevated levels Se is a bioaccumulative toxin to aquatic wildlife. Spinal deformities, death in fish, and embryonic deformities in waterfowl have been attributed to excessive concentrations of Se in waterbodies. The Se content of several rivers in Colorado originates from a variety of geochemical sources of dissolved solids in surface water and alluvial groundwater. Primary among these sources are the Mancos Shale in western Colorado, extending across the Colorado Plateau, and the Pierre Shale east of the Rocky Mountains. Deep percolation from diverted irrigation water leaches Se from the lower soil profile, providing a pathway for discharge to river systems.

Soil and surface water concentrations of Se in the Uncompahgre, Lower Gunnison and Upper Colorado River regions are some of the highest in the country. 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. Numerous sloughs, ponds, and abandoned gravel pits sit adjacent to the Colorado River in Mesa County and these areas are important wildlife habitats and breeding grounds. These

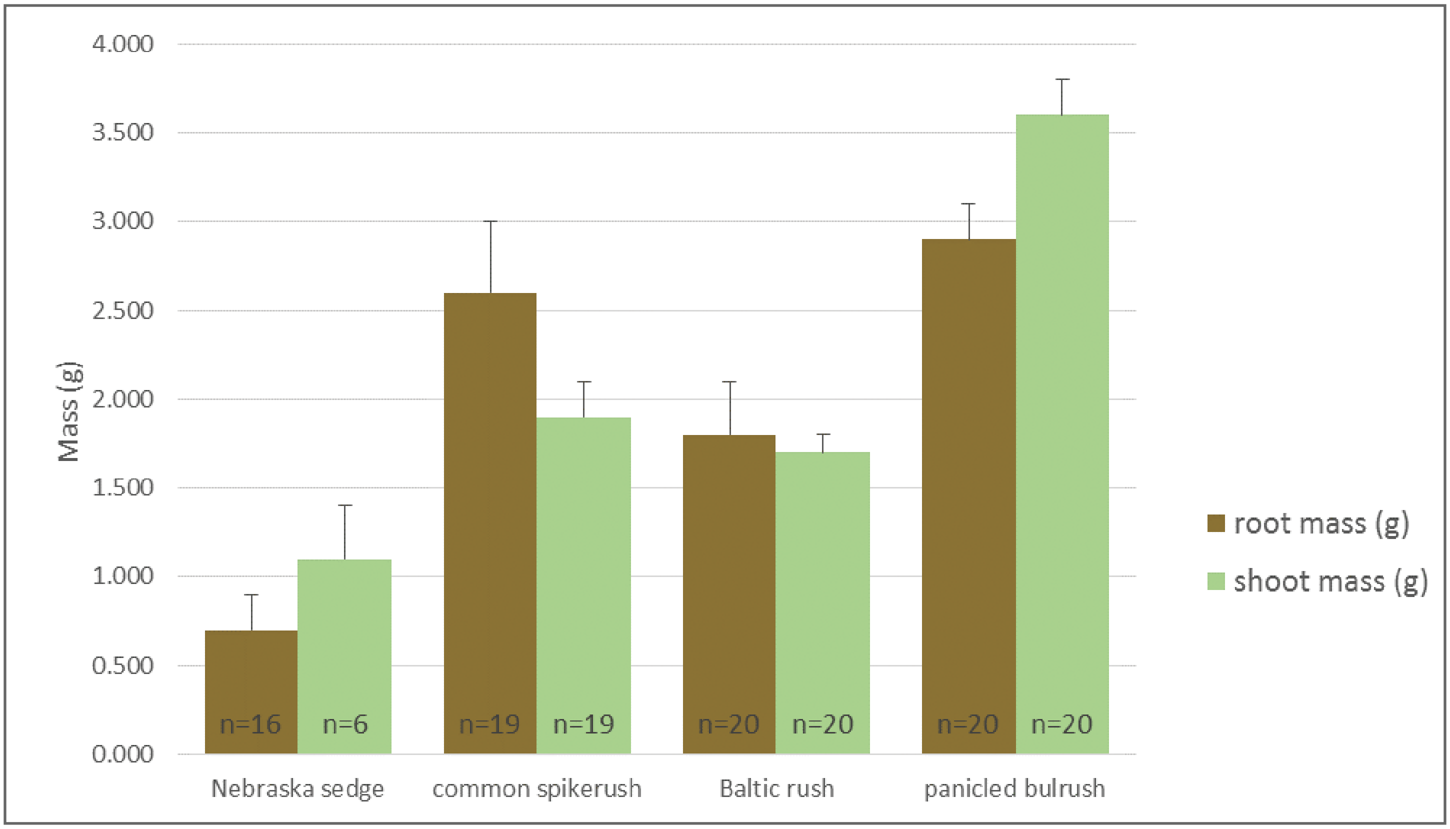


Figure 1. Average plant mass of four wetland plant species after a 4 month residence in a selenium rich gravel pit pond adjacent to the Colorado River in Mesa County, Colorado.

areas can also be hotspots for toxic Se concentrations. Aqueous Se has been found in these systems in excess of 100 ppb and tends to accumulate in bottom sediments.

Several stream segments within the Arkansas River Basin, including Wildhorse Creek and certain segments along the Arkansas River are also currently listed on the Colorado Department of Public Health and Environment (CDPHE) 303(d) list for Se, indicating that this issue is a statewide problem. Concentrations of Se in these reaches regularly can exceed the chronic toxicity level for aquatic life.

Prior studies have successfully demonstrated the Se phytoremediation capability of several halophytic wetland plant species in a laboratory setting. 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 taking up and sequestering Se in their root tissue and leaf and stem (referred to collectively as "shoot") tissue under field conditions. Floating wetland systems of the type described in this paper have been used in Midwestern United States studies to uptake nitrogen (N) and phosphorous (P) from storm water detention ponds. This project had the goal of expanding the examination of floating wetlands for Se remediation.

Methods

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. Test species were taken or derived from the 1999 study of Pilon-Smits et al. (1999). 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).*

Floating wetland mats were purchased from Beemats™, in New Smyrna Breach, Florida, and assembled at the study site. Beemats are comprised of buoyant, interconnecting square foam mat sections. Each mat section has an area of 60 cm x 60 cm, is 1 cm thick, and holds ten cups which each house plant replicates.

Study Area

The study site was a gravel pit pond known to exhibit excessive concentrations of Se. The pond is located adjacent the Colorado River in Mesa County, Colorado, and access was granted by the Mesa County Public Works Department. The constructed floating wetland was installed at the study site 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.

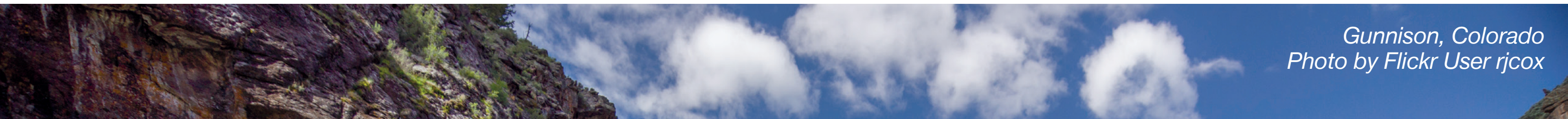
Results

Following a four-month residence at the study site, average total biomass of the test species was as follows: Panicled Bulrush, 6.5 g per replicate; Common Spikerush, 4.5 g per replicate; Baltic Rush, 3.5 g per replicate; and Nebraska Sedge, 1.8 g per replicate. Baltic Rush and Common Spikerush held the majority of their biomass in their roots, while the Panicled Bulrush and Nebraska Sedge had greater mass in their shoots (Figure 1). Common Spikerush, Baltic Rush, Panicled Bulrush, and Nebraska Sedge grew to average heights of approximately 42 cm, 41 cm, 39 cm, and 5.8 cm, respectively. Roots grew to depths of 53 cm, 45 cm, 44 cm, and 22 cm, for Panicled Bulrush, Common Spikerush, Baltic Rush, and Nebraska Sedge, respectively. Nebraska Sedge experienced a 70% mortality rate, while the Panicled Bulrush, Baltic Rush, and Common Spikerush experienced a 100% survival rate. One Common Spikerush was lost at the study site.

The greatest average Se concentration was found in the root tissue of the Panicled Bulrush, *3.8 mg/Kg.* Average Se concentration present in the root tissue of Common Spikerush, Baltic Rush, and Nebraska Sedge were 3.5 mg/Kg, 3.3 mg/Kg, and 2.7 mg/Kg, respectively (Figure 2). All species showed higher Se concentrations present in root tissue than in shoot tissue. Panicled Bulrush contained greater Se concentrations in roots than shoots by a factor of approximately three, Baltic Rush by a factor of approximately four, Nebraska Sedge by a factor of approximately five, and Common Spikerush by a factor of approximately seven. The Panicled Bulrush also had the highest Se concentration among all plant species in terms of shoot material, 1.2 mg/Kg. Common Spikerush, Baltic Rush, and Nebraska Sedge had average shoot concentrations of 0.5 mg/Kg, 0.7 mg/Kg, and 0.5 mg/Kg, respectively.

Discussion

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. Volatilization capability of Common Spikerush and Baltic Rush has been demonstrated by Pilon-Smits et al. (1999). The findings justify future inquiry into the volatilization potential of the panicled bulrush. Additional research that could progress from this study would be to evaluate the total Se load capable of being removed per area unit of floating wetland mats, and the overall impact that a large coverage could possibly have on Se-rich gravel pit ponds.



Gunnison, Colorado
Photo by Flickr User rjcox

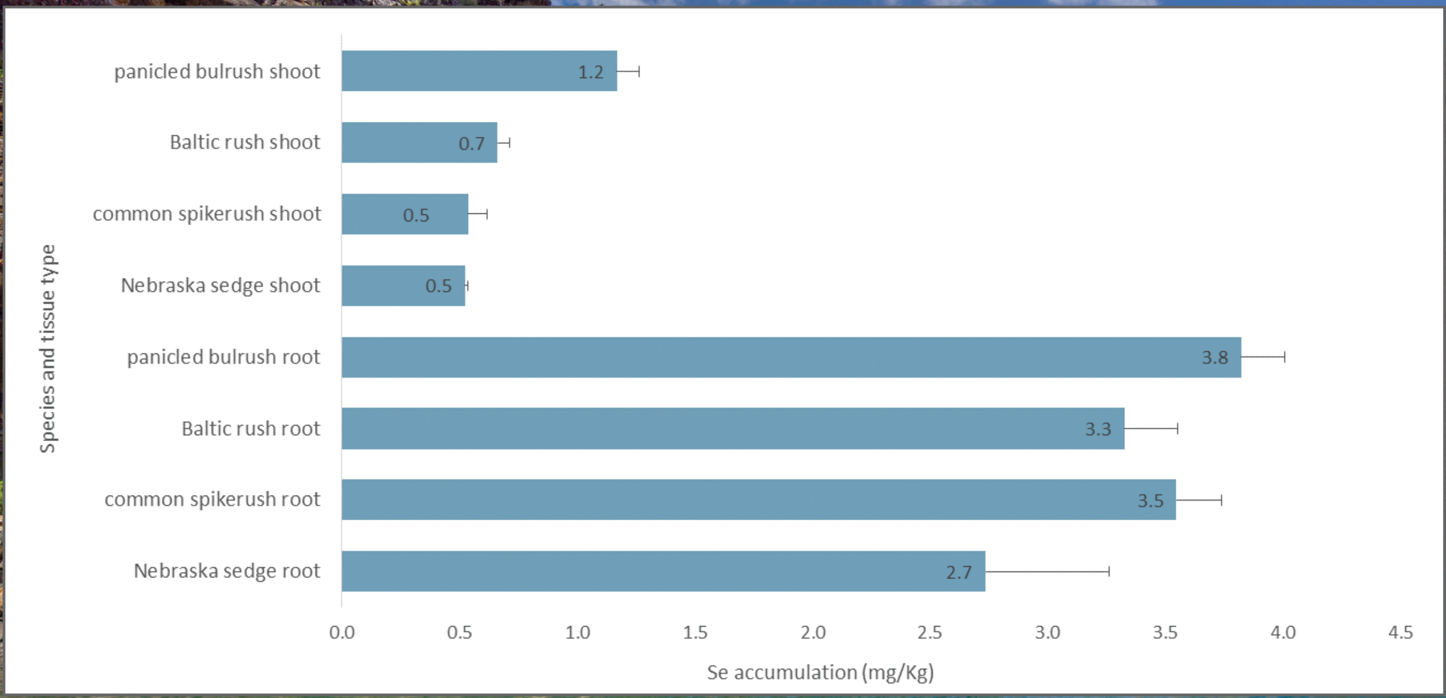


Figure 2. Average selenium concentration (mg/Kg) accumulated by the roots and shoots of four wetland plant species after a 4-month residence in a sleniuem rich gravel pit pond adjacent to the Colorado River in Mesa County, Colorado.

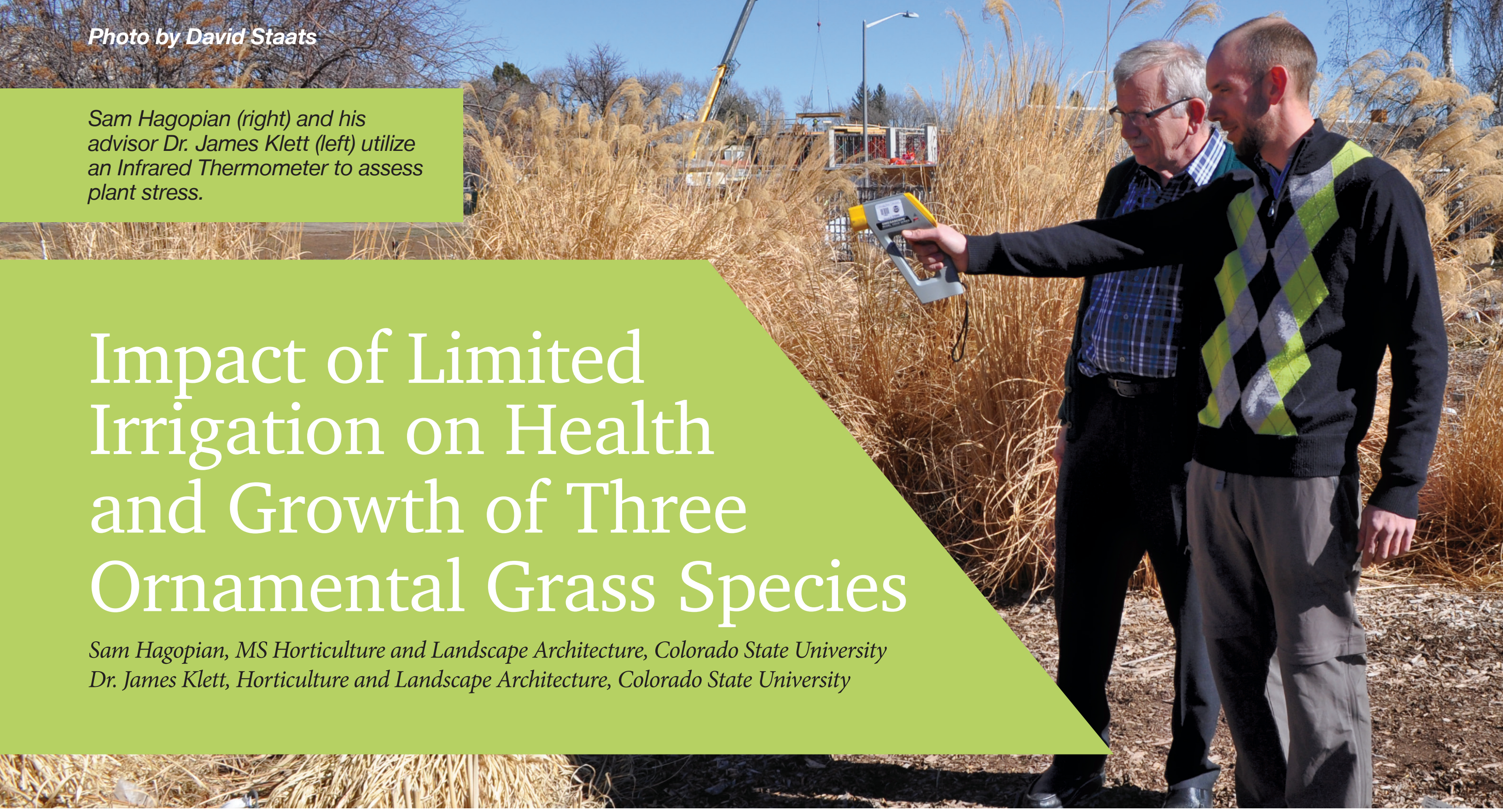


Photo by David Staats

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

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

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SYNOPSIS

Ornamental grass quality and plant stress were analyzed in this research study. Three different ornamental grass species were assessed under four irrigation regimes, in order to determine a standardized irrigation method. Water use within the soil profile was also analyzed.

Introduction

Water is one of the most valuable and limited 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. Discovering the stress range in which a plant will survive, grow, thrive, or wilt and fail to recover is of critical importance and has the potential to represent a large range of related species. As ornamental grasses become more important components of urban landscapes and large-scale nurseries, 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. More generally, it is important to understand if deficit irrigation is feasible with ornamental grasses. This research has large applications to Colorado in knowing if deficit irrigation is feasible once periods of drought are introduced. While previous research has touched on growing these grasses, this study serves as a pioneer in linking ornamental quality with physiological stress and growth, providing a baseline for the levels of stress these plants can endure while maintaining good aesthetic quality. The most applicable aspect of this research lies in quantifying the actual evapotranspiration (ET) that these plants undergo. Industry personnel and researchers base a majority of irrigation practices on ET, and this is why effective quantification of ET is a key aspect of precise irrigation management (Irmak, 2009).

Methods

Two studies were performed, termed 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 (ET_o). Irrigation treatments were calculated and applied once a week.

Two generalized categories of data were collected, plant stress, and ornamental quality. Plant stress parameters included: predawn water potential (Ψ), infrared canopy temperature, percent water content in the soil profile, and dry weight. Plant ornamental quality parameters included: height, width, circumference, green-up date, flowering date, floral impact, landscape impact, overall habit/lodging, color, self-seeding, and representative photographs.

The lysimeter study examined one spe-

Figure 1. Photographs of Calamagrostis brachytricha in Water Use Study at the beginning of flowering season. Treatments from left to right: 1) 0%, 2) 25%, 3) 50%, and 4) 100%.

cies 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 (ET_s). The same plant stress and aesthetic measurements were chronicled in the lysimeter study as in the water use study. 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). During dry down periods, entire pot and plant weight were measured on a daily basis, recording weight loss, and in turn ET_s. To measure plant stress during these periods, water potential readings were taken daily.

Results

Water Use Study - Stress Measurements

Water potential for both seasons showed the 0% treatment was significantly more stressed than the other three treatments. Infrared canopy temperature showed the same trend, with the 0% treatment being significantly more stressed than the other three treatments.

Water Use Study - Landscape Measurements

End of season height showed differences between treatments for each species. While results varied for each species, the trend of 0% being significantly smaller held true for all three species. End of season circumference followed the same trend, in the 0% being significantly smaller than all other three treatments. Floral impact, landscape impact, overall habit/lodging, and self-seeding showed that 0% held less aesthetic value than all other treatments. Each landscape category had slight differences between treatments for the 2014 and 2015 seasons, however these differences are considered negligible as all plants in the 25%, 50%, and 100% treatments were considered suitable for use in the landscape trade (Figure 1).

Water Use Study – Rooting Behavior

In order to extract the most detailed information, both year and species were combined in order to analyze by treatment and by depth. Research indicates that ornamental grasses cease accessing significant portions of water at a depth of between 20cm-30cm from the soil surface.

Lysimeter Study – Evapotranspiration (ET)

During the first two dry downs of 2014 and 2015 seasons there was no difference in ET between treatments. These dry downs took place in July and early August and lasted anywhere from 5 to 13 days (depending on local weather). This indicates that as the plants were growing, their initial foliage early in the growing season and increasing in both height and width, they use the same amount of water regardless of treatment. The more interesting data comes during the third and fourth dry downs in mid-August and September during both seasons. During the third dry down in both 2014 and 2015, the 25% and 50% treatments used less water than the 100% treatment. During the fourth dry down in both 2014 and 2015, the 25% treatment used significantly less water than the 50% and 100% treatments, and the 50% treatment used significantly less water than the 100% treatment. This confirms the hypothesis that during each season, as the plants gain circumference, begin flowering, and acquire fall color, the plants receiving deficit irrigation were using less water. Overall, the 25% treatment used 50-60% of the water used by the 100% treatment. This indicates that within a few months, Schizachyrium Scoparium 'Blaze' is capable of adapting to a lower water regiment, and effectively budget the water needed for proper survival.

Lysimeter Study - Stress Measurements

During the first two dry downs of 2014 and 2015 there was no difference in stress between treatments. The third dry down of 2014 and 2015 (mid-August) results in 25% and 50% being more stressed than 100%. The fourth dry down of 2014 and 2015 (late August/early September) results in the 25% being more stressed than the 50% and 100% treatments, and the 50% treatment being more stressed than the 100% treatment. This suggests that the less irrigation a plant receives, the more physiologically stressed they are than their fully irrigated counterparts. The one commonality to the final two dry down periods is that the 25% treatment was always significantly more stressed once the plants reach 5 to 7 days without water.

Lysimeter Study – Visual Ratings

There were no significant differences for height, width, circumference, floral impact, landscape impact, or overall habit between treatments for either the 2014 or 2015 season.

Discussion

Water Use Study

In regards to measurements of physiological stress, plant size, and aesthetic value for all three species, the 0% treatment was significantly more stressed while the remaining treatments are equally stressed. This indicates that plants grown with a 25% irrigation regiment are equally unstressed and hold the same aesthetic/landscape values as a plant receiving the 100% irrigation. Allowing for these grasses to be irrigated with 25% bluegrass ET allows for 75% water savings as well as plants that are of equal health and landscape quality as those irrigated with 100%. A 0% irrigation regimen was determined not to be a feasible option, resulting in plants not suitable for the landscape trade.

Water Use Study – Rooting Behavior

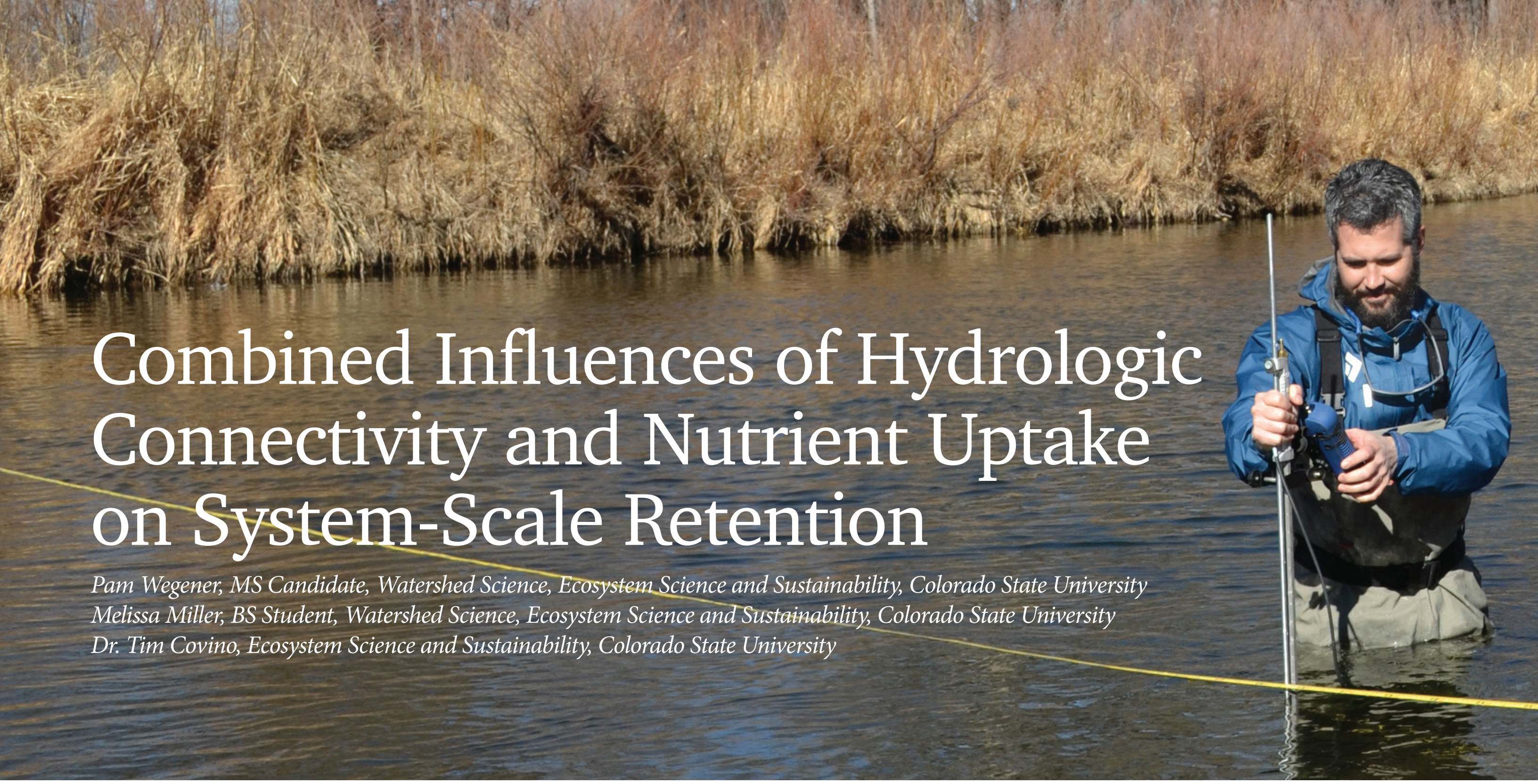
Ornamental grasses access a majority of their water between 20cm-30cm. Since this is a shallow depth, which is easily dried out by common earth elements (wind, erosion, etc.), it would seem more important to get a widely distributed irrigation pattern around these grasses as opposed to a deeply distributed pattern. It is also likely that applying mulch to the base of these grasses would aid in longer water retention.

Lysimeter Study

The most important conclusion comes from coupling the concepts of ET and water potentials. 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. This means that if these plants receive deficit irrigation and are subjected to a period of extreme drought, it is possible they may not be able to survive, while their well-watered counterparts will survive. Considering this was a two year study, these results would likely be exacerbated as time progresses. This information suggests that watering Schizachyrium Scoparium 'Blaze' at 25% irrigation is possible. However, irrigation events may need to be more frequent to compensate for the additional stress.

Conclusion

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 demands. However, the number of 0.25 inches is relatively sure to allow ornamental grasses to grow to their full potential while maintaining low levels of stress.



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

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

SYNOPSIS

CSU researchers collaborated to determine how hydrologic connectivity influences stream ecosystem metabolism. This research study was conducted within the Wild Basin Watershed, located within Rocky Mountain National Park, Colorado.

Introduction

From May-September 2015, researchers from Colorado State University's Ecosystem Science and Sustainability Department 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. In wet valley meadow systems, river-floodplain hydrologic connectivity controls the degree of exchange between the main channel and floodplain surface water-bodies (e.g., side-channels and ponds), and is therefore important for connecting nutrient sources and sinks, and in turn, enhancing stream ecosystem metabolism. For example, a floodplain surface water-body such as a side-channel may be a safe refuge for algae, which would be easily washed away by the faster moving water of the main channel. Such algae may require nutrients transported from the main channel for biologic processes and growth. After algae die, algal detritus can return to the main channel and become an important downstream energy resource for microbial respiration. Stream ecosystem metabolism describes the rate in which organic matter cycles through various compartments and can serve as an indicator of stream health.

An experiment was designed to test the hydrologic mechanisms that optimize stream ecosystem metabolism in the Wild Basin Watershed, an 88-km^2 watershed in Rocky Mountain National Park, Colorado. The Wild Basin Watershed is an ideal location to study the influence of river-floodplain (lateral) hydrologic connectivity on stream ecosystem metabolism because it consists of two reach segments with dramatically contrasting hydrologic responses to snowmelt: an unconfined multi-thread wet valley meadow, and a valley-confined single-thread channel. The North Saint Vrain Creek drains the Wild Basin Watershed and is dominated by seasonal snowmelt; streamflow rises abruptly in late May during peak snowmelt, and then decreases back to baseflow conditions by September. During high flows, the unconfined segment can dissipate flow laterally via the floodplain, whereas the confined segment is valley-constrained. As a result, the confined segment has less variability in river-floodplain hydrologic exchanges relative to the unconfined segment from high to low flows.

The goals of the research study were two-fold. First, the research focused on quantifying the timing and magnitude of water and dissolved organic carbon (DOC) fluxes in the unconfined versus the confined segment to evaluate the relative retention/transport potentials for each landscape type. DOC is an important energy resource for microbial respiration, and as such, DOC retention is strongly related to stream ecosystem metabolism. Second, the research study focused on the influence of lateral hydrologic connectivity on stream ecosystem metabolism by comparing metabolism rates measured at the outflow of the unconfined segment versus the outflow of the confined segment. Additionally, metabolism rates were measured in two floodplain surface water-bodies in the unconfined segment to evaluate the contributions of floodplain water-bodies to stream ecosystem metabolism from high to low flows.

Methods

In March 2015, prior to snowmelt, 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

Dr. Tim Covino (facing page), Melissa Miller (center), and Pam Wegener (right) conducting field work.

seven ponds in the floodplain. The monitoring sites consisted of automatic sensors that continuously recorded water height (stage), colored dissolved organic matter (CDOM), and dissolved oxygen (DO) concentrations. Each site was visited approximately weekly to download the data, calibrate the instruments, and collect grab samples which were field-filtered and sent to the Fort Collins Rocky Mountain Research Lab to analyze for nutrients and major cations and anions.

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, which involves stretching measuring tape across the width of the stream and taking stream velocity measurements at various increments along the channel transect. 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. First, an empirical relationship was developed between CDOM and DOC concentrations analyzed from grab samples. Then, that relationship was used to transform continuous CDOM to continuous DOC, and used those data in conjunction with flow to calculate daily DOC fluxes and balances for the segments.

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. This method assumes that the more hydrologically connected the side-channels and ponds are with the main channel, the more in-phase the stage fluctuations are between those water-bodies and the main channel. The relative connectivity values for each of the floodplain water-bodies were averaged to categorize periods of "high" and "low" connectivity. Lateral hydrologic connectivity in the unconfined segment was strongly related to flow, with high connectivity occurring during peak flows from around June 10th–July 10th, 2015.

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. Ecosystem metabolism rates include primary productivity (the autotrophic production of organic carbon and oxygen) and respiration (the auto- and heterotrophic consumption of organic carbon and oxygen). During daylight hours, primary productivity releases oxygen to the water, and stream DO concentrations increases. During dark hours, primary productivity essentially shuts down, respiration is the dominant metabolic process and consumes oxygen from the water, and stream DO concentrations decrease. The DO change approach essentially calculates metabolism as a function of the magnitude of diurnal DO change, in which greater changes in diurnal DO concentrations are associated with higher metabolism rates.

Results & Discussion

The unconfined segment buffered water and DOC fluxes relative to the confined segment. The unconfined segment transported a net total of 0.12 $m^3\ ha^{-1}$ of water and 0.08 $g\ ha^{-1}$ of DOC per meter downstream, whereas the confined segment transported a total of 1.9 $m^3\ ha^{-1}$ of water and 7.2 $g\ ha^{-1}$ of DOC per meter downstream during the monitoring period. While the confined segment was a consistent source of water and DOC, the unconfined segment displayed variable source/sink dynamics, transporting water and DOC during low flows and storing water and DOC during high flows.

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, which we attribute to increased water residence times that extended the duration of contact between microbes and their substrate and facilitated organic matter processing. Metabolism rates measured at the outflow of the confined segment were consistently lower than rates measured at the outflow of the unconfined segment, which were more variable and peaked at intermediate levels of connectivity. It is believed that the confined segment had relatively low and consistent metabolism rates from high to low flows because it was valley constrained. As such, 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 – which peaked at intermediate levels of connectivity – 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. During high flows, energy resources such as DOC are stored in unconfined segment floodplain water-bodies and are then utilized when flows decline, residence times increase, and processing rates are optimized. This in turn suggests that intermittent connectivity is crucial to stream ecosystem metabolism in riparian wetlands.

The ability of unconfined wet valley systems to retain DOC (an important energy resource) relative to other landscape types is key to the disproportionate contribution of these landscape features to biogeochemical processing in river networks. However, there is a surprising lack of research on how stream ecosystem metabolism – an integrative measure of nutrient and organic matter processing in fluvial systems –responds to seasonal changes in the strength of river-floodplain hydrologic connectivity. As a consequence, constructed wetlands, for example, are commonly built using compacted clay substrate and periphery berms that result in decreased hydrologic connectivity relative to natural wetlands. 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.

In Memory of Former Senator James Isgar

Photo Courtesy of the Colorado General Assembly

Melissa Mokry, Editor, Colorado Water Institute

Former Colorado Senator James "Jim" Isgar, an influential and inspiring advocate within the Colorado water resource community, politics, and agriculture, passed away March 4, 2016. Jim served as a valued member of the Colorado Water Institute Advisory Board from 2005-2009. His passion and understanding of water resources, stemmed from his dryland farming experiences, involvement in policy, and decision-making.

Isgar's list of accomplishments is quite impressive and notable. Over the course of his life, he was a major proponent of the Animas-La Plata Project. He learned about the complexities of water resource controversy through his experience serving on the La Plata Water Conservancy District Board. He was appointed to the State Board of Agriculture in the late 1980s. Eventually Isgar would go on to become Colorado State Senator, serving from 2001-2009. Isgar supported almost every bill related to water resources during his time in the Senate. Subsequently, Isgar was appointed the State Director of the United States Department of Agricultural Rural Development for the state of Colorado in 2009. While Isgar will be greatly missed, his legacy lives on. Coloradoans will benefit from his advocacy and policy-making for years to come.

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

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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

SYNOPSIS

Logging has greatly impacted riparian regions over the years. This research study focused on assessing trout density, growth, and diet within two streams located in the Colorado Front Range. The study also focused on assessing logjam densities.

Introduction

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 (floating logs downstream to use for railroad ties), snag removal, and beaver trapping have further reduced physical habitat complexity, such as channel spanning logjams, in streams.

Logjams reduce water velocities and increase groundwater levels, which facilitate the formation of multi-thread channel reaches and dynamic water exchange between surface and groundwater. High densities of logjams create a positive feedback mechanism that increases wood retention and logjam formation. However, 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 alternative stable state has a simplified physical habitat template, characterized by a single stream channel and reduced pool habitat.

This research study focused on utilizing the small amount of true old growth forest (> 350 years old) still remaining in the Colorado Front Range (United States) to intensively study patterns in trout density, growth, and diet among two streams with varying riparian forest stand ages (~120 and >350 years old) and logjam densities. As part of our initial effort, data on fish density and growth rates was collected; then diet samples at both sites during summer and fall seasons were also collected to investigate any differences in diet composition between the two sites. Here, presented below are the results on differences in population densities, individual growth rates, and diet composition.

Study Area

Two field sites for intensive sampling were selected including: a high and low wood site (Table 1). Both of these sites were sampled in Summer and Fall 2014 (Table 1). The first site, North St. Vrain, has an order of magnitude more wood per square meter than the second site, Glacier Creek (Table 1). Although the stream area is about the same, the high wood site has about twice the pool area compared to the low wood site (Table

Adam Herdrich collecting samples during field work.

Photo by Pam Sponholtz
Background photos also by Pam Spnholtz

Table 1. Elevation, riparian forest stand age, and stream habitat areas at North Saint Vrain and Glacier creeks.

Site	Elevation (m)	Forest stand age (yrs)	Valley Length (m)	Stream area (m^2)	Pool (m^2)	Riffle (m^2)	Wood (m^3)
N. St. Vrain	3017	>350	500	6900	1150	5750	3486
Glacier Creek	2712	122	900	7164	676	6488	312

1). It is also important to note that the high wood site is at higher elevation compared to the low wood site.

Methods

Brook Trout Sampling and Analyses

Fish populations were sampled in August and October 2014 at both the high and low wood sites via electrofishing, to obtain population estimates. Approximately 30 Brook Trout *Salvelinus fontinalis* (when available) were collected from each site for growth and diet analyses. Average growth rates were estimated from otolith (or "ear bone") sections. These structures create rings similar to tree rings and when measured, can give useful estimates of annual individual growth. Average growth rates were then estimated and compared using Von Bertalanffy growth curves.

Diet samples were collected from the same 30 fish at each site and date. Diet compositions were analyzed using a multivariate community statistical approach. The proportions of insects consumed at each site and date were compared, and differences in these proportions between sites were used to determine how similar diet compositions were.

Local- vs. Landscape- scale

The above analyses provided habitat, or local, scale estimates (m^{-2}). To account for the large difference in stream area among study sites and allow results to be examined on a landscape scale, per square meter estimates were multiplied by total habitat area and divided by stream valley length (Table 1; linear m $valley^{-1}$).

Results

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 (Figure 1). Average growth rates were almost identical for the two sites; however, Brook Trout in Glacier Creek reach an estimated larger overall length by approximately three-quarters of an inch (Figure 2). Diets differed between the high and low wood site during the summer (average difference = 81.09; Figure 3), but were more similar during the fall (Figure 4). Differences in the summer diets were explained by Brook Trout consuming a high proportion of ants at the low wood site (Table 2). Brook Trout at the high wood site consumed far more midge larvae during the summer than those at the low wood site (Table 2). Brook Trout at the low wood site consumed more stone fly nymphs, water mites, and assorted wasps and bees than those at the high wood site (Table 2). In general, during the summer, fish at the low wood site had higher proportions of terrestrial insects and water mites while fish at the higher wood site consumed a higher proportion of smaller aquatic benthic invertebrates and these taxa explained over 90% of the differences in diet (Table 2).

Discussion

Brook Trout biomass was significantly higher at the high wood site at both the square meter and valley scale. It is believed that instream wood has a strong effect on Brook Trout density due to the creation of low velocity habitat. 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. Other research being conducted on stream benthic invertebrates suggests that large wood increases aquatic insect production that probably also influences fish population density.

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. Therefore, average fish size is similar at both sites. Diet data indicate the invertebrate taxa differed significantly between

Table 2. Results from a procedure comparing the relative abundance of various insect taxa in fish diets at the low and high wood sites during summer 2014. Contributions to overall difference in diets by each taxa are indicated (Contribution %) and cumulative percentage (Cumulative %).

Species	Common Name	Low Wood Abundance	High Wood Abundance	Contribution %	Cumulative %
Formicidae	Ants	38.16	22.4	21.67	21.67
Chironimidae	Midge Larvae	0.35	33.77	20.62	42.29
Perlidae	Stonefly Nymph	19.18	5.89	12.74	55.03
Acari	Water Mites	14.29	0	8.81	63.84
Hymenoptera	Wasps, Bees, and Ants	10.09	2.6	7.35	71.19
Heptageniidae	Mayfly Nymph	4.86	5.28	5.2	76.39
Chalcidoidea	Chalcid Wasps	0.5	7.33	4.58	80.96
Ephemerellidae	Mayfly Nymph	0.92	5.91	3.88	84.84
Baetidae	Mayfly Nymph	3.96	4.89	3.6	88.44
Simuliidae	Black Fly Larvae	0.13	4.12	2.55	90.99

the high and low wood sites during the summer season. Brook Trout at the low wood site consumed more terrestrial taxa, particularly ants, and riffle species, such as stone flies. Brook Trout at the high wood site consumed more midge larvae. The preponderance of midge larvae in the high wood diets is predictable because of the high proportion of low velocity pool habitat that Chironomids prefer. Most likely, Brook Trout are keying in on the increased production of smaller benthic invertebrate species. Brook Trout at the high wood site may also consume midge larvae because there are fewer drifting insects due to higher competition. Previous research has shown that stream-dwelling salmonids may switch to benthic-foraging (preying on aquatic invertebrates on the stream bottom) when drifting insect biomass (terrestrial and some larger aquatic invertebrates in the water column) is reduced below a certain threshold.

In this research study, the small amount of true old growth forest (> 350 years old) still remaining in the Colorado Front Range (United States) was utilized to understand how mountain headwater streams in the western United States functioned pre-European colonization. For this project, animal responses to instream wood were examined between two streams with varying riparian forest stand ages (~120 and >350 years old) and logjam densities. Trout biomass was significantly greater in our 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.

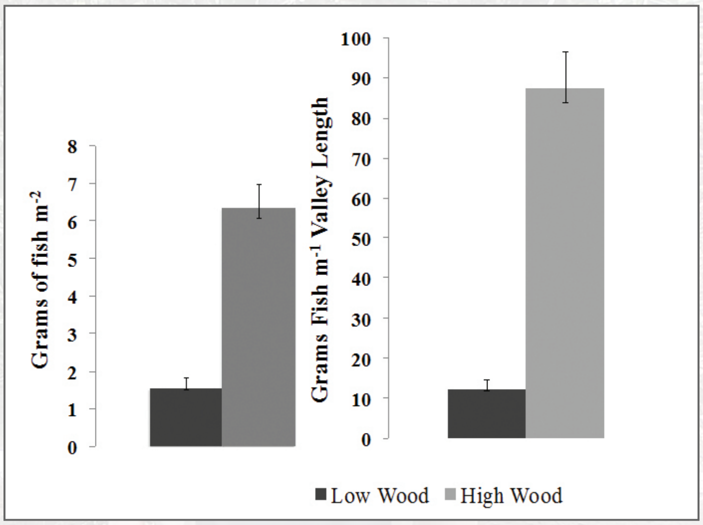


Figure 1. Biomass of fish at the low and high wood sites for summer 2014. The figure on the left shows grams of fish per square meter (local scale), while the figure on the right shows grams of fish per meter of valley length (landscape scale). At the high wood site, there is about 4 times more fish biomass at the local scale and nine times more at the landscape scale.

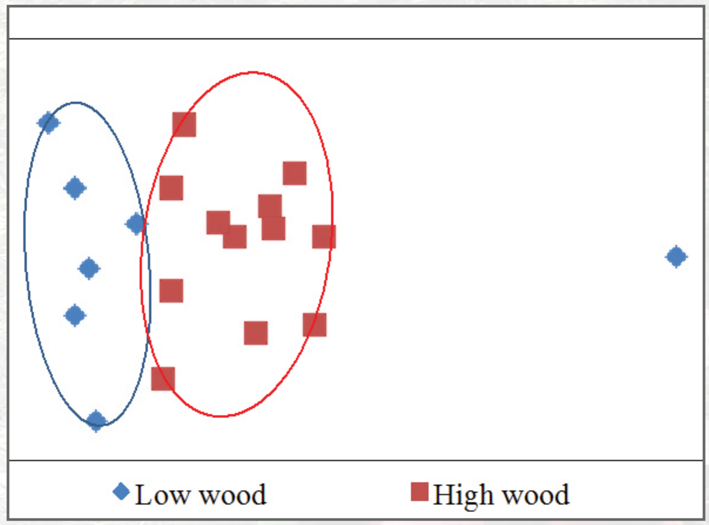


Figure 3. A two dimensional representation of diet compositions at the high and low wood sites during summer 2014. The diets form two distinct groups due to differences in prey consumed. The difference occurs because of higher consumption of small aquatic invertebrate larvae at the high wood site.

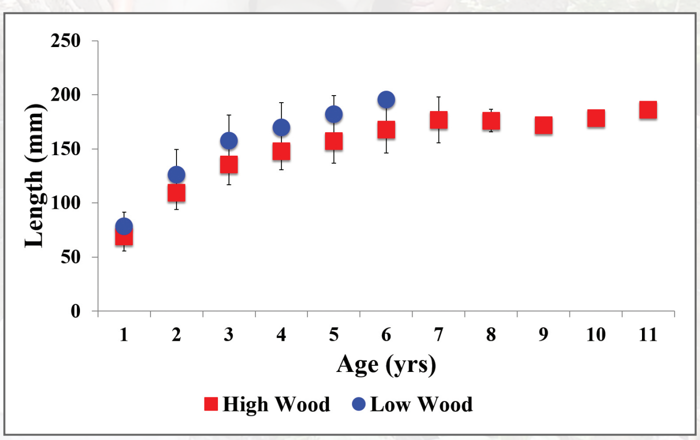


Figure 2. Average length at age for brook trout from the high wood and low wood sites. Lengths at ages are very similar for both sites, indicating similar growth rates at both sites.

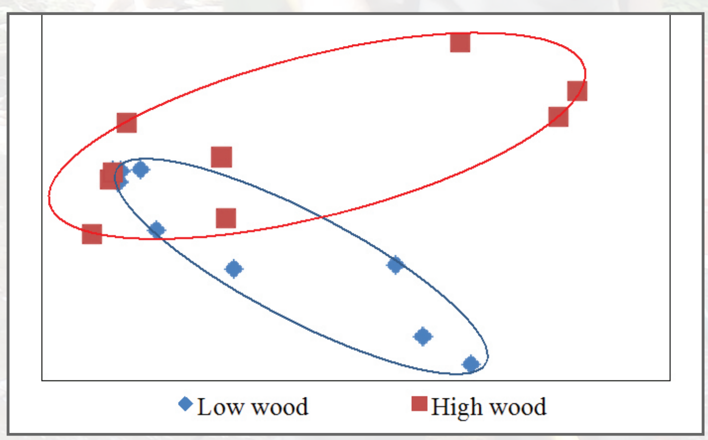


Figure 4. A two dimensional representation of diet compositions at the high and low wood sites during fall 2014. The two groups overlap because the diets are more similar during the fall sampling period compared to the spring.

Using Reanalysis Data to Find Signal Strength of Root Zone Soil Moistures

Precipitation Feedback in the Upper Colorado River Basin and Western High Plains for Drought Early Warning Purposes

Peter Goble, MS Atmospheric Science, Colorado State University
Nolan Doesken, Colorado State Climatologist
Dr. Russ Schumacher, Atmospheric Science, Colorado State University

SYNOPSIS

It is important to continue to improve drought early warning systems. This research study focused on quantifying the root zone soil moisture on warm season precipitation irregularities within the Upper Colorado River Basin and Western High Plains.

Introduction

Because of the swift and chaotic nature of the atmosphere, precipitation forecasts based on numerical atmospheric models begin to break down at around one week's lead time. Seasonal forecasts for precipitation are computed by determining statistical relationships between the more slowly varying land and ocean surfaces, and the net tendency of the atmosphere over the coming weeks. Drought typically develops when precipitation is lower than normal on seasonal or longer timescales, so tracking statistical relationships between land and ocean, as well as seasonal precipitation is a key to building a smarter drought early warning system.

The amount of water in the uppermost layer of soil that is within access range of local flora is one land variable with the potential to aid in improving seasonal precipitation forecasts and drought early warning systems, particularly during the warm season. In the warm season, energy imbalances arise between land and atmosphere because the land absorbs the lion's share of insolation. This difference in energy between the land and lowermost layer of atmosphere is balanced through either sensible heating of the atmosphere or moistening of the atmosphere through transpiration of plants (latent heating). If a source of lift is present, this transpired water may be cycled back into the soil as precipitation.

Motivation

In order to improve the local drought early warning system in the Upper Colorado River Basin and Western High Plains this study aimed to quantify the relative influence of root zone soil moisture on warm season precipitation anomalies, primarily as a function of watershed.

Methods

Precipitation data for this study were taken from rain gauge measurements and interpolated using PRISM climatology. Soil moisture data were from an ensemble of land surface models. The land surface models used were the Variable Infiltration Capacity (VIC) Model, Mosaic Model, and Noah Model. Data were collected at daily resolution for the time period from January 1st of 1985 to December 31st of 2014.

The Dolores River in Western Colorado
Photo by Flickr User 64MM

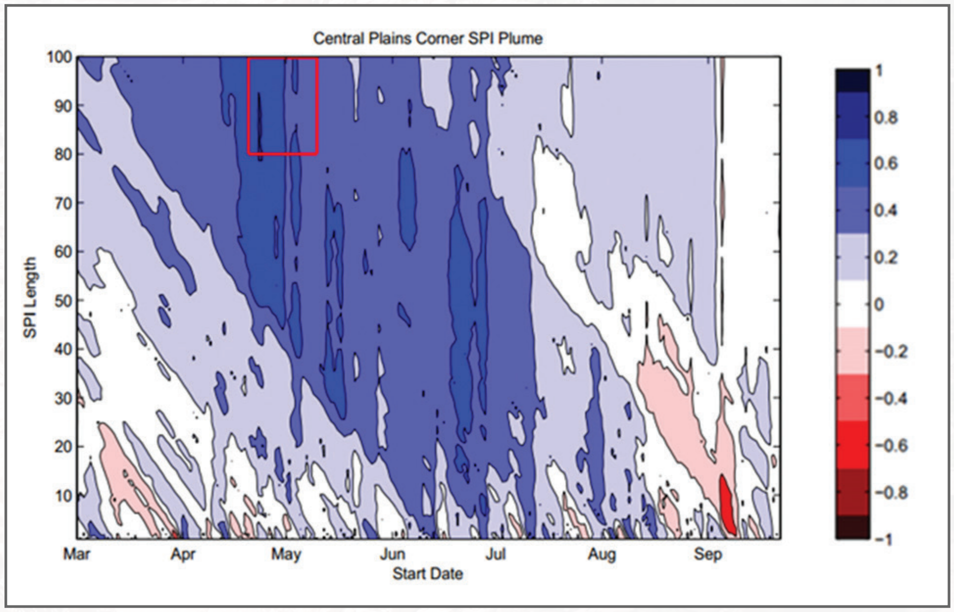


Figure 1. Shown here is the correlation between standardized RZSM anomalies and SPIs for all days of the warm season for accumulation periods of 1-100 days for one of the nine subregions analyzed. All correlations greater than 0.3072 are significantly greater than zero at 95% confidence. The red box indicates data that would be considered when making a 90-day SPI hindcast starting on May 1st for the Central Plains Corner Region.

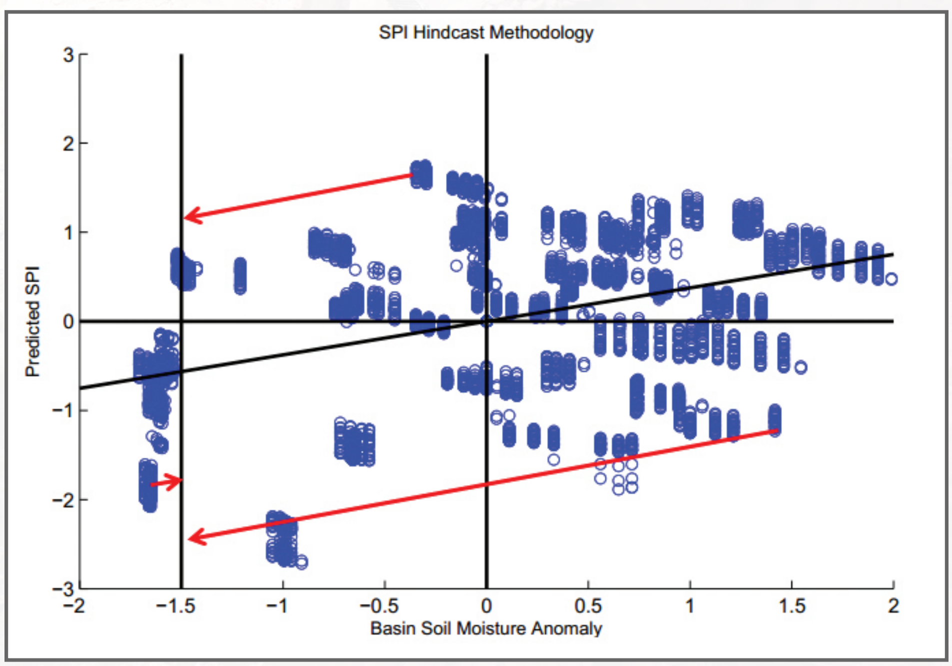
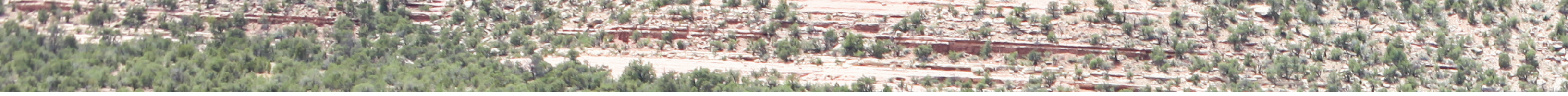


Figure 2. This scatterplot shows all of the data from the 1985-2014 period being considered for in the issuance of a precipitation hindcast for one of the nine subregions for the 90-day period beginning on May 1st, 2002. The black line at -1.5 illustrates the value of the 2002 subregion soil moisture anomaly, and the red arrows illustrate the method by which regressed SPIs are derived from actual SPIs.



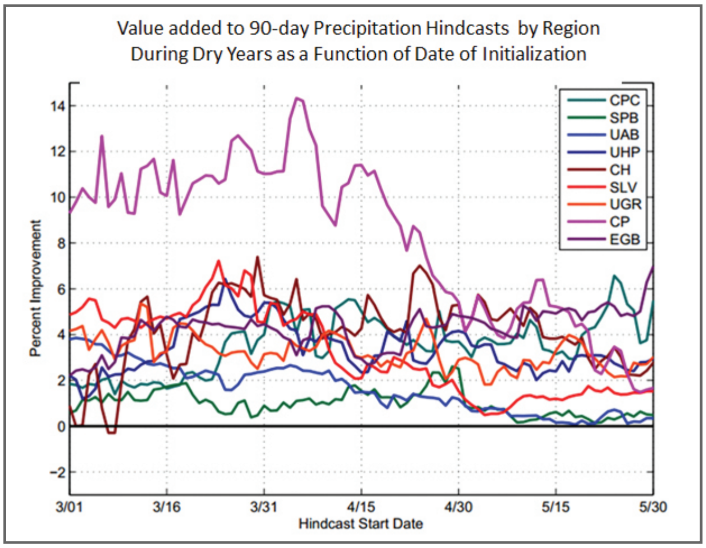


Figure 3. Each line here illustrates the average percent improvement over forecasting climate average precipitation that was made for years where each basin had a RZSM anomaly below -0.5 sigma for the 90 days following the day listed on the x-axis.

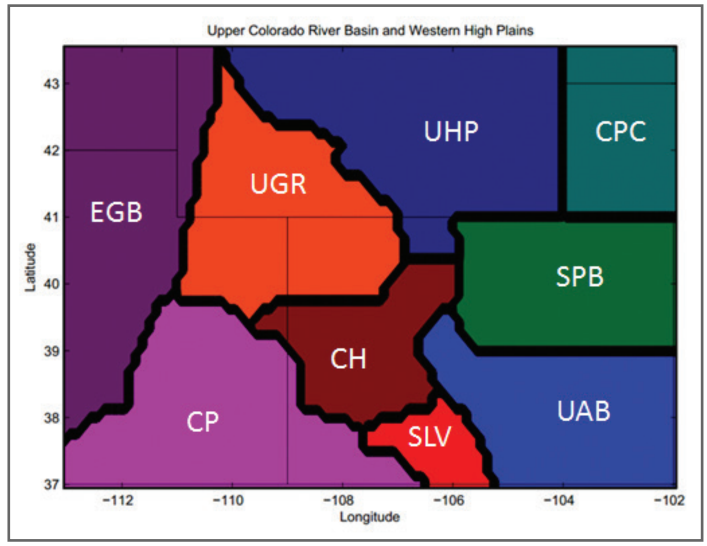


Figure 4. This map is a color-coded illustration of the nine subregions being considered in this study. The colors and labels correspond directly with what is seen in Figure 3.

For this study, the root zone was approximated as being the top meter of soil.

Data were imported for longitudes of -113 to -102 degrees and latitudes of 37 to 43.6 degrees. For the purpose of this, study soil moisture data and precipitation data were first averaged together as a function of subregion. There were nine subregions drawn primarily to divide different watersheds, but were further influenced by political boundaries and other topographic features in order to make the size of each subregion more homogenous (Figures 3 and 5). The Upper Rio Grande Basin was left as its own subregion, despite its smaller size since this river impacts a distinctly different part of the nation's water supply.

Soil moisture data were standardized for each basin, and a standardized anomaly was calculated for each day of the time series. Seasonal precipitation was evaluated by finding a standardized precipitation index for each day of the year, and for accumulation windows of 1-100 days (McKee et al., 1993).

Following the calculation of SPIs, a correlation analysis was conducted between subregion standardized RZSM and the SPIs for precipitation accumulations of the subsequent 1-100 days. Using these correlations, precipitation was hindcasted for each year and basins where statistically significant correlation existed.

Hindcasts were done in two ways: in the first way all 30-years of data were used in order to not eliminate the data from years such as 2002 and 2012, which were historically dry. The second way did not include data from the year being hindcasted. This ensures that the answer is not implicit in the data used to make a hindcast. Avoiding over-fitting to the dataset results from similar hindcast start dates and window length was considered when making a hindcast (Figure 1). These SPI values were then regressed, using the average least squares line of all such situations to their expected value if the standardized RZSM anomaly for the subregion were equal to what is seen in the year being hindcasted. The hindcasted precipitation value is then determined from the hindcasted SPI value. A 10-90% confidence range was developed taking the 10th and 90th percentile regressed SPIs and finding the precipitation value corresponding to these SPIs on the gamma distribution specific to the situation being hindcasted.

Results

In years in which basin-wide root zone soil moisture anomaly was less than -0.5 sigma, 90-day precipitation forecasts could be improved over forecasting a climate average by 4-14% using root zone soil moisture data and initializing at the most appropriate time of year. With the exception of the Colorado Headwaters Subregion in the middle of March, 90-day precipitation hindcasts issued for March-May up until June-August could be improved at least marginally over a climate average forecast.

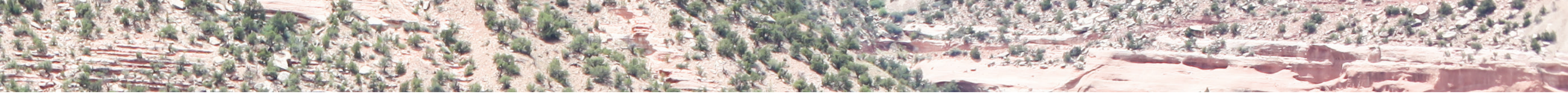
The magnitude of dryness associated with the onset of severe droughts as seen in the summers of 2002 and 2012 cannot be predicted using this method alone, but can in some cases be hinted at. The May-July dryness of 2002 and 2012 was captured within 10-90% confidence bounds for five of the nine subregions.

There was a latitudinal gradient in the seasonality of this relationship indicating that areas farther south in the basin are more vulnerable to a RZSM-precipitation feedback earlier in the season.

Only five of the nine subbasins captured the magnitude of this dryness in their 10-90th percentile confidence range, and only four of those five were anomalously dry.

Conclusions

Improvements to seasonal precipitation forecasts are achievable for the Upper Colorado River Basin and western High Plains using RZSM that extend beyond the



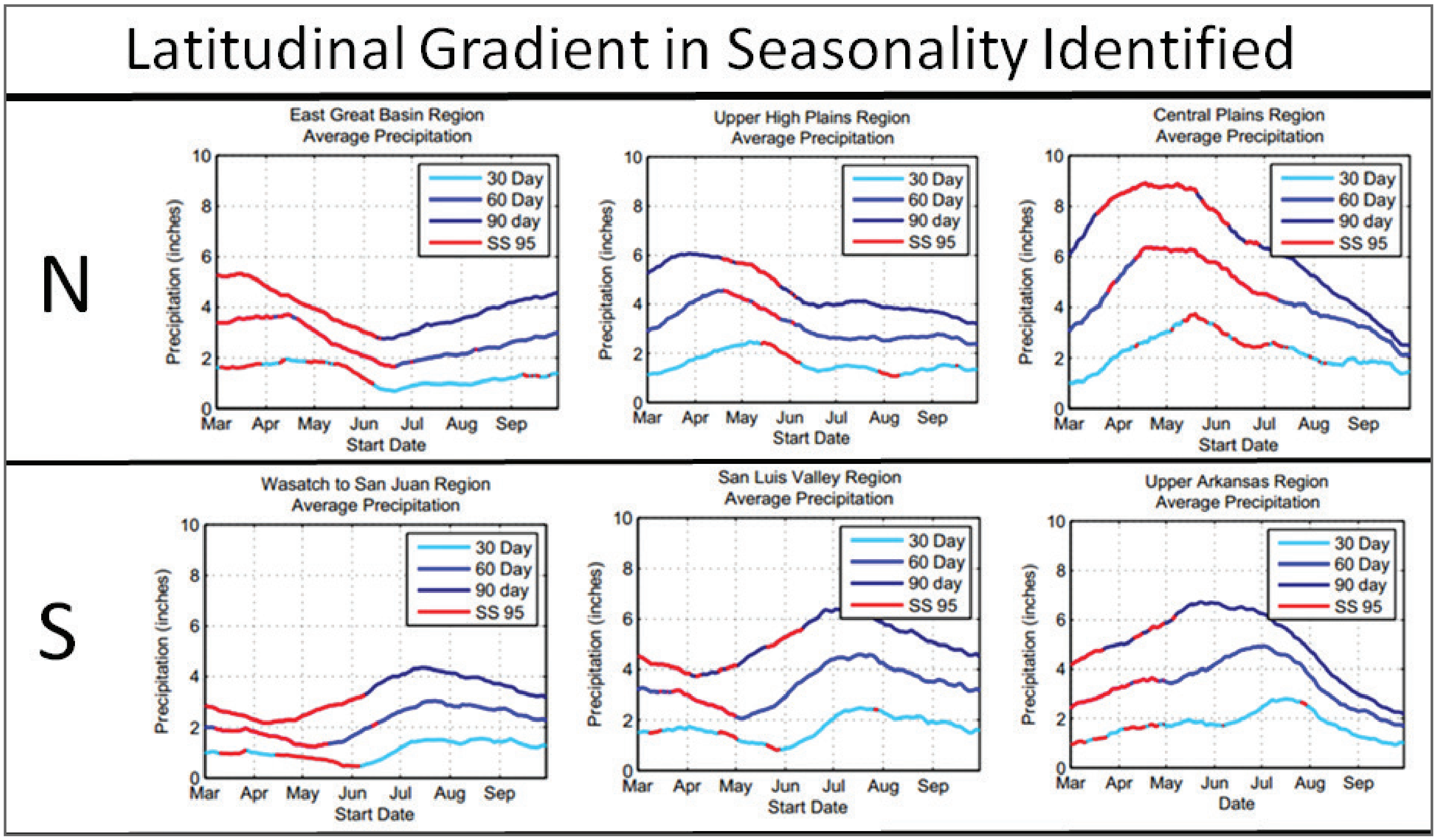


Figure 5. Each panel here illustrates the expected amount of precipitation for a subregion over a 30, 60, and 90-day accumulation window. The top three panels are the northernmost subregions. The bottom three panels are the southernmost subregions. The red lines illustrate where there is at least 95% confidence in a positive correlation between RZSM anomalies and total precipitation accumulation over the subsequent 30, 60, and 90 days.

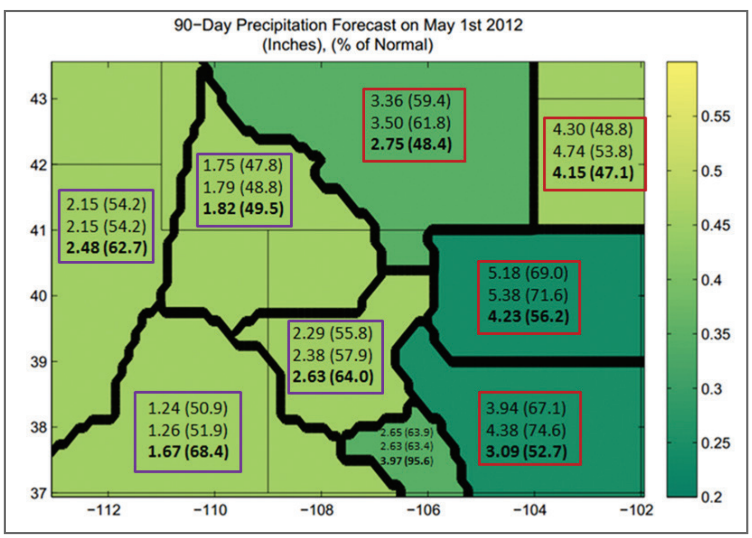


Figure 6. Here area-averaged 10th percentile precipitation hindcasts for May 1st through July 29th of 2012 are depicted (inches, percent of normal). The top numbers are precipitation hindcasts with and without the hindcasted year's data included. Bottom numbers are the values that verified. Shading indicates strength of correlation between midnight May 1st RZSM and the SPI-value for the subsequent 90 days. Lighter shaded regions are significant at higher confidence. Thicker black lines delineate subbasins whereas thinner ones may just be state boundaries. Purple boxes indicate subbasins where the 90-day SPI on May 1st was much drier than normal and red boxes were placed in regions where dryness verified below the 10th percentile hindcast.

range of reliable numerical weather prediction. The season in which RZSM had the strongest relationship with future seasonal precipitation levels was not the same for each of the nine subregions. Precipitation and RZSM correlated more strongly for areas farther south earlier in the year. This result is encouraging from a drought early warning perspective as it helps regional drought monitors pinpoint areas where the importance of root zone soil moisture is enhanced. Despite showing statistically significant connections between RZSM and warm season precipitation anomalies, there is a large noise: signal ratio between the two, meaning severe drought development is still difficult to predict even when considering RZSM.

First Norm Evans Endowed Lecture Featured Mike Connor

Lindsey Middleton, Communications Specialist, North Central Climate Science Center

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

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 include water policy relations and land consolidation. Connor's experience in water use and policy includes five years as Commissioner of the Bureau of Reclamation, where he dealt with water supply, water conflict, water rights agreements, as well as water and energy initiatives.

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 Department of the Interior's goals, achievements, and shortcomings in its involvement in water issues.

Connor explained that for nearly eight years the department has operated under President Barack Obama, who has taken an interest in water issues. "I would bet that since John F. Kennedy," he said, "there has not been a president as personally engaged on water issues as Barack Obama." 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. This type of work has not always been the agency's primary focus.

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. Since then, the agency has constructed 475 dams, 337 reservoirs, and 900 pumping plants. The Bureau of Reclamation operates 53 hydropower plants—another 144 in total that exist on Reclamation facilities. "No other federal entity has been more influential in developing the modern West than the Bureau of Reclamation," said Connor.

That long-standing focus on development helped populations in the West thrive, but the effects were not always positive. "Consequences for land, rivers, air, and human health were many and are still with us today," said Connor.

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.

"My predecessors and I at Reclamation recognize these changing dynamics," said Connor, "and [we] are progressively trying to operate in a different manner." This includes "pursuing the elusive notion of sustainability," he noted, as well as the prospect of including a variety of diverse interests in water in the West. Such groups include: tribal governments, recreationists, environmentalists, and scientists.

"Our goal is to diverge from litigation driven initiatives and move toward more strategic and collaborative approaches to water management," said Connor.

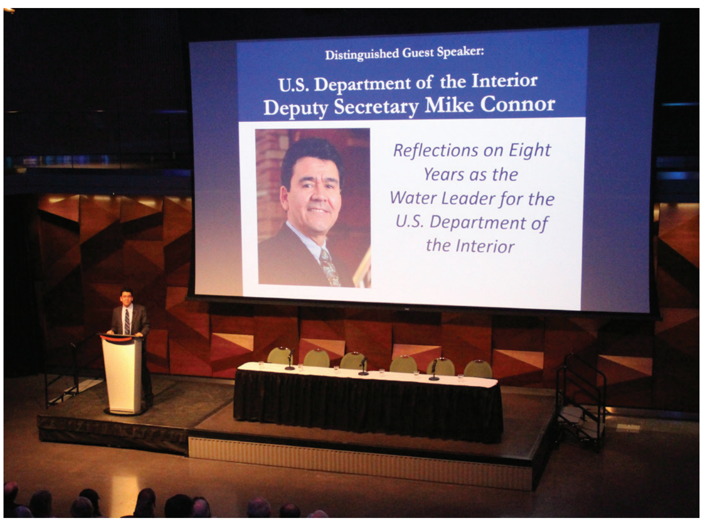
Examples he gave of these efforts include the 10 of 24 approved basin studies that have been completed that evaluate long-term water supply and demand imbalances; the support, funding, and implementation of Indian water settlements; WaterSMART, which focuses on water conservation; and the Natural Resources Investment Center, which facilitates public-private partnerships investing in sustainability.

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.

Examples of efforts already underway in climate research and planning include Minute 319, an agreement between the U.S. and Mexico that culminated in reconnecting the Colorado River with the Sea of Cortez in 2014, and multi-agency partnerships to mitigate wildfire risk.

To be successful in this arena, said Connor, future governmental approaches will need to include multiple parties and long-term planning, and importantly, an emphasis on shared authority.

"It's absolutely critical we work together at all levels of government—federal, state, tribal, and local. Each of us has a



Photos depicting the events of the Norm Evans Endowed Lecture.

Photos by Kim Hudson

role," said Connor.

Following his lecture, Connor fielded questions from a panel of CSU students and faculty that included Brad Udall (Colorado Water Institute), Stephanie Kampf (Ecosystem Science and Sustainability), Kelsea Macilroy (Doctoral Candidate, Sociology), and Pete Taylor (Sociology), and also answered questions from the audience.

Connor answered a question from Kampf regarding the role of climate and hydrologic science in facing future challenges in the West by saying, "We are behind the curve in understanding the impacts of climate change on water resources" on the basin level. "We're trying to institutionalize a larger role for science in the department," he said.

Macilroy, the only student on the panel, asked about barriers and opportunities to collaborate on water issues based on her experience in hearing that collaboration can mean being forced to give something up. "What are some of those things that bring people to the table to collaborate and then keep them there?" she asked. Connor replied that litigating can consume time and effort, and determining solutions means being proactive instead—he has seen repeated successes on a watershed by watershed basis, and said this makes him optimistic for the future of collaboration. Building on that idea, Taylor asked about opportunities in collaboration, and Connor discussed the success of providing proactive incentives—i.e., the carrot instead of the stick.

Audience questions included Colorado River Compact concerns, water storage issues, groundwater regulation, and the impacts of key local water projects.

Norm Evans was a director of the Colorado Water Institute (then called the Colorado Water Resources Research Institute) from 1967-1988, and in addition to his involvement in many aspects of the water community, took part in ensuring the preservation of historical landmarks. His legacy includes community-oriented projects, promoting discussion on water management issues, and the maintenance of informational reference materials.

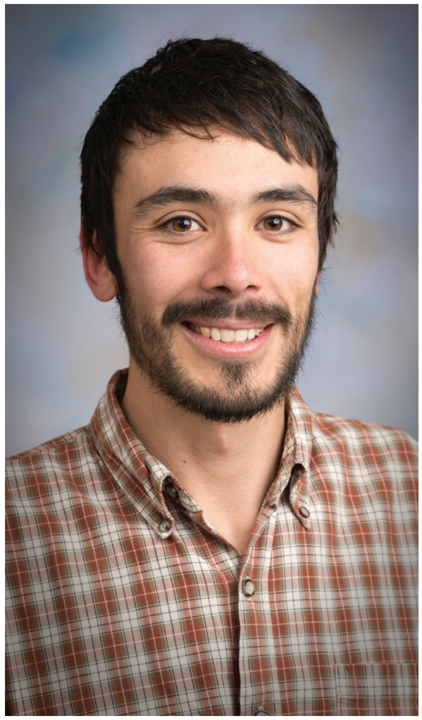
The Norm Evans Endowed Lecture Series is a contribution to science, education, and public service in the name of Evans to honor his scientific approach to the handling and use of water and his work for the Fort Collins community. Ken and Ruth Wright, whose own legacy in water includes decades of scientific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

Arkansas River Basin
Photo by Larry Lamsa

Blake Osborn

Lindsey Middleton, Communications Specialist, North Central Climate Science Center

In June of 2015, Blake Osborn joined the Colorado Water Institute as an Extension Regional Water Specialist for the Arkansas and Rio Grande River Basins. Osborn recently graduated from the University of Wyoming with a Masters of Science in Hydrology and Water Resources, and he earned his Bachelor of Science in Natural Resources Management from Colorado State University. For a few years between the degrees, he worked in agriculture and for the Forest Service working on watershed health projects. Osborn's graduate work at the University of Wyoming was part of the Wyoming Center for Environmental Hydrology and Geophysics (WyCEHG), a research team funded by a National Science Foundation grant that, in part, is quantifying a water budget for a headwaters catchment in Wyoming. Much of Osborn's work focused on tracing water through the catchment using stable isotopes, and involved paleohydrologic records, snow monitoring, and geophysics work.



Blake Osborn

This component of his graduate work, coupled with his research experience in the lab and the field, has translated to his role at Extension. "I looked at plant water use, and learned everything from basic plant physiology to the methods I used to evaluate water use efficiency in plants," says Osborn. "I definitely want to incorporate that into my work going forward."

As Regional Water Specialist for the Arkansas and Rio Grande Basins in Colorado, Osborn has had the opportunity to get involved in a handful of on-the-ground projects, and he hopes to add a few more initiatives to his docket. Among the projects he's currently involved in is the Lawn Irrigation Self-Audit (LISA), a Web-based irrigation scheduling tool for homeowners. LISA uses Colorado Agricultural Meteorological Network (CoAgMet) station data to deliver a personalized watering schedule for lawns based on estimated local evapotranspiration of turfgrass. "The goal is to give homeowners the knowledge and tools necessary to irrigate their lawns more efficiently," says Osborn.

Osborn is also involved with committees in his region, such as the Arkansas River Basin Water Forum Committee. Among his roles, he will be presenting information about the Environmental Risk Assessment and Management System (eRAMS) tool, which is a platform for the development and use of online data and modeling systems for the sustainable management of land, water, and energy resources. Osborn will help spread the word about eRAMS to water conservancy districts, and he eventually hopes to take on projects validating the tool's crop and water budgets in both the Arkansas and Rio Grande basins.

Osborn has also been involved with the Arkansas River Management Action Committee (ARMAC), which looks to identify and evaluate conservation practices in the basin that are feasible in terms of water quality improvement, water savings, and agricultural productivity.

Water quality is a topic of growing interest in both the Arkansas and Rio Grande basins, and Osborn says he looks forward to future research that would build on work in both basins. The interest in water quality is driven at least in part by wildfire in headwaters regions. "It's evolving to be even bigger though," says Osborn, "and people are looking at watershed health in terms of how the watershed functions and what that means for all of us downstream. When talking about watershed health we often think only of the headwaters regions, and rightfully so since this is our major source of water. But it's important to look at the entire watershed from peaks to plains." He anticipates that water quality, climate variability, and the impacts of agricultural water transfers will be topics of increasing interest in the region.

Blake Osborn

Water Resources Specialist

Administration - Extension Regional Staff

Colorado State University

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Water Research Awards March 16, 2015 - May 12, 2016

Andales, Allen, Soil and Crop Sciences, Coca-Cola Company, Water Irrigation Scheduler for Efficient Application (WISE) Online Tool Promotion and Improvement in Colorado, $25,000

Arabi, Mazdak, Civil & Environmental Engineering, National Science Foundation, Urban Water Innovation Network (U-WIN): Transitioning Toward Sustainable Water Systems, $1,500,000

Bagley, Calvin, Center for Environmental Management of Military Lands, Army Corps of Engineers Alaska, Stream, Lake, & Habitat Survey & Silviculture Joint Base Elmendorf-Richardson, $135,500

Bagley, Calvin, Center for Environmental Management of Military Lands, Army Corps of Engineers Alaska, Storm Water Discharge Monitoring and Modeling, $46,949

Bailey, Ryan, Civil & Environmental Engineering, United States Department of Agriculture, Agricultural Research Service, Integration of SWAT and MODFLOW and Inclusion in the Geospatial Modeling Interface, $60,000

Bailey, Larissa, Fish, Wildlife & Conservation Biology, Department of Interior, National Park Service, Comparison of Sampling Methods for Aquatic Invertebrates at Agate Fossil Beds National Monument, Cooperative Ecosystem Studies Unit, $5,894

Baker, Daniel, Civil & Environmental Engineering, Department of Defense, Army Corps of Engineers, Web-Based Tools to Inform Fish Passage and Environmental Flow Decisions, $20,000

Bareither, Christopher Alan, Civil & Environmental Engineering, National Science Foundation, Enhancing Design of Water Balance Cover Systems Composted of Mixed Mine-Waste Materials, $337,200

Bauder, Troy, Soil & Crop Sciences, Colorado Department of Public Health & the Environment, Outreach for Agricultural Nutrients and Regulation 85, $85,000

Bauder, Troy, Soil & Crop Sciences, Colorado Corn Administrative Committee, Nutrient Rate, Placement, and Timing impacts on Corn Yields and Water Quality in Colorado, $11,250

Caldwell, Elizabeth, Center for Environmental Management of Military Lands, Department of Defense, Army Corps of Engineers Alaska, Stormwater Management Plan Compliance, US Army Garrison Hawaii, $95,000

Caldwell, Elizabeth, Center for Environmental Management of Military Lands, Department of Defense, Army Corps of Engineers Kansas City, Clean Water Act Program Support, Fort Leonard Wood, Missouri, $550,135

Clements, William H., Fish, Wildlife, & Conservation Biology, Colorado Division of Parks and Wildlife, Development and Validation of Rapid Assessment Techniques for Determining Effects of Petroleum Hydrocarbons on Stream Communities, $84,643

Doesken, Nolan J., Atmospheric Science, University of Oklahoma, Engaging Citizen Scientists to Ground-Truth the U.S. Drought Monitor, $36,294

Doesken, Nolan J., Atmospheric Science, Colorado Water Conservation Board, Colorado Mesonet Project, $150,000

Doesken, Nolan J., Atmospheric Science, World Meteorological Organization, Expanding precipitation measurements in the Commonwealth of The Bahamas through the CoCoRaHS (Community Collaborative Rain, Hail, and Snow) Network, $10,000

Essah, Samuel, San Luis Valley Research Center, Colorado Potato Administrative Committee, Reducing Irrigation Water and Fertilizer use in Potato Production Systems in the San Luis Valley, $48,105

Gates, Timothy K., Civil & Environmental Engineering, Routt County Conservation District, Reconnaissance and Scoping for Assessing the impact of Current and Altered Irrigation Practices on Groundwater Conditions and Return Flows to the Yampa and White Rivers, Colorado, $12,249

Henry, Charles S., Chemistry, Hach Company, Development of Novel Systems and Methods for Determining Phosphate in Aqueous Systems, $32,500

Johnson, Lynn Eugene, Cooperative Institute for Research in the Atmosphere, Department of Commerce, National Oceanic and Atmospheric Administration, Assessment of Gridded Hydrological Modeling for NWS Flash Flood Operations, $79,701

Julien, Pierre Y., Civil & Environmental Engineering, Korean Water Resources Corporation, Multivariate Regression Analysis and Model Development for the Estimation of Sediment Yield From Ungauged Watersheds in the Republic of Korea, $240,000

Kampf, Stephanie K., Ecosystem Science & Sustainability, Department of the Interior, Bureau of Land Management, Effectiveness of Post-Fire Mulch Treatments at Hillslope to Watershed Scale, $24,952

Khosla, Rajiv, Soil & Crop Sciences, Colorado Corn Administrative Committee, Precision Water, Seed and Nitrogen Management for Enhancing Efficiency, Productivity, and Profitability of Irrigate Corn in Colorado, $47,094

Lemly, Joanna, Colorado Natural Heritage Program, United Stated Department of Agriculture, United States Forest Service, Forest Research, Fen Mapping for the Rio Grande National Forest, $28,750

Loftis, Jim C., Civil & Environmental Engineering, Department of the Interior, National Park Service, Water Resources Tools and Database Development, $184,706

MacDonald, Lee H., Natural Resource Ecology Laboratory, California Department of Forestry and Fire Protection, Quantifying Cumulative Effects Over Time in Two Little River Watersheds, Northwestern California, $71,206

Norton, Andrew P., Bioagricultural Sciences & Pest Management, City of Boulder Open Space and Mountain Parks Department, Effects of Russian Olive Removal on Soils and Understory Plant Communities in the Boulder Creek Floodplain, Boulder, Colorado, $7,247

Reardon, Kenneth F., Chemical & Biological Engineering, National Science Foundation, Workshop on Food-Energy-Water Nexus Issues in Energy Production, $49,952

Sauer, Sally Marie, Soil & Crop Sciences, Colorado Corn Administrative Committee, Evaluation of Drought Tolerant Corn Yield Performance at Different Plan Densities in Dryland Conditions, $21,240

Schipanski, Meagan Erin, Soil & Crop Sciences, United States Department of Agriculture, National Institute of Food and Agriculture, Sustaining Agriculture Through Adaptive Management to Preserve the Ogallala Aquifer Under a Changing Climate, $2,400,531

Schipanski, Meagan Erin, Soil & Crop Sciences, United States Department of Agriculture, Natural Resources Conservation Service, Demonstrating the Potential of Cover Crop and Forage Mixtures to Improve Soil Health, Productivity, Profitability in Water Limited Regions, $995,451

Schneekloth, Joel, Colorado State University Extension, United States Department of Agriculture Risk Management Agency, Update of Consumptive Use Tables for Crops, $3,300

Schumacher, Russ S., Cooperative Institute for Research in the Atmosphere, Department of Commerce, National Oceanic and Atmospheric Administration, Multi-Disciplinary Investigation of Concurrent Tornadoes and Flash Floods in the Southeastern United States, $143,197

Sharvelle, Sybil E., Civil & Environmental Engineering, Starbucks Corporation, Phase 2: Water Recycling Feasibility Assessment & Bench Scale Testing, $170,173

Waskom, Reagan M., Colorado Water Institute, University of Colorado, Investigating the Beneficial Links Between Oil and Gas Production and Agriculture Using Water as the Common Currency, $199,018

Waskom, Reagan M., Colorado Water Institute, Department of the Interior, United States Geological Survey, 104B State Water Resources Research Institute Program Fiscal Year 2016, $92,335

Wohl, Ellen E., Geosciences, National Geographic Society, Assessing the Impacts of Logging on Carbon Dynamics of Mountain River Basins, $5,000

Wohl, Ellen E., Geosciences, United States Department of Agriculture, United States Forest Service, Forest Research, Enhancing the Benefits of Large Wood and Beaver Dams in River Corridors, $56,642

Wohl, Ellen E., Geosciences, National Science Foundation, Connectivity in Geomorphology: The 47th Annual Binghamton Geomorphology Symposium, $42,000

Wohl, Ellen E., Geosciences, National Science Foundation, Longitudinal Patterns of Organic Carbon Storage in Mountainous River Networks, $85,652

Rifle Falls
Photo by Kyle Kress

USGS Recent Publications

Response of selenium concentrations in groundwater to seasonal canal leakage, lower Gunnison River Basin, Colorado; 2013, Scientific Investigations Report 2016-5047; J.I. Linard, P.B. McMahon, L.R. Arnold, J.C. Thomas

Numerical experiments to explain multiscale hydrological responses to mountain pine beetle tree mortality in a headwater watershed; 2016, Water Resources Research (52) 3143-3161; Colin A. Penn, Lindsay A. Bearup, Reed M. Maxwell, David W. Clow

Groundwater quality, age, and susceptibility and vulnerability to nitrate contamination with linkages to land use and groundwater flow, Upper Black Squirrel Creek Basin, Colorado, 2013; 2016, Scientific Investigations Report 2016-5020; Tristan P. Wellman, Michael G. Rupert

Characterization of hydrology and water quality of Piceance Creek in the Alkali Flat area, Rio Blanco County, Colorado, March 2012; 2015, Scientific Investigations Report 2015-5147; Judith Thomas

Non-invasive flow path characterization in a mining-impacted wetland; 2015, Journal of Contaminant Hydrology; James Bethune, Jackie Randell, Robert L. Runkel, Kamini Singha

Hydrogeochemical effects of a bulkhead in the Dinero mine tunnel, Sugar Loaf mining district, near Leadville, Colorado; 2015, Applied Geochemistry; Katie Walton-Day, Taylor J.Mills

Installation of a groundwater monitoring-well network on the east side of the Uncompahgre River in the Lower Gunnison River Basin, Colorado, 2014; 2015, Data Series 955; Judith C.Thomas

Hydraulic, geomorphic, and trout habitat conditions of the Lake Fork of the Gunnison River in Hinsdale County, Lake City, Colorado, Water Years 2010-2011; 2015, Scientific Investigations Report 2015-5043; Cory A. Williams, Rodney J. Richards, Keelin R. Schaffrath

Organic carbon burial in lakes and reservoirs of the conterminous United States; 2015, Environmental Science and Technology; David W. Clow, Sarah M. Stackpoole, Kristine L. Verdin, David E. Butman, Zhi-Liang Zhu, David P. Krabbenhoft, Rob Striegl

Evaluation of groundwater levels in the South Platte River alluvial aquifer, Colorado, 1953-2012, and design of initial well networks for monitoring groundwater levels; 2015 Scientific Investigations Report 2015-5015; Tristan Wellman

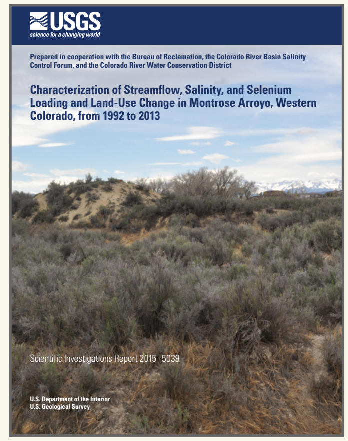
Characterization of streamflow, salinity, and selenium loading and land-use change in Montrose Arroyo, western Colorado, from 1992 to 2013; 2015 Scientific Investigations Report 2015-5039; Rodney J. Richards, Jennifer L. Moore

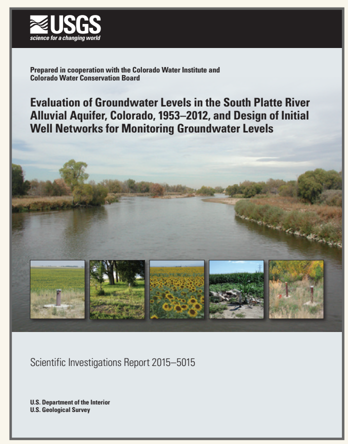
Evaluation of mean-monthly streamflow-regression equations for Colorado, 2014; 2015 Scientific Investigations Report 2015-5016; Michael S. Kohn, Michael R. Stevens, Andrew R. Bock, Stephen J. Char

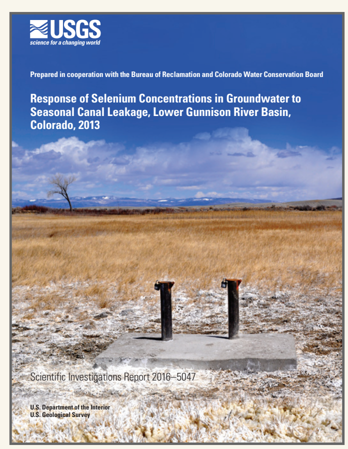
Analysis of historic agricultural irrigation data from the Natural Resources Conservation Service monitoring and evaluation for Grand Valley, Lower Gunnison Basin, and McElmo Creek Basin, western Colorado, 1985 to 2003; 2015, Open-File Report 2014 1261; John W. Mayo

Monitoring-well installation, slug testing, and groundwater quality for selected sites in South Park, Park County, Colorado, 2013; 2015, Open-File Report 2014-1231; Larry R. Rick

Pesticide concentrations in frog tissue and wetland habitats in a landscape dominated by agriculture; 2015, Science of the Total Environment; Kelly L. Smalling, Rebecca Reeves, Erin L. Muths, Mark Vandever, William A. Battaglin, Michelle L. Hladik, Clay L.Pierce







Water Calendar

August

3-5 **NWRA 2016 Western Water Seminar; Sun Valley, ID**
nwra.org/2016-western-water-seminar.html

24-26 **Colorado Water Congress Summer Conference; Steamboat Springs, CO**
This high-energy conference is packed with great topical content. It's a don't-miss event for those who wish to stay informed about water issues in Colorado while engaging in numerous professional development activities.
cowatercongress.org/summer-conference.html

September

11-14 **2016 RMSAWWA/RMWEA Joint Annual Conference; Keystone, CO**
Join annual conference of the Rocky Mountain Section of the American Water Works Association and the Rocky Mountain Water Environment Association.
rmsawwa.org/

11-14 **31st Annual WateReuse Symposium; Tampa, FL**
Water professionals attend to learn about the latest innovations in water reuse, to network with colleagues, and to find solutions to critical water supply issues.
watereuse.org/news-events/conferences/annual-watereuse-symposium/

16 **Colorado River District Annual Seminar; Grand Junction, CO**
Every Autumn, the Colorado District hosts a seminar on current and sometimes historical Colorado River Basin issues.
coloradoriverdistrict.org/events/annual-water-seminar/

28-29 **Annual 21st Century Energy Transition Symposium; Fort Collins, CO**
Formally known as the Natural Gas Symposium. The Energy Institute at Colorado State University is hosting the sixth annual Natural Gas Symposium and the symposium is open to everyone.
naturalgas.colostate.edu/symposium-2016/

October

11-13 **2016 Sustaining Colorado Watershed Conference; Avon, CO**
A River Runs Out of it, Building Strong Upstream Communities
coloradowater.org/scw-conference-2016

26-27 **South Platte Forum; Loveland, CO**
southplatteforum.org/

November

2-3 **2016 Upper Colorado River Basin Water Forum; Grand Junction, CO**
Complex Systems in Flux: Changing Relationships between Water, People, and the Environment
coloradomesa.edu/water-center/forum/

13-17 **AWRA 2016 Annual Water Resources Conference; Orlando, FL**
awra.org/meetings/Orlando2016/

14-16 **NWRA Annual Conference; San Diego, CA**
nwra.org/2016-annual-conference.html

December

2 **Colorado WaterWise 8th Annual Water Conservation Summit; Denver, CO**
coloradowaterwise.org/event-2182580


Emerald Lake
Photo by John B. Kalla

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Hygiene, Colorado
Photo by Bryce Bradford