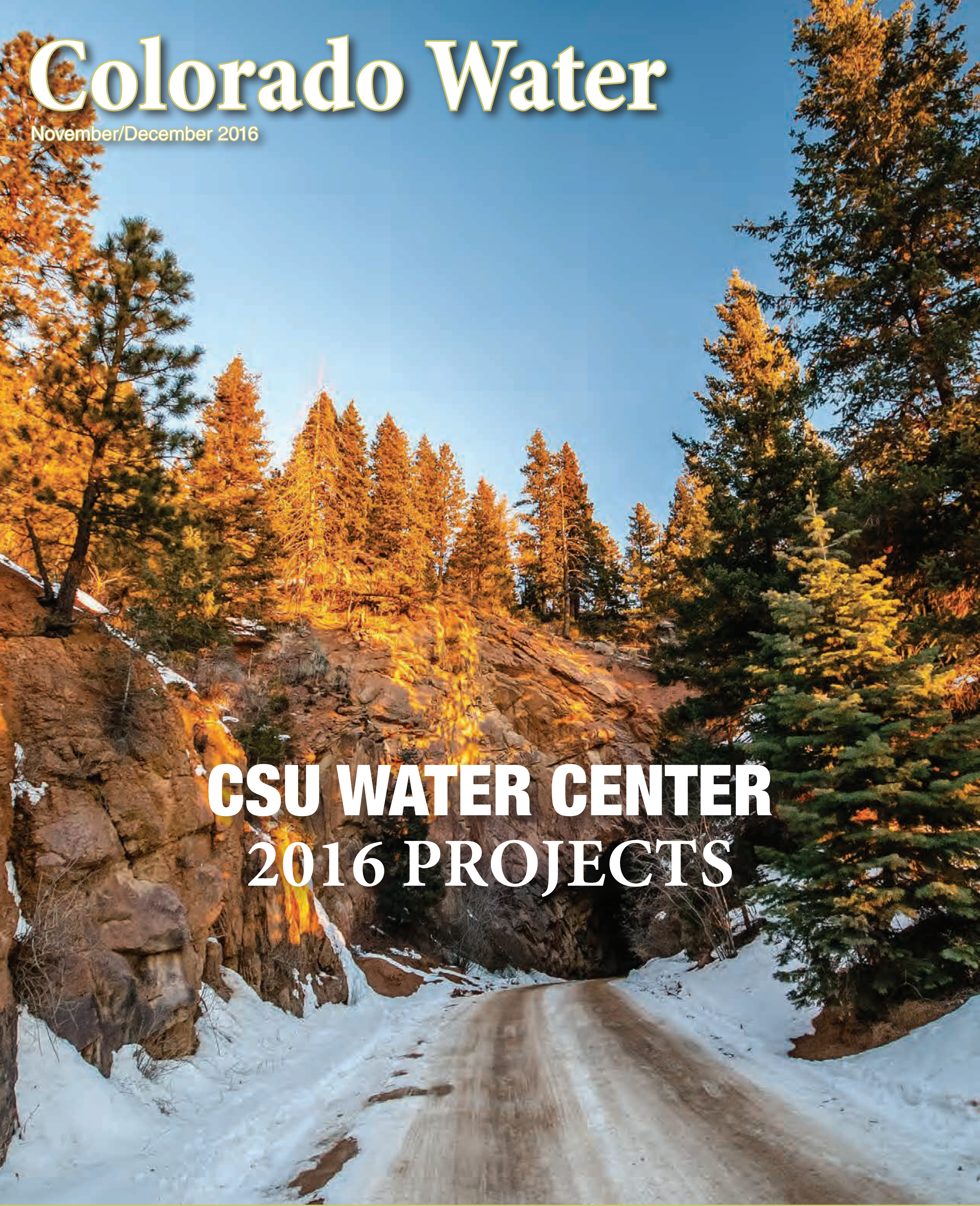
Colorado Water

November/December 2016



CSU WATER CENTER 2016 PROJECTS

Colorado State University

This issue of *Colorado Water* focuses on CSU Water Center funded projects completed over the last year. With support from CSU Provost Rick Miranda, the CSU Water Center has awarded approximately $545,000 in seed funding for innovative water scholarship to faculty since 2013, resulting in over $11 million awarded in external funding.

The CSU Water Center has a mission to *catalyze excellence in water research, teaching, and engagement by fostering interdisciplinary collaboration and creative scholarship*. To accomplish this goal, the Water Center brings together a network of 200 faculty members across the CSU campus and seeks to engage students and faculty in interdisciplinary research, teaching and outreach. Our aim is to better engage the CSU community by:

- Enhancing connections in water across the university, specifically with all eight of CSU's Colleges and within our three land grant mission areas—research, education and outreach.
- Supporting CSU faculty, staff, students, and visiting scholars and the missions of their departments and colleges.
- Increasing capacity at CSU to serve local, regional and global communities to better manage water resources effectively and efficiently.
- Engaging and partnering with CSU faculty and students through research and service projects, educational programs, and campus events.
- Informing interested faculty, staff, students and community members of water related opportunities, events, jobs, internships, and research funding, both on and off campus.
- Serving as a tool for faculty to more effectively apply their own research.

Our request for proposals calls for projects that will catalyze transformative water research, and teaching, and engagement through interdisciplinary collaboration and creative scholarship among CSU faculty and students. A list of the Water Center's FY17 projects are available at http://watercenter.colostate.edu/faculty_grants.shtml.

The Water Center helps foster CSU's capacity to address a diversity of water-related topics. Through the Water Center's organizational efforts, CSU's water faculty, staff, and students are better equipped to work towards improving water in Colorado, the U.S., and internationally. Our vision is that CSU will continue to advance as a center of excellence and a leader in water scholarship.

In 2015, CSU faculty and staff updated the former Water Resources Interdisciplinary Studies Program to the Sustainable Water Interdisciplinary Minor (SWIM). The minor offers undergraduate students an opportunity to gain a deeper knowledge of the many dimensions of water management. SWIM is offered in partnership with the School of Global Environmental Sustainability (SoGES) and is administered through the CSU Water Center.

One of the challenges of interdisciplinary education is the need for practitioners who can work across disciplines to solve complex water problems. To address this concern, the CSU Water Center is working on developing an interdisciplinary graduate certificate in water. The certificate can be added to any existing CSU graduate program and would be a means to foster interdisciplinary training. The Water Center received significant interest for this type of program and will spearhead the development of this program during FY17.

For more information on Water Center activities and programs visit our website at www.watercenter.colostate.edu and sign up for our e-newsletter "The Current" at http://watercenter.colostate.edu/current.shtml.

Reagan Waskom
Director, Colorado Water Institute

COLORADO
WATER

Volume 33, Issue 5

Colorado Water is a publication of the CSU Water Center. The newsletter is devoted to highlighting water research and activities at CSU and throughout Colorado.

Published by
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Supported by
This publication is financed in part by the U.S. Department of the Interior Geological Survey, through the Colorado Water Institute; the Colorado State University Water Center, College of Agriculture, College of Engineering, Warner College of Natural Resources, Agricultural Experiment Station, and Colorado State University Extension.

Cooperators include the Colorado State Forest Service, the Colorado Climate Center, and CSU's Water Resources Archive.

CSU WATER CENTER

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Colorado Water Institute

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Photo by Zach Dishner

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Foothills near Colorado Springs, CO
Photo by Daniel Hoherd

Water is Blood, Water is Life—Water Governance and Use in Turkana, Kenya

Stacy Lynn, Research Scientist, Natural Resource Ecology Laboratory, Colorado State University
Project Team: Michele Betsill and Melinda Laituri

Conrad Marshall tours a new water diversion and irrigation scheme for a community in Turkana County, Kenya. This community field was estimated to be approximately 100 acres in size, with parcels split among community members. Photo by Stacy Lynn.

SYNOPSIS

The discovery of two aquifers in Turkana County, Kenya is estimated to satisfy the public's need of access to water for 70 years. This research project focused on providing a multi-disciplinary analysis assessing historic water use, the spatial and temporal distribution of water sources, as well as water governance throughout Kenya.

Introduction

Two expansive aquifers (and several smaller aquifers) were discovered in 2013 to be sitting deep below the arid landscape of Turkana County, the driest and poorest county in Kenya. United Nations Educational, Scientific, and Cultural Organization (UNESCO) estimates that the aquifers contain water sufficient to meet Kenya's water needs for 70 years. The discovery of these aquifers has introduced a very compelling and complex social-ecological situation. Turkana County, which has for thousands of years been water scarce and water limited, and which has for all intents and purposes sat largely outside the Government of Kenya's realm of interest, may be transformed into a water source for the entire country. These aquifer discoveries come one year following the equally ground-breaking discovery of large oil reserves in Turkana, launching Turkana County from near neglect into prominence as it becomes one of the most promising sources of natural resource development in Kenya and possibly East Africa.

The discovery of valuable new natural resource reserves can create complex social-ecological challenges around governance, development, and social and ecological sustainability. The mixed potential for positive and negative outcomes can be daunting, with all stakeholders expecting a share in the benefits, yet hoping to minimize their costs and burdens. The key to sustainable management of these and other resources is a critical look at governance regimes that control who has the power to make management decisions and what those decisions might be, with an understanding of the potential burdens and benefits of governance and use decisions for various stakeholders and ecosystem components. Taking a social-ecological systems approach to evaluating governance and decision-making allows an in-depth assessment of the impacts that these decisions may have through the local social-ecological system and beyond. A situation where the benefits of development are realized outside the local system and the burdens are realized within it would demonstrate a mismatch in space that could compromise sustainability of the Turkana County social-ecological system.

Complex social-ecological research requires multi-scale interdisciplinary approaches that are founded on active public engagement and a deliberate systems approach to design and inquiry. This project focused on evolving water governance arrangements, and how development of new and existing water sources is being planned for the future. Our team's objectives were to conduct baseline research to assess the state of the system in Turkana – the relationship that people have with water in their everyday lives, how communities, Turkana County government, the Nation and NGOs are using and developing water, and what their hopes and worries are for the future of water development. With this information, we aimed to create a community-driven proposal to further explore and anticipate the potential for water governance and development decisions to have positive and negative impacts (i.e., benefits and burdens) for Turkana pastoralists, other stakeholders, and the ecosystem. The essential question proposed in the larger proposal is, *"What are the social and ecological consequences of the transformation from water scarce to water source, at a time when a new constitution and devolution of government makes the development of all water sources more pressing and possible?"* This project presented an opportunity to set the groundwork for this exploration, connect with key stakeholders, and involve local communities and other stakeholders in the development of our research questions and hypotheses.

Water storage tanks near Lodwar, Turkana County, Kenya. These tanks draw water from the aquifer below in morning and evening and water is used to irrigate expansive fields that are being developed. Photo by Stacy Lynn.

With Financial Support from CSU's Water Center, Our Team:

1. Conducted a literature review of water governance in Kenya, with a focus on Turkana County in a global water governance, development and climate context.
2. Conducted a multi-disciplinary proof-of-concept research study that: a) describes historical water use issues as framed by Turkana pastoralists themselves (water sources, policies, access, conflict, quality, quantity, and other relevant issues), b) identifies existing governance mechanisms for management and distribution of water resources, key actors involved in decision-making, and horizontal and vertical connections and information flows, and c) assesses the spatial and temporal distribution of water sources, and the community-identified social and ecological costs and benefits of water development.
3. Submitted a large research proposal to the NSF CNH program (November 2015) that aims to build and expand on this pilot study, using information and insights gained through the course of this research project to design a longer-term study of water governance and social-ecological burdens and benefits of water development. This field research allowed the project to incorporate questions from a locally-framed community-driven perspective to complement its theoretical underpinnings.

Methods

It was hoped that by gathering data along an east-west transect a diversity of issues would be raised by the communities. However, Turkana is a large and difficult county to navigate by vehicle and some areas are insecure. Hence, it was necessary to limit the study area to locations within approximately two-hours of the research base in the town of Lodwar. Five villages were selected with assistance from a partner at World Food Programme's Lodwar office to span from the western border of Turkana County eastward to the shores of Lake Turkana: Nayenae, Kakwenya, Lobei, Nadoto, and Nabei/Eliye Springs.

The field portion of the study took place in September 2015. Ten focus groups were conducted in the five communities, one with men and one with women in each community. Two local translators with experience conducting focus groups assisted with each of the focus groups and one community member was chosen from each focus group to assist with translations, ensure that information exchange was accurate, and to help with interpretation. Each focus group lasted approximately two hours and included 9-22 participants. All focus groups maintained active discussion throughout, and were digitally recorded for future reference.

Focus groups contained questions about how people use water each day, where they got their water and the type of source, recent climate and weather, severe historical droughts and floods, water development and infrastructure, cultivation, and water

Sophia Achor translates for Stacy Lynn and Conrad Marshall to conduct a focus group with women in a community to the north of Lodwar, Turkana County, Kenya. Photo by Stacy Lynn.

A deep well that has been dug in an ephemeral tributary of the Turkwel River. Turkana pastoralists will expand these wells, digging ever deeper to reach water as the dry season progresses, until the wells are several people deep. Water is accessed via the circumventing path, collected in buckets, and passed upward via a chain of people. Photo by Stacy Lynn.

A camel baby and its mother browse an acacia tree. Camels are an important species of livestock for Turkana pastoralists because of their ability to go without water for many days, unlike cattle, goats, and sheep, making them more resilient to drought than other livestock species. Photo by Stacy Lynn.

needs into the future. Meetings were held with government officials in the town of Lodwar. Meetings were also held with several NGOs that have an interest in water development and sustainability including: World Food Programme, Friends of Lake Turkana, and Oxfam. Irrigation schemes fed by both river and aquifer water were visited.

Results

Focus group participants reported without exception despite some spatial variation in rainfall amount, that very little rain had fallen in the past two years (only one rain gauge is located in the town of Lodwar). Each group independently reported that when very little rain falls, vegetation does not respond.

At the time of the field study, all cattle had been moved to the west into the hills bordering Uganda, while camels, goats, and sheep largely remained local. Focus group participants reported that while moving the cattle far from home carries great risk to the herd and human safety due to the likelihood of cattle raids, there was no other choice. This fear was greatest in communities in western Turkana County. To the east along the shores of Lake Turkana, in communities that rely on both livestock and fishing for their livelihoods, focus group participants were extremely worried about both drought and the construction of the Gibe III dam across the border in Ethiopia on the Omo River, which feeds Lake Turkana. The dam had just been completed and was being filled. Lake levels were reported to be decreasing, however it would be difficult to determine whether this decrease was due to the dam's filling or the dry conditions. Since Lake Turkana is a saline lake, as water levels go down, salinity goes up, threatening fisheries that both provide for local livelihoods and provide a high quality food source for the entire region.

Community focus groups and conversations with Ministry officials strongly informed the proposal that was submitted to NSF. The most fundamental change to the proposal was a shift from looking at only aquifer water, to incorporating all water in the system, including deep aquifer, shallow aquifer, river, rain, lake and dam water. Turkana community members had indicated that decisions made about one water source may be impacted by availability of, access to, and decisions for other sources of water. This also allows the proposal to encompass issues related to the building of the Gibe III Dam in Ethiopia. Other concerns that were articulated during community focus groups included:

- Participants agreed strongly that everything is interconnected. They also mentioned that without available water and good water management, the system would be at risk of collapse, and people would die because there is nowhere else for them to go.
- Fears that the national government will put more effort into developing the aquifer water for national benefit rather than for local use, when water is sorely limited in Turkana County.
- Boreholes and irrigation trenches that are dug in community lands with donated funds frequently break after installation, and expensive repairs often are not possible.


(Left) A community member in the village of Napuu pumps water at a community hand pump. (Right) Two boys sell fish along the shores of Lake Turkana. The lake, which forms the eastern edge of Turkana County, is an important contributor of protein to the system via small-scale fisheries. This brings diversity to the diets of all Turkana County residents. Lake Turkana is threatened by the construction of the Gilgel Gibe III Hydroelectric Dam on the Omo River in Ethiopia. The Omo River is the primary source of Lake Turkana's water. Alteration of flood regimes and offtake of water for cultivation is reducing lake levels and increasing salinity, worrying people who depend on the lake and its fish for their livelihoods and ultimately for their survival. This is a complex cross-border situation. Photos by Stacy Lynn.

Communities would like to transition to easy-to-maintain equipment such as solar pumps.

- Cattle raiding in Central Turkana is most commonly experienced in the west along the Uganda border. Cattle raiding can lead to extreme livelihood insecurity, as well as loss of human life. With the climate becoming drier and hotter (reports from the participants themselves), people fear increased contact with other pastoral groups, increasing the risk of raiding.
- Signs of rain are no longer predictable or reliable as they had been in the past, so management regimes are less predictable as a result. The few agricultural schemes that rely on river water fail in drought years and do not provide a food production buffer when it is most needed.
- Drought is increasing in frequency, and because there is less recovery time between droughts, livestock health suffers. Livestock, especially cattle and sheep, are dying from starvation and lack of water. Livelihoods are also suffering as a result of low milk production, primarily for cattle. It is also hotter now than it used to be. Herds are not recovering to normal numbers before the next drought hits.
- Preferred forage grasses are less available than they once were, species composition may be changing.
- The invasive alien species *Prosopis juliflora*, which was introduced as an erosion-control mechanism in Kenya in the 1980's, is threatening local livelihoods through multiple pathways, including impacts on livestock health (particularly of goats) via damage to teeth and gums, drawdown of the water table by deep *P. juliflora* tap roots, and competition with native forage species.

Discussion

This project identified some of the benefits and burdens that may be realized by multiple stakeholders as a result of governance regimes and water use decisions that are undertaken at different levels of society in Turkana County. The integration of interdisciplinary concepts and methods has been critical to studying and addressing issues surrounding the governance of the new water, as well as evaluating its relationship with existing water. We present the compelling question of whether Turkana, which has for thousands of years been water scarce and water limited, and which has for all intents and purposes sat largely outside the Government of Kenya's realm of interest, will be fundamentally transformed from a system driven by non-equilibrial dynamics, to one where these processes are buffered by newly-discovered water resources and follow a more equilibrial pattern. While this driving question has not yet been answered, that is the goal of the project proposed to NSF.

For each of five preliminary water development scenarios, a 1) water source; 2) water governance arrangement; 3) use decision under consideration; 4) hypothesized social and ecological impacts; and 5) methods were outlined for study in the greater proposal. The five water development scenarios included:

1. State-run large-scale irrigated crop production projects developed in Turkana using deep aquifer water;
2. County-run large-scale irrigated crop production projects for County-wide benefit using deep aquifer water;
3. County-run large-scale irrigated fodder/forage production projects for County-wide benefit using deep aquifer water;
4. River water diverted via canals for cultivation in designated areas near rivers; and
5. Village drills (with partner NGO) shallow groundwater borehole in central village location.

This research is transformative in its approach to assessing water development scenarios, and looks at outcomes for both the ecosystem and pastoralist livelihoods via an assessment of governance and distribution of burdens and benefits of water development options. It will contribute to broader societal goals by informing a diverse group of ecosystem stakeholders in Kenya, from communities to NGOs to county and national government ministries.

Can Clarifying a Conflict Instead of Attempting to Resolve it Lead to Improved Civil Dialogue?

MaryLou Smith, Policy and Collaboration Specialist, Colorado Water Institute
Project Team: Martin Carcasson and Neil Grigg

SYNOPSIS

The Northern Integrated Supply Project (NISP) is being considered for permitting by the U.S. Army Corps of Engineers (USACE), which is controversial to some individuals. Understanding that disagreement related to NISP cannot be resolved in a public hearing, researchers focused on understanding various beliefs and values through an experimental dialogue.

Introduction and Background

Over the years, working with stakeholders who have conflicting interests in water policy, we have discovered that building relationships and gaining trust leads to the resolve required to create mutually beneficial strategies. The work is time consuming, the progress is gradual, yet ground can be laid for collaboration on tough issues going forward. At the same time, we have attended numerous public hearings designed to collect opinions from the public for consideration by those assigned to make permitting decisions about projects such as the Northern Integrated Supply Project (NISP)*. Public hearings on projects such as NISP are important as a means of insuring all views are heard and considered, but they tend to increase polarization. Recognizing that the issues surrounding NISP cannot be settled by public dialogue, but interested in whether such dialogue could lead to increased understanding and respect for different beliefs and values behind conflicting positions, we organized an experimental dialogue with a grant from the CSU Water Center.

Table 1. Participant statements regarding opinions of NISP.

As a state we badly need storage to accommodate future demand, and NISP will help meet that need without drying up farms.
My concern is that NISP will drive excessive growth, discourage conservation and encourage excessive water use in order to pay for it.
There are several creative ways to share and exchange water, but they all need a bucket to run them out of, so it is important to add more buckets to the system.
Someone will perfect the water right for these seasonal and inconsistent flows; better for it to be an entity sensitive to northern Colorado needs and desires than a Denver Metro municipal water supplier.
I am concerned that healthy, free-flowing river systems are undervalued; we may only recognize the value of their ecosystem services after we have lost them.

Recruiting and Scheduling

Finding those willing to participate in the dialogue was more difficult than expected largely because of the level of distrust between proponents and opponents of NISP, and because of skepticism about the value of such a dialogue. We found five participants willing to engage in the experimental dialogue—two proponents and three opponents. Because of scheduling challenges, the initial plan for four sessions, each two hours in length, was adapted to one two-hour session followed two weeks later by one six-hour session. An advantage of the alternate schedule was an opportunity to dig deeply on one or two topics; a disadvantage was the lack of time between multiple sessions for facilitators to strategize and build on the previous session. A total of just eight hours under either scheme proved to be too little for optimal results.

Dialogue and Results

Session One: Telling Our Stories

The initial two-hour session was designed to set a relationship framework for the subsequent content-focused dialogue. To quickly move beyond the tendency to introduce oneself with surface information, each participant was asked to tell their story—who are you, and what can you tell us about yourself that would help us understand why you volunteered for this experiment? The stories given by the participants were rich in detail, shedding light on their perspectives regarding the NISP issue. For example, one participant said: "Growing up, we had so little water that we were allowed only one bath per week." Another participant said "My work in forestry convinced me that we humans are using far more resources than we can justify." Another said "I was taught that if you want to have something for the future you have to set it aside now." Sharing life experience instead of polarizing positions set the stage for understanding and trust critical to civil dialogue.

Preparing and Categorizing Position Statements

In an attempt to evaluate and discuss the various opinions related to NISP, each participant was asked to submit a list of up to ten statements about why they support or oppose the project. An example of statements can be seen in Table 1. The facilitators grouped the statements into categories and distributed them to participants ahead of the second session with the goal of stimulating respectful and curiosity-provoking dialogue. Categories were (1) growth; (2) storage technology; (3) flows/river health; and (4) institutional decision making/trust.

Second Session—A Dialogue about Water and Growth

The second session, a six-hour dialogue in a retreat-like setting, began by participants deciding how to tackle such a large set of issues in such a short time. The group chose to start with the topic of growth. Likely because of the trust developed during the first session, the tone of the dialogue was one of questioning rather than of positioning. The discussion led to a consensus that while growth has a lot to do with water supply needs, the issue of growth is one that goes far beyond water and that reconciling competing values is made more difficult by the complexity of issues within issues. In fact, we found that competing values can reside inside one individual. For instance, one participant valued limiting growth to what the environment can sustain over the long haul, but was also concerned that limiting growth can price low income residents out of the housing market.

Evaluation and Next Steps

A written evaluation of the process showed that participants considered the experience valuable in that it raised the level of civil dialogue and helped clarify the conflict. However, participants and facilitators alike wished for more time to delve deeper into issues. Participants felt that the process significantly helped them communicate with respect for and curiosity about others' opinions, but were uncertain how what occurred in the small group could be scaled up to a larger number of stakeholders. See Table 2 for a sample of evaluation comments. A "post-dialogue" session to discuss possible next steps reiterated that participants were positively affected by the process and had formed relationships that would be helpful to them going forward. They encouraged staging such dialogues in the future with a wider variety of affected stakeholders, such as those living in and out of basin communities needing the water NISP would provide. They also agreed on the need for developers and planners to work in concert with water providers to explore more deeply the complexities of growth, economics, and the environment.

Conclusion

Many of the issues we face today, including that of whether or not the NISP should be approved, can be characterized as "wicked" problems. Martin Carcasson, one of the facilitators of this experimental dialogue has written that wicked problems "have no technical solution, but due to inherent underlying competing values and tensions, call for ongoing communicative processes of broad engagement that helps communities and organizations develop mutual understanding across perspectives." Did this experiment shed light on how we can better design such communicative processes? At root, we learned that building relationships and trust prior to engaging in dialogue is critical, and that such trust building can be accomplished in less time than might be expected if approached thoughtfully. We also learned that those with conflicting views can engage in dialogue from a space of respectful curiosity if the process of their interaction is carefully designed toward that end. How to "scale up" such a process to include more stakeholders with time to delve more deeply into the issues is a question we need to examine further.

Table 2. Comments shared by participants in the written evaluation.

I wish we had more time to push deeper into more uncharted waters of disagreements.
Helped personalize the issues and provide context, plus it was fun.
Learned a lot about opposition opinions.
It was useful to have a wide-ranging conversation about water, growth, and planning, with a variety of perspectives at the table.
Writing and sharing the statements ahead of time helped improve the listening because we went into the dialogue with more understanding of the range of thinking.
Some seem to come at the issue of growth as "that's just the way it is" while others question underlying assumptions.
I would like a more outcome oriented process, not trying to solve the problem, but discussing potential solutions.

> "Public hearings on projects such as NISP are important as a means of insuring all views are heard and considered, but they tend to increase polarization."

**NISP is currently being considered for permitting by the U.S. Army Corps of Engineers (USACE). The project would include building two off-stream reservoirs to store water diverted from the Cache la Poudre River to provide water supplies for anticipated future growth of fifteen entities, including towns and special districts.*

Flow and Sediment Transport Monitoring Using Seismic and Infrasound Signals

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Rick Aster, Geosciences, Colorado State University
Brian Bledsoe, Engineering, University of Georgia
Tim Covino, Ecosystem Science and Sustainability, Colorado State University

SYNOPSIS

Very few individuals are cognizant that subtle ground vibrations stem from standard Earth surface processes including water discharge and sediment movement, all of which can be measured using seismometers. By deploying seismometers and infrasound sensors on two rivers in Colorado, researchers were able to assess the applicability of quantifying flow and sediment transport through ground vibrations.

Introduction

Most people associate seismic waves with geologic processes like earthquakes and volcanic eruptions and many have even felt the ground motion associated with these geologic events. Few, however, are aware that subtle ground vibrations, measureable with seismometers, occur as a result of common Earth surface processes such as ocean waves, water discharge, and sediment movement in rivers. As a result, application of shallow, subsurface geophysical instruments

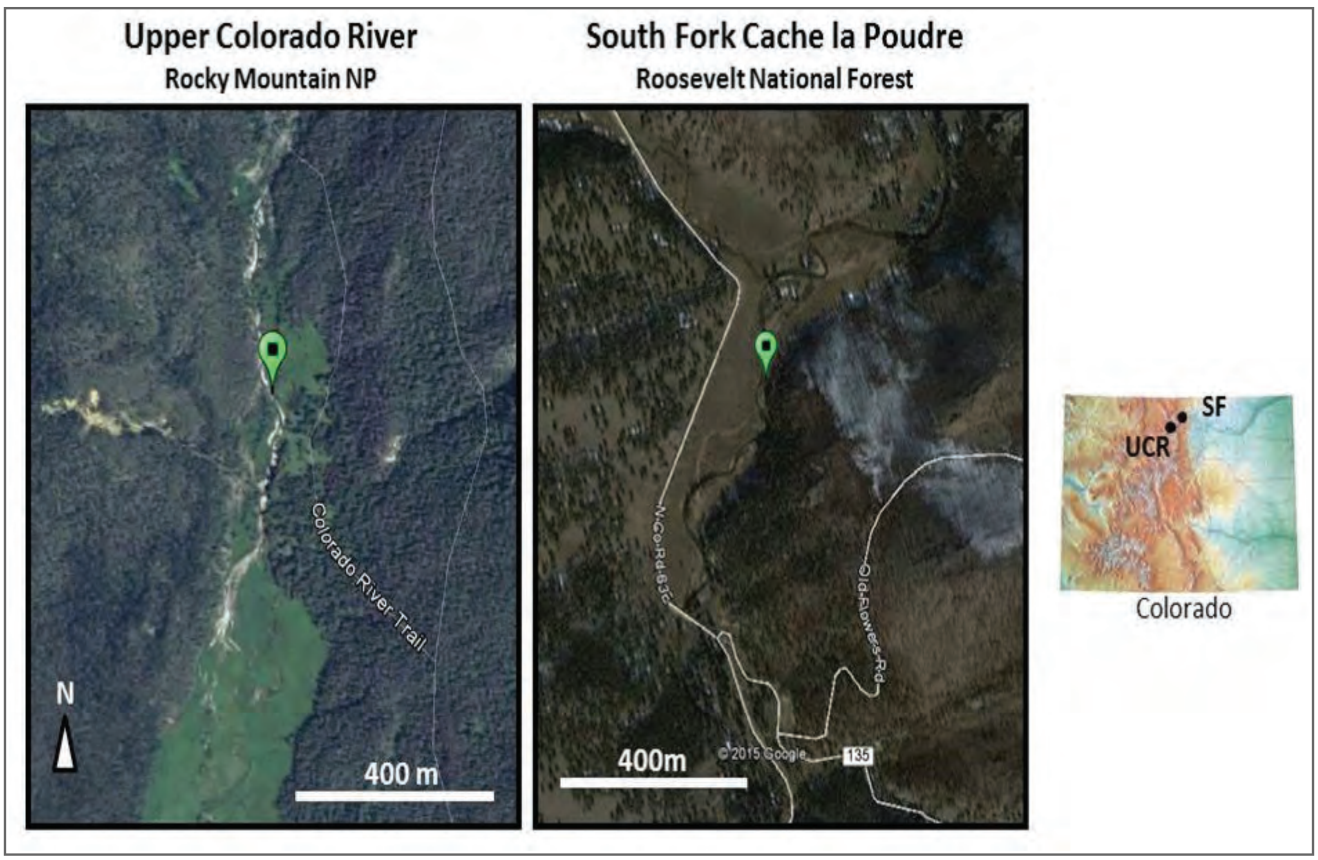


Figure 1. Location of seismographs and infrasound equipment on the Upper Colorado River (UCR) and the South Fork Cache la Poudre River (SF). River flow is to the south on the Upper Colorado River and to the north on the South Fork. Images from Google Earth. Derek Schook assisted with Figure 1.

Figure 2. Image of the South Fork Cache la Poudre River showing locations of three seismographs in 2015. Flow is from left to right, and discharge was gaged on the foot bridge shown. Photo by Rick Aster.

offers unique opportunities to measure fluvial processes in a safe, non-invasive, and continuous manner. A streamside technique for monitoring flow and sediment transport is especially useful during high discharges when flow depth and turbulence are too great to safely work in rivers.

Over the past decade researchers have seismically monitored bedload transport in gravel bed rivers and documented seasonal variations in signals using seismic observations of discharge and sediment transport rates. Additionally, measurements of a controlled experimental flood in the Grand Canyon identified bedload transport through an observed increase in seismic energy on the rising limb compared to the falling limb of flow. Here, we deployed seismometers and infrasound sensors on two small rivers (drainage area 29-183 km^2) in Colorado to test the applicability of quantifying flow and sediment transport using ground vibrations or river 'noise'. Very limited seismo-acoustic research has been conducted on smaller rivers. Discharge on the South Fork is only 1-17 m^3/s, which is more than two orders of magnitude lower than those observed during the Grand Canyon controlled flood.

Study Sites

Geophysical instruments were deployed along the South Fork Cache la Poudre and Upper Colorado Rivers (Figure 1) in 2015 and along the Upper Colorado River only in 2016. Flow and sediment transport data on the South Fork, collected in collaboration with the U.S. Forest Service (USFS) Rocky Mountain Research Station to assess post-High Park Fire burn effects provides the basis for comparison of river flux and ground vibrations over the 2015 snowmelt hydrograph, during a short-duration, high-intensity rain storm, and in response to a small dam release. The Colorado River in Rocky Mountain National Park (RMNP; Figure 1) has ongoing discharge, suspended and bedload data related to research on channel response and restoration following a 2003 debris flow.

Methods

Three, three-channel seismographs and two, three-element infrasound arrays were installed in late May 2015 along the South Fork Cache la Poudre River (Figure 2). In addition, two three-channel seismographs were deployed along

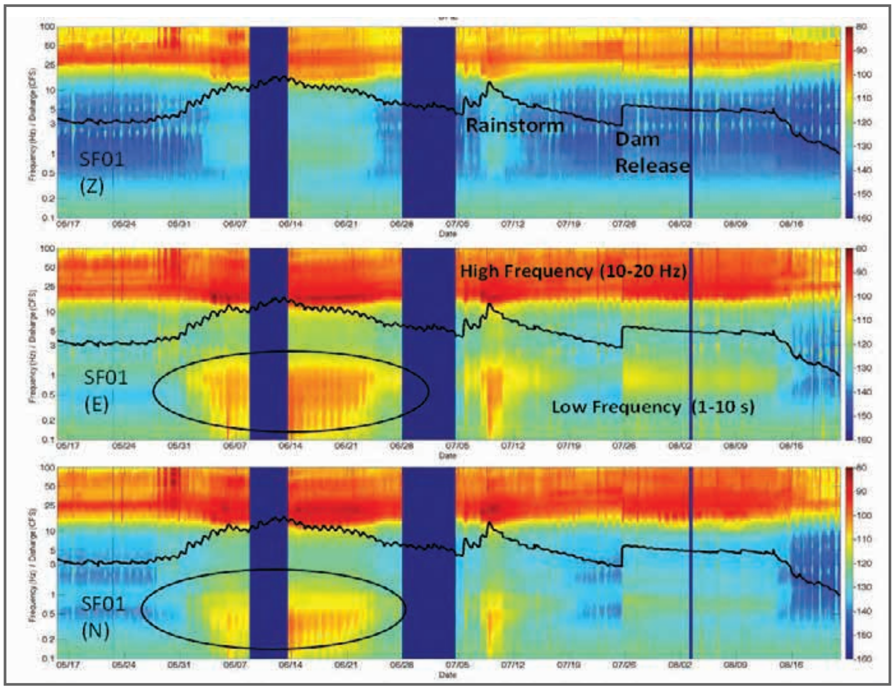
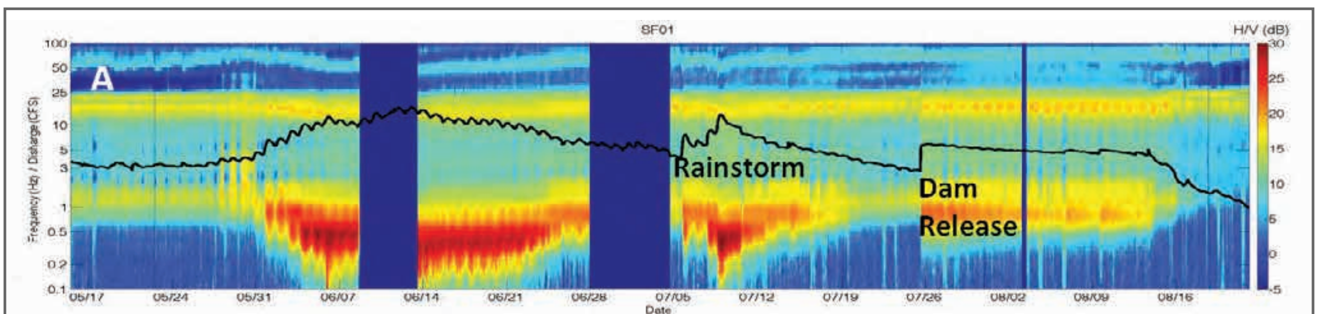


Figure 3. Acceleration spectrograms for the three components of SF01 (location shown in Figure 1) with discharge plotted as black line. Low frequency signals are strongly excited on the horizontal components during high discharge (lower portions of panel), likely due to the seismometer tilting, outlined in black ovals.



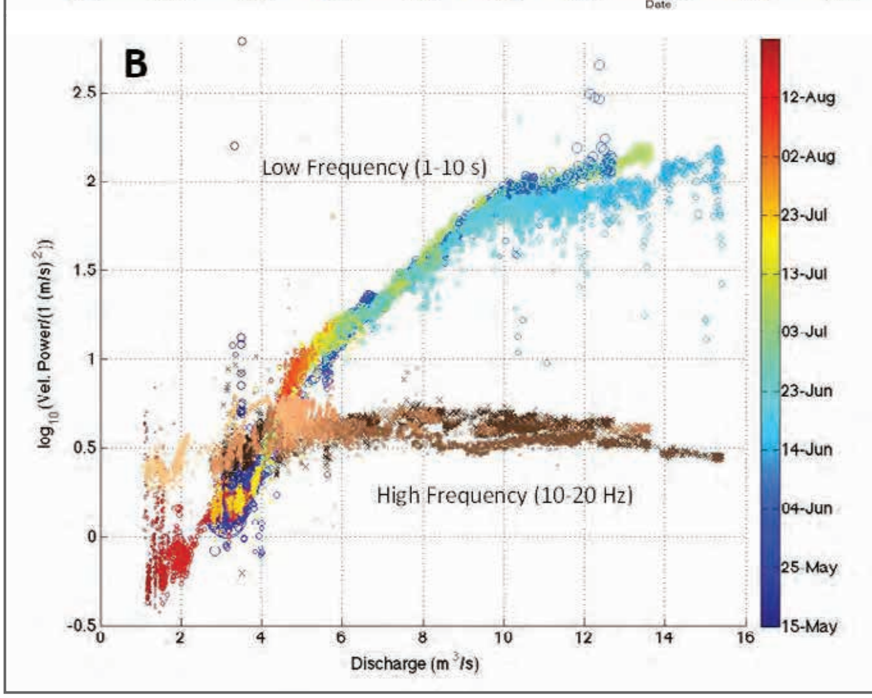


Figure 4. A) Acceleration H/V spectrogram for SF01 in A with discharge shown in black line. B) High Frequency velocity H/V ratios versus discharge over time.

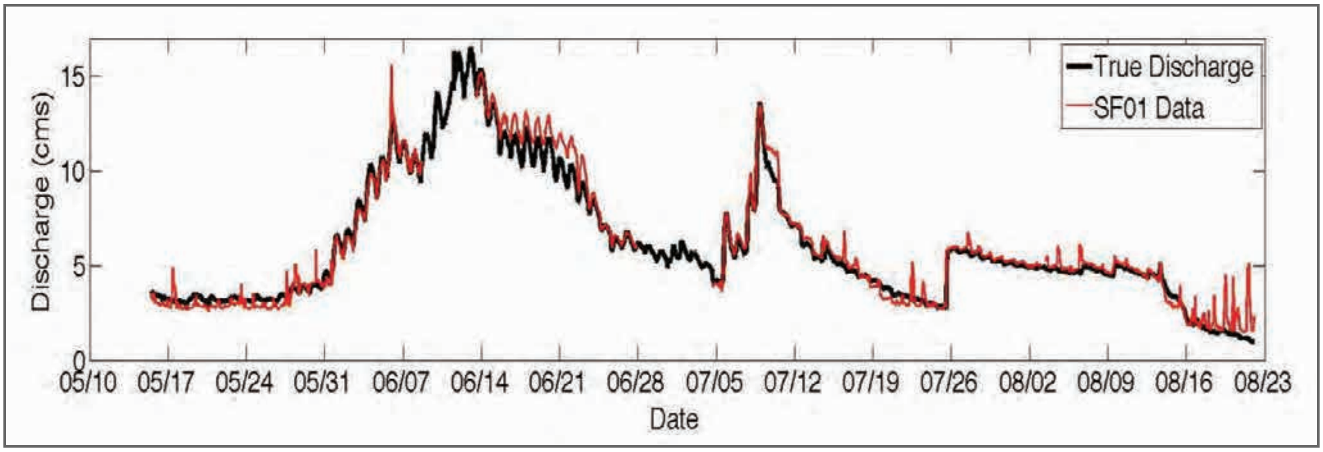


Figure 5. Discharge during summer 2015 from continuous measurement using a pressure transducer (black line) compared to synthetic discharge (red line) calculated from integrated velocity seismic noise power between 0.30-10.00 s and smoothed with a 1-hour moving average.

the Upper Colorado River in RMNP in early June 2015. At both locations, seismometers were deployed in shallow holes close to the water table approximately 1 m from the high-water bank. This is possibly the first sediment transport and monitoring study to place seismometers within the floodplain directly adjacent to a fluvial system. Proximity to Fort Collins and river access via a footbridge enabled flow and sediment transport to be monitored multiple times per week spanning snowmelt along the South Fork. In contrast, access to the Upper Colorado River site was more limited in the early season because of high, unwadable discharges. As a result, Upper Colorado flow and sediment transport measurements were collected after peak discharge in 2015 when flows were sufficiently low to cross the river. In 2016, four, three-channel seismographs were installed in the late spring on the Upper Colorado River in RMNP. Discharge and sediment transport data were collected over the snowmelt hydrograph and into the fall.

Results and Interpretation

We present results of correlations between seismic power and discharge collected on the South Fork in 2015 only because 1) discharge and suspended sediment are strongly correlated; 2) bedload transport was measured non-continuously so is not conducive to time series analysis; and 3) flow and sediment transport data from the Upper Colorado River in 2015 span the receding limb, which generates lower ground vibrations, and 2016 data are still being collected.

Analysis of seismographic data from the South Fork (Figure 3) shows strong river signals across the instrumental response band (~2-100 Hz). Seismic energy at peak runoff on the South Fork site is over 100 times that observed during low flow conditions. Spectra show strong peaks that vary with stream flow and with seismic component (e.g., systematic differences occur between vertical and horizontal components of motion). This suggests different underlying mechanisms for the excitation of compressional and shear/surface wave components of the seismic wavefield.

High frequency H/V ratios (Figure 4) remain constant over varying discharge and are likely generated by a resonance frequency within the low velocity, finer-grained, floodplain sediments adjacent to the seismometer. In contrast, the low frequency ratios change by several orders of magnitude, which may indicate sensor tilt in response to elevated discharge. A logarithmic transfer function was generated between discharge and low frequency, horizontal component seismic energy. This enabled discharge rates to be estimated solely from seismic energy, with an accuracy of < 0.30 m^3/s (Figure 5).

Conclusions

Seismometers are able to measure the shaking of river noise created during snowmelt runoff, a short-duration rain storm, and a small dam release during 2015 on the South Fork Cache la Poudre River. Low frequency (~0.10-1 Hz) vibrations on predominantly the horizontal components are associated with increases in discharge. This is likely due to higher discharges tilting the seismometer either through resonance of the stream channel or direct coupling of the sensor with the water table. High frequency (~10-20 Hz) vibrations probably correlate with bedload transport, as has been observed in other fluvial systems. Additional data collection and analysis on the Upper Colorado River in 2016 will further test the relationship between seismic noise and discharge. Future research on both rivers would benefit from continuous collection of bedload transport to more fully interpret the sediment transport component of the seismic energy.

Presentations and Educational Opportunities

One oral and one poster presentation were given at professional meetings as a result of this research. Plans for a manuscript are ongoing, and will include analysis of Colorado River data from 2015 and 2016. Seven undergraduates, two MS students, and two PhD students from Geosciences, and one graduate student from Ecosystem Science and Sustainability were involved in the field work phase and data collection in 2015 (Figure 6). A summer session of NR220 Natural Resources Ecology and Measurements with 50 students visited the South Fork site, as did the WR417 Watershed Measurements class during fall 2015. During 2016, two undergraduates, two MS students, and two PhD students from Geosciences were involved in equipment installation and data collection in 2016. Additionally, in fall 2016, the WR417 class will take a field trip to the South Fork site.

Acknowledgements

We thank CSU Water Center for funding our multidisciplinary grant. Special thanks to Sandra Ryan for sharing unpublished data. Thanks to Iris Passcal for loan of the instruments, Dennis Harry for use of field equipment during installation, and RMNP for ongoing support in research along the Upper Colorado River. Special thanks to David Dust, Breanna Van, Mike Wyatt, Jay Merrill, John Harris, Bryce Johnson, Ford Fowler, Josh Nuget, Michael Baker, Holden DiLalla, and Garrett Brown for field assistance.

(Background Photo) Poudre River by Flickr User Sharlee H.

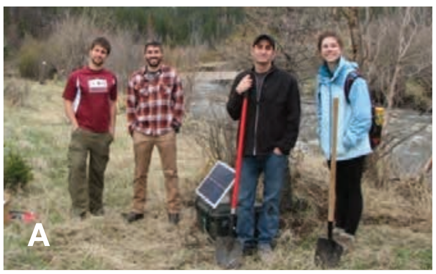


Figure 6. A) South Fork Cache la Poudre River with Geoscience students installing a compound seismographic-infrasound station with instrument box and solar panel. Photo by David Dust; B) Seismometer installation along the South Fork near the right bank. Photo by Rob Anthony; C) Students loaded with equipment ready for the hike into the Upper Colorado River to install equipment. Photo by Rick Aster; D) Seismometer installation at the Colorado River field site. Photo by Rick Aster; E) Students loaded with equipment after the May 2016 Colorado River installation with instrument boxes in background. Photo by Christina Anthony.

Impact of Shale-Gas Development on Surface Water and Lake Sediment Contamination

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Project Team: William Hanneman and Yury Desyaterik

SYNOPSIS

Throughout portions of the United States, water systems are at risk as result of natural gas extraction from shale. This research study focused on determining the impacts of unconventional oil and gas operations have on the Conemaugh River Lake, located in western Pennsylvania.

The development of natural gas extraction from shale in the United States poses threats to our water resources. Relative to conventional oil and gas well drilling, the drilling and stimulation of unconventional oil & gas wells (hydraulic fracturing) requires larger volumes of water. The larger volumes of water used to stimulate hydrocarbon production via hydraulic fracturing lead to larger volumes of water returning to the surface (a.k.a. flowback and produced water) that need to be properly managed. Produced water can be disposed of into underground injection control wells, minimally treated for in-field reuse, or treated at centralized waste treatment plants and eventually discharged to surface water. Treated produced water is also used to irrigate crops in some areas. Flowback and produced waters associated with hydraulic fracturing typically contain high concentrations of salt as well as a variety of organic, inorganic, and radioactive contaminants. Discharge of this wastewater into surface waters is of significant concern because of the high concentrations of contaminants and the fact that wastewater treatment facilities are not adequately equipped to remove contaminants such as radioactive elements, surfactants, and petroleum distillates. Contamination to watersheds as a result of inadequate treatment poses a potential pollution problem for the general public and also ecosystems surrounding these areas.

Organic contaminants in shale gas derived waters and wastewaters are of growing concern. Depending on the drilling company and the local formation characteristics, between 10-20 chemical additives are utilized during fracturing. Hydraulic fracturing fluids include unique organic compounds designed to function as biocides, breakers, corrosion inhibitors, cross linkers, friction reducers, scale inhibitors, and surfactants. Organic contaminants of particular concern, and a main focus of this research, are biocides and surfactants. Biocides are of concern because these chemicals are used to suppress microbial populations at the well and are inherently toxic. Surfactants are of concern because these chemicals can be persistent and widespread in the environment. Additionally, surfactants produce a co-solvent effect that can dissolve previously immobile chemicals, thereby increasing the extent of contamination. In addition to the organic

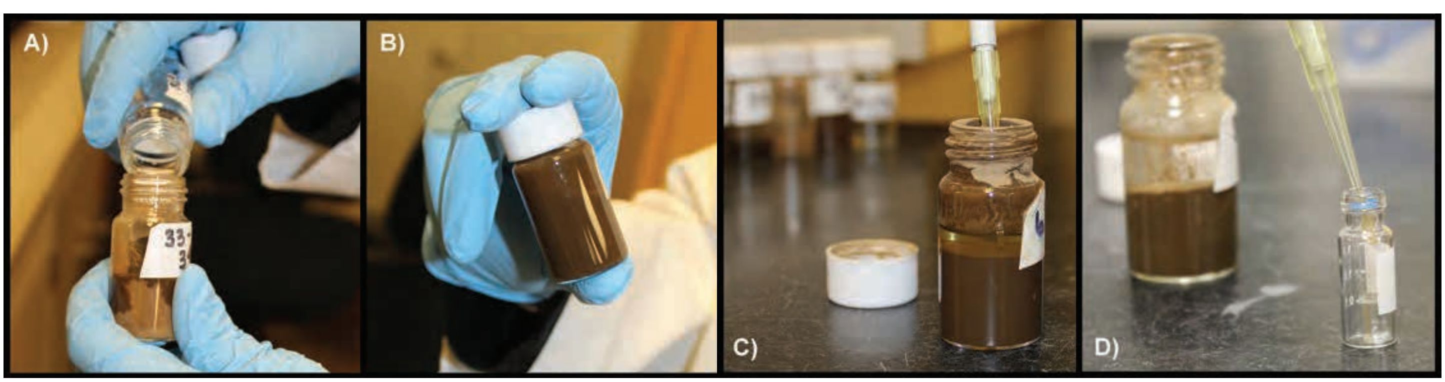


Figure 1. Liquid-solid extraction of contaminants from the soil was conducted by adding a 50/50 mixture of acetone and hexane to the soil sample (A) and thoroughly mixing (B) including placing the samples on a shaker table (not shown). The sample was then allowed to settle and a portion of the extractant was taken from the vial (C) and placed into a chromatography vial for analysis (D). Photos by Molly McLaughlin.

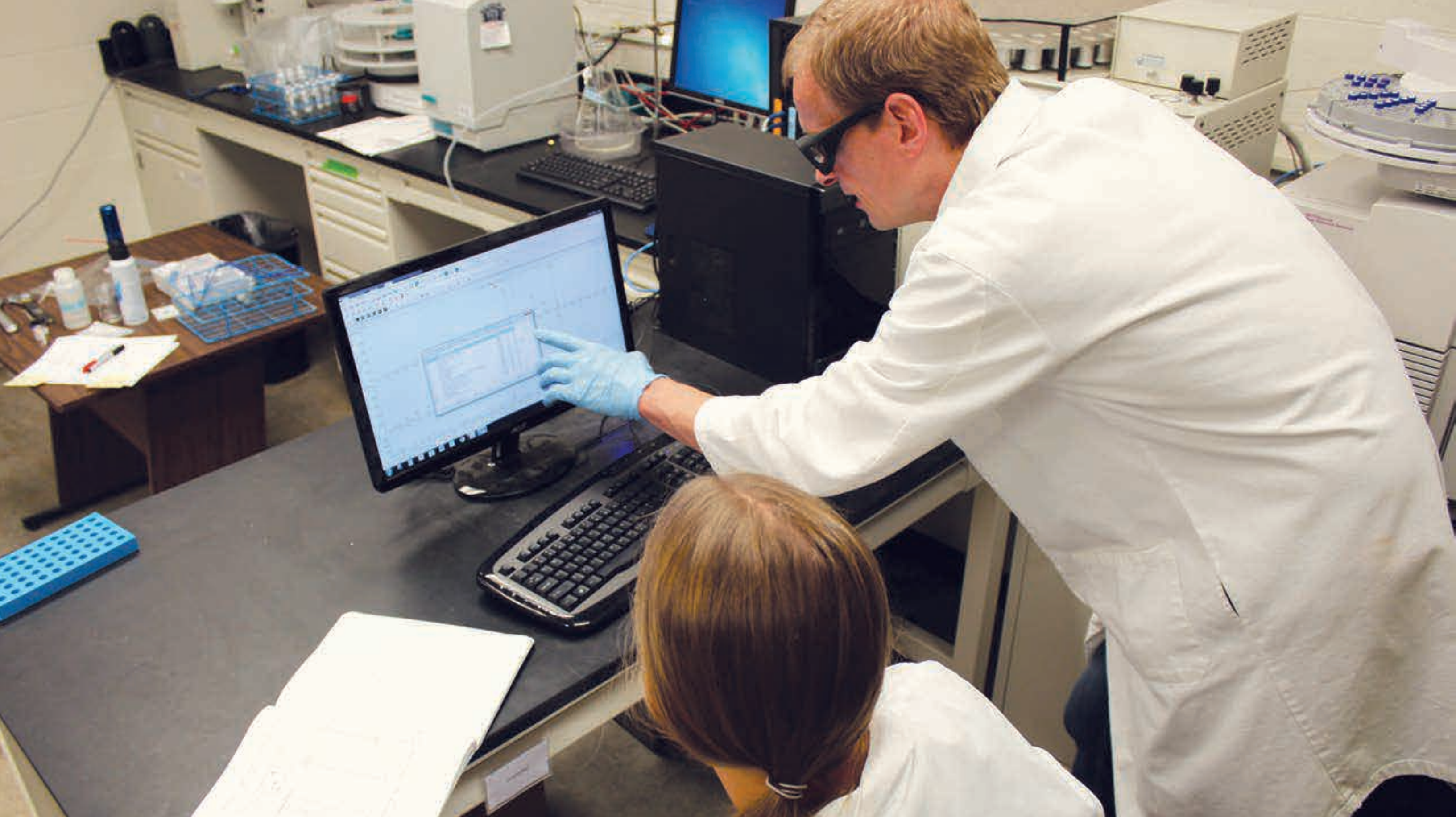


Figure 2. Once the extraction step was complete, samples were analyzed for petroleum derived hydrocarbons using gas chromatography coupled with mass spectrometry (GC-MS). In this photo, Dr. Jens Blotevogel shows PhD student, Molly McLaughlin, how to identify compounds using the library on the GC-MS. Photo by Cali Campbell.

chemicals contained in hydraulic fracturing fluid, there are also organic contaminants that are native to shale formations that come to the surface as a component of the produced water. A main class of these is petroleum-derived hydrocarbons which include diesel range organics (DRO), gasoline range organics (GRO), and polyaromatic hydrocarbons (PAHs), some of which are toxic and/or carcinogenic.

This study analyzed the impacts of unconventional oil and gas operations on the Conemaugh River Lake in western Pennsylvania, an area that has experienced a substantial increase in oil and gas activity in the past decade. The Conemaugh River Lake was formed by a flood control dam built by the U.S. Army Corps of Engineers (USACE) in 1952. Five centralized waste treatment plants that are treating shale-gas extraction wastewaters are located upstream of the Conemaugh River Lake including the Josephine Brine Treatment facility where radium concentrations above radioactive waste disposal threshold regulations have been found in the sediments downstream. Waste from conventional oil and gas operations has been accepted at the centralized waste treatment plants upstream of the Conemaugh River Lake since 1995, while unconventional waste was only accepted at these facilities from 2005-2011. Additionally, there are high sediment accumulation rates and sedimentation in the lake is well-structured allowing for temporal resolution of contaminants entering the lake. This sampling location was selected for all of the reasons listed above, however, the results of this study are also applicable to other watersheds with similar amounts of shale-gas development and/or oil and gas wastewater treatment facilities. Quantification of the impacts and possible toxicity within the watershed could have significant repercussions with respect to oil and gas wastewater management in the future.

During this study, the sediment record of the Conemaugh River Lake was analyzed for evidence of impacts from upstream centralized wastewater treatment plants treating oil and gas wastewater. In order to do this, intact sediment cores were collected from several locations in the Conemaugh River Lake. Sediment sampling was selected to provide a more comprehensive, time-composited approach for environmental assessments. Sediment is deposited in lakes over time and an age model was used to determine the age of sediment at each depth. Contaminants discharged from centralized wastewater treatment plants associate with solids in the stream and eventually accumulate in sediments. As a result, the impacts of oil and gas extraction on the sediment and in the watershed can be determined with respect to time.

The sediments that were collected were analyzed for organic contaminants known to be elevated in shale-gas wastewaters, including surfactants, biocides, and petroleum derived hydrocarbons. The sediment cores were divided by depth and an age model was used to determine the age of sediment at each depth, as mentioned previously. Contaminants were extracted from the sediment using a liquid-solid extraction method where an acetone-hexane solvent was used to remove chemicals from the soil (Figure 1). This solvent solution was then analyzed for contaminants including surfactants, biocides, and petroleum-derived hydrocarbons. Petroleum-derived hydrocarbons were analyzed using gas chromatography coupled with mass spectrometry (Figure 2). Surfactants and biocides were analyzed using liquid chromatography-time-of-flight mass spectrometry.

Results showed that at least three types of surfactants were present in the sediment including nonylphenol ethoxylates (NPEs), C-14 alkylated polyethylene glycols (PEGs), and polypropylene glycols (PPGs). Nonylphenol ethoxylates are commonly used by the oil and gas industry and are known to breakdown into nonylphenol, an endocrine disrupting compound. C-14 PEGs are not considered toxic, but are commonly used by the oil and gas industry and therefore a good indicator of oil and gas impacts on the sediment. Analysis also revealed a range of petroleum derived hydrocarbons in the sediment including many polyaromatic hydrocarbons (PAHs) such as fluoranthene, a known carcinogen and one of the EPA's 16 priority pollutant PAHs. Benzo(a)pyrene, which is also a PAH and a carcinogen was also found in the sediment and has been found in well water in Dimock, Pennsylvania, an area that was previously polluted by unconventional oil and gas activity. Other petroleum-derived hydrocarbons were also found including nonadecane, heptadecane, and 1-hexadecene, all of which have been found in produced water from unconventional oil and gas operations. Biocides were not found in the sediment samples likely because glutaraldehyde, one of the most commonly used biocides, degrades in a few weeks while other biocides, such as didecyl dimethyl ammonium chloride (DDAC) likely bind strongly to the sediment.

The results from the petroleum derived hydrocarbon analysis, including fluoranthene, pyrene, nonadecane, and heptadecane showed an increase during the time period (2005-2011) in which unconventional oil and gas wastewater was accepted to the wastewater treatment plants. Figure 3 shows the results for the two PAHs, fluoranthene, and pyrene. Data on the volume of unconventional and conventional wastewater treated each year was obtained from the Pennsylvania Department of Environmental Protection and the peak in petroleum-derived hydrocarbons is associated with the year in which the largest volume of unconventional wastewater was treated. A peak in NPE and C-14 PEG surfactants was also seen during the 2005-2011 time period, showing that the concentration of these surfactants increased as the volume of wastewater treated increased. Both fluoranthene and pyrene are also a by-product of coal combustion, which is why they are also present prior to 1995. NPEs and other surfactants are also present prior to 1995 because surfactants are used in a variety of household products including detergents and shampoos.

These results show that the historic impacts of unconventional oil and gas extraction can be detected within sediment profiles. As a result of the larger volumes of water used and the different geological formations that are targeted in unconventional versus conventional extraction, the impacts of these two industrial activities can potentially be differentiated. These results can be used to inform regulations on the treatment of this wastewater in the future. In fact, in early June, the EPA finalized a rule that banned the disposal of hydraulic fracturing waste at centralized wastewater treatment plants, effectively preventing this practice from happening again. As with many regulations involving the oil and gas industry, this new rule has been very controversial. The results of this study will provide further evidence for why such a rule is probably needed.

As a result of this study, a proposal was submitted in conjunction with Drs. William Burgos, Nathaniel Warner, and Patrick Drohan from Pennsylvania State University to the National Science Foundation (NSF) Geobiology and Low-Temperature Geochemistry Program titled "Collaborative Research: Impact of Oil & Gas Wastewater Disposal on Lake and River Sediments." Additionally, the results of this study, along with the results obtained by our collaborators at Pennsylvania State will soon be submitted to a peer-reviewed journal.

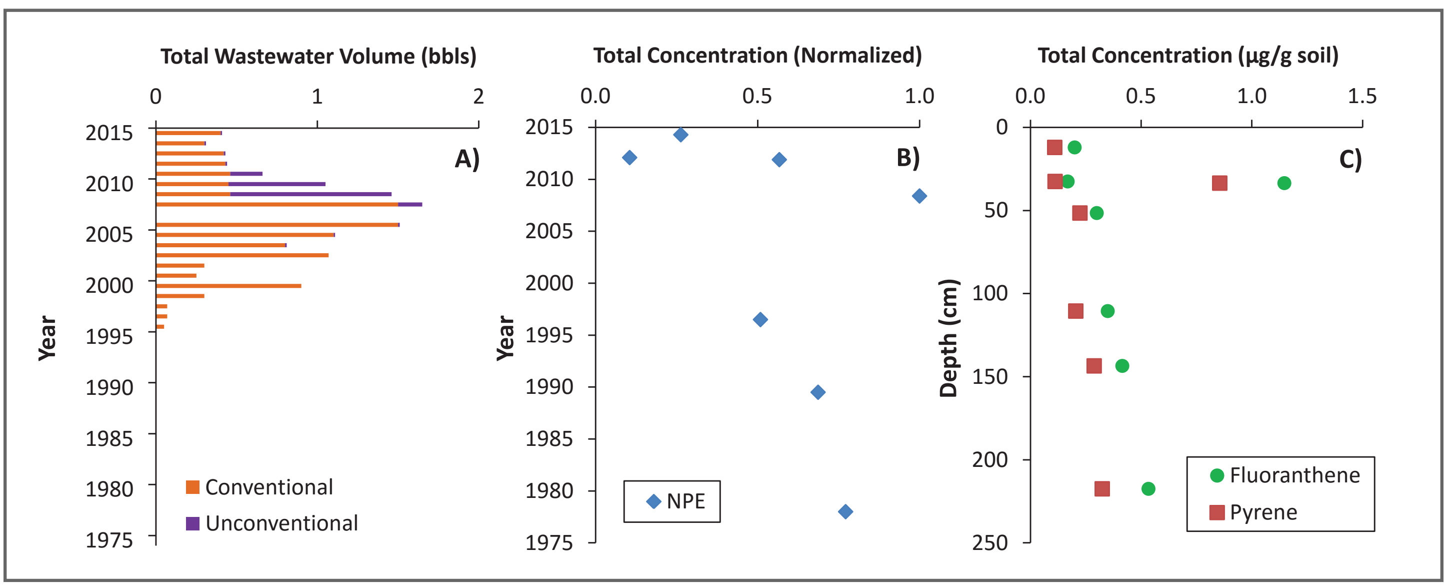


Figure 3. A) Volume of conventional and unconventional wastewater treated in centralized wastewater treatment plants upstream of the Conemaugh River Lake each year; B) normalized concentrations of nonylphenol ethoxylates (NPEs) surfactants extracted from Conemaugh River Lake sediment; and C) quantified concentrations of fluoranthene and pyrene extracted from Conemaugh River Lake sediment core.

Subsurface Water Storage Initiative

Tom Sale, Civil and Environmental Engineering, Colorado State University
Ryan Bailey, Civil and Environmental Engineering, Colorado State University
Mike Ronayne, Geosciences, Colorado State University, and
Bill Sanford, Geosciences, Colorado State University

SYNOPSIS

A subsurface water storage (SWS) initiative was created to develop partnerships with Colorado water managers. Emphasis was also placed on collaborating with cities within the Front Range of Colorado to determine the current efforts and performance of aquifer storage and recovery (ASR) wells.

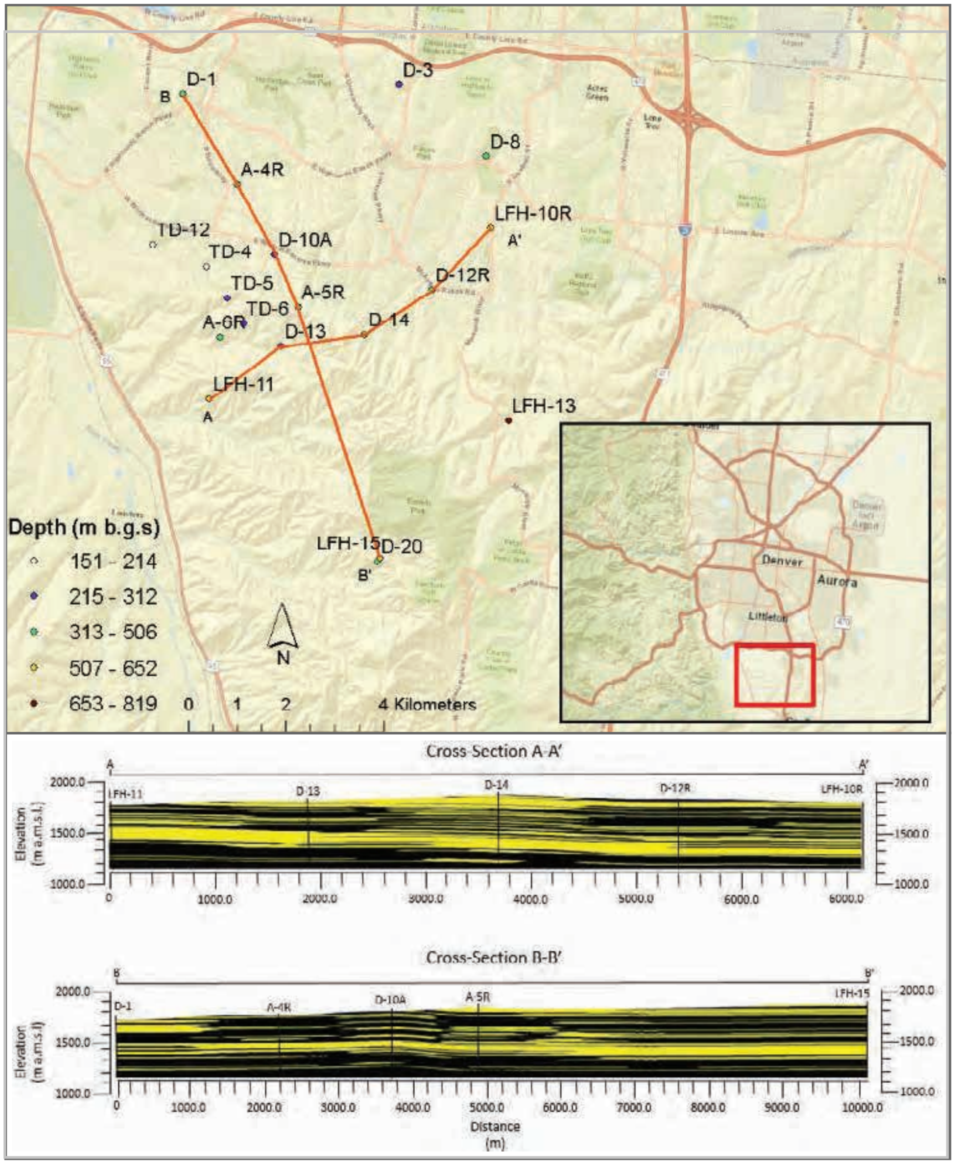


Figure 1. Base map and geologic cross sections in the vicinity of Highlands Ranch, Colorado. On cross-sections, sandstone is represented by yellow, and siltstone-shale is black. The horizontal scale is marked in kilometers; vertical scale is in meters.

Introduction

In July of 2015, the Colorado State University (CSU) Water Center awarded Drs. Sale, Ronayne, Bailey, and Sanford a $15k grant to advance a CSU subsurface water storage (SWS) initiative. The central tenants of the project were to: 1) build relationships with Colorado water purveyors that will set a foundation for a well-funded SWS program at CSU; and 2) through student research, develop knowledge, tools, and people who can advance SWS in Colorado and around the world. The following documents result from funded activities.

Results

Activities 1 and 2—Meeting with Interested Parties and Proposals

Parties interested in SWS were contacted, meetings were held, funding opportunities were identified, and five proposals were submitted. Meetings involved both faculty and students. All five proposal were funded, including: the Town of Castle Rock $25k, South Metro Water Supply Authority (SMWSA) $50k, City of Fort Collins $50k, Colorado Water Conservation Board $50k, and the CSU Water Center $20k. Details regarding newly funded projects are presented in the following text. All of the noted projects hold the promise of long-term funding.

Town of Castle Rock ($25k)

The purpose of this project was to demonstrate CSU's Theis Well Field Superposition model as a: (1) a diagnostic tools for well fields; (2) provide the means of predicting the long-term performance of aquifer storage and recovery (ASR) wells, based on the Town's ongoing ASR test well program; and (3) evaluate sustainable yields from the Denver Basin Aquifers in the vicinity of Castle Rock, Colorado.

South Metro Water Supply Authority ($50k)

This project focused on demonstrating novel tools to characterize the hydrogeology of potential ASR well fields. Emphasis was also placed on validating CSU's Theis Well Field Superposition for prediction of the performance of ASR wells based on fifteen years of ASR water level and pumping records from Centennial Water and Sanitation's well field. Also, the SMWSA project helped to validate CSU's ASR cost model based on pumping and cost data from Centennial Water and Sanitation's well field.

City of Fort Collins ($50k)

The joint project with Hemenway Groundwater Engineering and partnership helped researchers develop conceptual designs for ASR well fields within the vicinity of Fort Collins, Colorado. Researchers focused on exploring critical feasibility issues including: water rights, domain/control of water, water quality, and costs. A preliminary plan for an ASR test well program in the Fountain Formation was also created.

Colorado Water Institute - Fountain Formation Study ($50k)

This study focused on resolving the feasibility of ASR in the Fountain Formation based on the following: (1) published hydrogeologic reports; (2) data from the Colorado State Engineers AquaMaps database; (3) inspections of geologic outcrops; (4) collection and analysis of water samples; (5) meetings with local drilling and pump contractors; (6) meeting with staff in the state engineers office; and (7) hydraulic and cost modeling.

CSU Subsurface Water Storage Symposium ($20k)

Time and funding was also allocated to organize a subsurface water storage symposium at CSU for November 2016, featuring key note speaker David Pyne and presentations by other interested parties in Colorado. In addition, conversations were initiated with the North Poudre Irrigation Company and the Loveland-Fort Collins Water District. Furthermore, steps needed to develop the National Science Foundation Subsurface Water Storage Center at CSU were explored. It is hoped that these initiatives will also lead to additional funding for SWS research at CSU.

Activity 3—Student Research

Graduate student Cat Cannan, MS Hydrogeology, was supported by this project during spring 2016 and investigated the hydrogeologic framework in the South Metro area and performed numerical flow modeling to evaluate the impact of geologic heterogeneity on ASR system performance. This work provides insight into the fate of stored water in a realistic aquifer setting.

> "The geologic cross-sections are used as input for pattern-based geostatistical simulation to create multiple realizations of the aquifer structure in the South Metro region of the Denver Basin."

Describing the Hydrogeologic Framework

To characterize the heterogeneity in the region and create representative geologic cross-sections, geophysical well logs in the vicinity of Highlands Ranch were evaluated to identify the position of sandstone and siltstone-shale interbeds. Geophysical and visual logs for ten wells were downloaded from the Colorado Division of Water Resources well log database (https://data.colorado.gov/Water/DWR-Well-Geophysical-Log/cfyk-gwjj). Gamma ray, shallow resistivity, and deep resistivity data for each well were converted into digital datasets at 0.15 m intervals using NeuraLog digitizing software (NeuraLog Inc., Stafford, Texas). Threshold values corresponding to resistivity and gamma ray lines were chosen such that resistivity values above the threshold indicated sandstone, while gamma counts above the threshold indicated siltstone-shale. To account for the varying strengths and weaknesses of each geophysical method, a combination of all three parameters was used to make a lithology call for each depth interval.

Geologic cross-sections were generated using RockWare (RockWare Inc., Golden, Colorado) by importing the location and lithologic calls for each of the ten wells, allowing the program to interpret lithology between boreholes. Northwest-southeast and southwest-northeast cross-sections were chosen so that each section was based on a minimum of five wells, the sections were perpendicular to one another, and the sections were oriented along or perpendicular to the major axis of the Wildcat Mountain alluvial fan, an important depositional structure characterized by abundant coarse-grained material. The cross-sections are shown in Figure 1.

Flow Modeling

The geologic cross-sections (Figure 1) are used as input for pattern-based geostatistical simulation to create multiple realizations of the aquifer structure in the South Metro region of the Denver Basin. For each realization, numerical flow modeling is being performed to investigate the influence of heterogeneity (i.e., inclusion of sandstone and siltstone, sand body geometry, and connectivity) on ASR system performance. The current modeling considers a single well with 90-days of injection, a 30-day storage period, followed by 90-days of groundwater extraction. Injection/extraction rates are based on data from the Arapahoe Aquifer wells operated by Centennial Water & Sanitation District. We are using three metrics to evaluate ASR performance: (1) furthest extent of head change (i.e., area of hydraulic impact bounded by zero drawdown); (2) particle travel distance (the minimum, maximum, and average distance traveled for a suite of injected particles); and (3) recovery efficiency (the percentage of injected water molecules that are recovered during the extraction phase). Particle tracking is being performed to evaluate metrics (2) and (3). Multiple realizations allow for the generation of statistically significant results. Preliminary results, based on comparison to a homogeneous aquifer model, indicate that performance metric: (1) have minimal sensitivity to the imposed geologic structure. Metric (2) is highly sensitive. Interconnected high-K sand bodies allow for rapid migration of some particles (water molecules) away from the injection site. This highlights the important difference between headchange propagation and particle transport behavior. Metric (3) is moderately sensitive to the heterogeneity. Recovery efficiencies are generally lower (compared to a homogeneous model) when heterogeneity is included.

Improving Precipitation Use Efficiency in Dryland Cropping Systems

Meagan Schipanski, Soil and Crop Sciences, Colorado State University

Overview

Dryland agriculture (i.e. non-irrigated crop production in arid and semi-arid regions) represents 44% of the global agricultural land area and more than 90% of wheat production in the United States. The spatial extent of dryland agriculture is anticipated to increase over time. In the western U.S., large areas are experiencing reductions in available irrigation water due to climate change and the redirection of water to rapidly growing urban areas. In addition to increased demand for water, the frequency and intensity of both droughts and intense rainfall events are expected to increase in the region as climate change progresses.

Increasing soil carbon levels has the potential to improve cropping system resilience in the face of climatic variability. Soil carbon can foster soil aggregation, increase soil porosity, and improve water infiltration rates, thereby increasing precipitation capture efficiency. Soil aggregation is also a critical variable controlling soil wind erosion susceptibility as the size and strength of soil aggregates affects how easily they can be carried away by the wind. Soil residue cover and soil moisture near the surface of the soil are other important factors that can influence wind erosion. In dryland cropping systems, wind erosion is a major force that can influence long-term soil quality and productivity.

Figure 1. Limited spring residue cover following corn in a no-till crop rotation near Stratton, Colorado, may leave soil vulnerable to evaporation and wind erosion. In contrast, dense residue following winter wheat harvest can protect soil from wind erosion and retain soil moisture. Photos by Cassandra Schnarr.

The intensification of crop rotations under no-till management provides an opportunity to increase organic carbon and foster aggregation in soil surface layers. Due to limited rainfall and high evapotranspiration potential, the dominant rotation in the region is a two-year winter wheat-fallow rotation. The 14-month fallow period increases soil water storage relative to continuous wheat and produces more consistent wheat yields. However, the fallow period is highly inefficient and stores at most 25% of incoming precipitation for the following wheat crop. In addition, the fallow period has contributed to the evolution of herbicide resistant weeds and increases wind erosion susceptibility. The adoption of no-till management has reduced evaporative losses due to increased surface residues and allowed for a reduction in the frequency of fallow in rotations and diversification to include corn, millet, or forage crops.

In no-till cropping systems, rotation impacts on soil carbon and soil structure are concentrated in surface layers where it is most difficult to measure soil moisture dynamics. It is in this surface soil layer that soil aggregation dynamics influence wind erosion susceptibility. Utilizing a long-term cropping systems experiment, we analyzed the relationships between crop rotation diversity and soil moisture dynamics to increase our understanding of the aggregation process and linkages to wind erosion susceptibility.

Activities

We collected data from the 30-year old Dryland Agroecosystem Project (DAP) research sites near Sterling, Stratton, and Walsh, which represent a gradient of potential evapotranspiration across eastern Colorado. Graduate student, Cassandra Schnarr, collected monthly soil moisture samples from 0-2.5 cm, 2.5-5 cm, 5-10 cm depths from wheat-fallow, wheat-corn-fallow, continuous grain crop, and continuous forage crop treatments at all three DAP sites from March-October 2014. Soil samples were also collected for dry aggregate strength and size distribution, which are key indicators of soil susceptibility to wind erosion. Wind erosion research and dry aggregate fraction analysis was conducted in collaboration with Dr. John Tatarko, U.S. Department of Agriculture, Agricultural Systems Research Unit (USDA-ARS).

Findings

Preliminary results suggest that the current or previous year's crop had a stronger effect on both soil moisture and soil aggregation than longer-term cropping system legacies. For example, fallow periods following a winter wheat crop had higher surface soil moisture and a lower proportion of smaller soil aggregates susceptible to wind erosion than fallow periods following corn. This is likely influenced both by the longer fallow period following winter wheat and the quality of the residue during the fallow period (Figure 1). In addition, we continued construction of dual-probe heat-pulse sensors in collaboration with Dr. Jay Ham to continuously monitor soil moisture dynamics near the soil surface within the DAP sites (Figure 2).

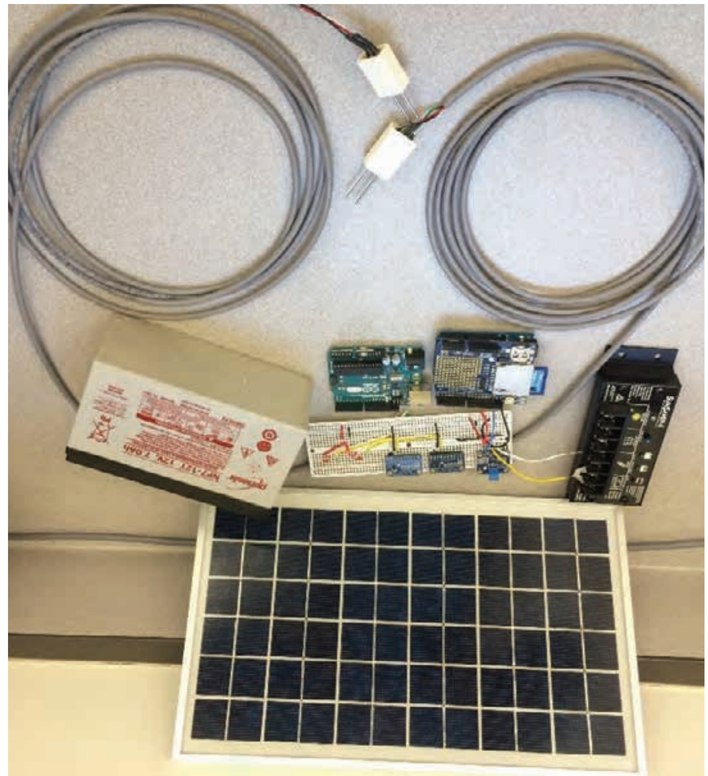


Figure 2. A constructed dual-probe heat-pulse sensor for continuous soil moisture measurements. These sensors combine low-cost Arduino microprocessors with heat conducting and sensing probes that are powered by a small solar panel. Photo by Cassandra Schnarr.

Outcomes and Impacts

Presentations

Schnarr, C., M. Schipanski, J. Tatarko. Cropping system effects on wind erosion potential. Abstract accepted for presentation at ASA/CSSA/SSSA meeting, Phoenix, AZ, November 7-9, 2016.

Schnarr, C. and M. Schipanski. 2016. Keeping the farm on the farm when the wind blows. Technical Bulletin, Wheat Field Days 2016. Colorado State University Agricultural Experiment Station.

Additional Funding Leveraged

USDA NIFA Coordinated Agricultural Project. 2016-2020. Sustaining agriculture through adaptive management to preserve the Ogallala Aquifer under a changing climate. Lead PI M. Schipanski, CoPIs E. Kelly, R.Waskom, C. Rice, C. West, K. Wagner, B. Auvermann, C. Ray, M. Marsalis, J. Warren, B. Guerrero. ($9,800,000)

Figure 3. (Left) Angie Moore, CSU Research Technician, collecting soil samples at the Dryland Agroecosystems Project long-term site near Stratton, Colorado. Photo by Cassandra Schnarr.
(Right) Sergi Domenech Carbo, exchange student from Spain, collecting soil samples at the Dryland Agroecosystems Project long-term site near Stratton, Colorado. Photo by Cassandra Schnarr.

Open-Source Software to Aggregate Weather Data for Health Studies

Brooke Anderson, Environmental and Radiological Health Sciences, Colorado State University
Project Team: Brian Bledsoe, Neil Grigg, Sheryl Magzamen, and Michelle Dellorto

SYNOPSIS

Environmental epidemiology provides the opportunity to understand the juxtaposition between ambient exposures such as severe weather, air pollution, and human health risks. Open-source tools were developed to allow researchers to better comprehend epidemiological research with an emphasis on water-related weather exposures such as tropical storms and flood events.

In environmental epidemiology, we often study the links between ambient exposures—like temperature, severe weather, air pollution, floods, and human health risks. However, the signal of these risks can often be difficult to pick out from the noise of normal variation in health outcomes. Therefore, environmental epidemiologic studies can sometimes require a very large spatial and temporal analysis, including many cities over several years, to precisely estimate the risks related to these ambient environmental exposures. These multi-city, multi-scale environmental health studies require researchers to collect, clean, and aggregate large and complex exposure datasets.

We used the support of the CSU Water Center to develop free, open-source tools to facilitate epidemiologic studies of water-related weather exposures, including exposures related to extreme rainfall, floods, and tropical storms. U.S. agencies, like the National Oceanic and Atmospheric Administration (NOAA) and the United States Geological Survey (USGS), monitor exposure data, including precipitation and streamflow, and make historical datasets of these exposures available. However, collecting data for this study required identifying all station monitors near study sites, pulling data from all monitors, and aggregating monitor data to generate a study-site average (including removing monitors with too much missing data over the study period). Data collection has typically been done with point-and-click web interfaces that require several manual steps to collect and quality control data. For a study of a hundred or more cities (which is not unusual for environmental epidemiology studies), the collection of environmental exposure data can require separately collecting the data for hundreds to thousands of monitors.

Recently, many U.S. agencies have created or improved web services to allow their historical data to be pulled directly from their web-based databases, rather than requiring the use of a point-and-click interface. In essence, the agency gives researchers the rules for finding the right web address for the data they want, based, for example, on a monitor identification number and a date range. Because this process has consistent rules, a researcher can write software that will take a monitor identification number and date range as inputs and will pull the data from the agency's web database and save it to his or her local computer, rather than getting the data for each monitor one at a time. The idea behind this process is similar to web scraping, but most agencies now provide an Application Program Interface (API) that formalizes the process, provides a greater guarantee that the rules for finding web-based data will remain fairly stable, and allows the agency more oversight in ensuring no one abuses this process.

The graduate student funded on this Water Center grant, Rachel Severson, led our efforts to develop open-source software to use these web services, so that a researcher can use simple code within the R programming language to collect county-level datasets of daily or hourly weather observations. The result is the open source R package 'countyweather', which is currently available on GitHub (Figure 1). This package was developed so that a researcher only needs to input U.S. county identifiers (FIPS codes) and desired date ranges, since health data is often available only aggregated to

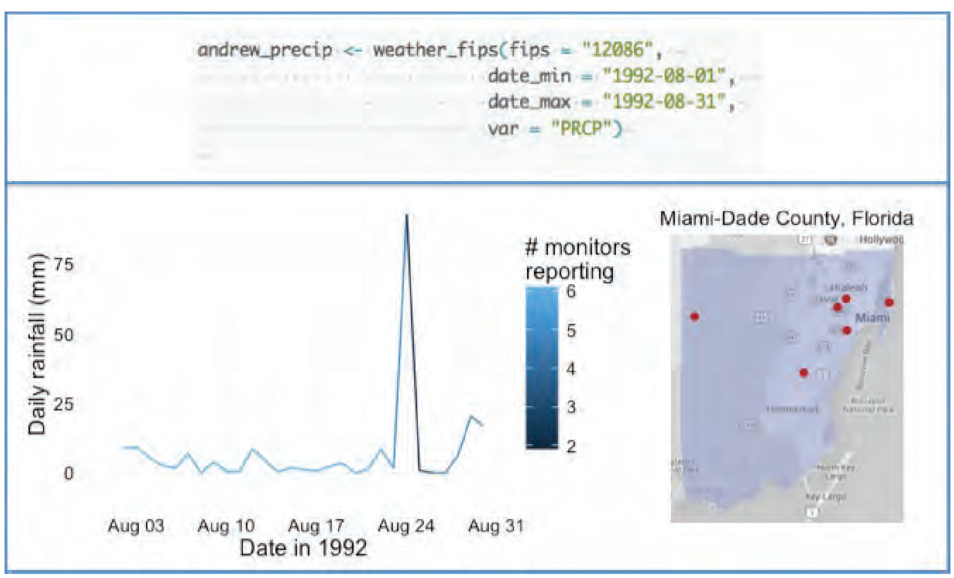


Figure 1. This figure illustrates the use of the `countyweather' R package to gather precipitation data from Miami-Dade County, Florida during Hurricane Andrew (1992). `Countyweather' was created by graduate student Rachel Severson and PI Brooke Anderson.

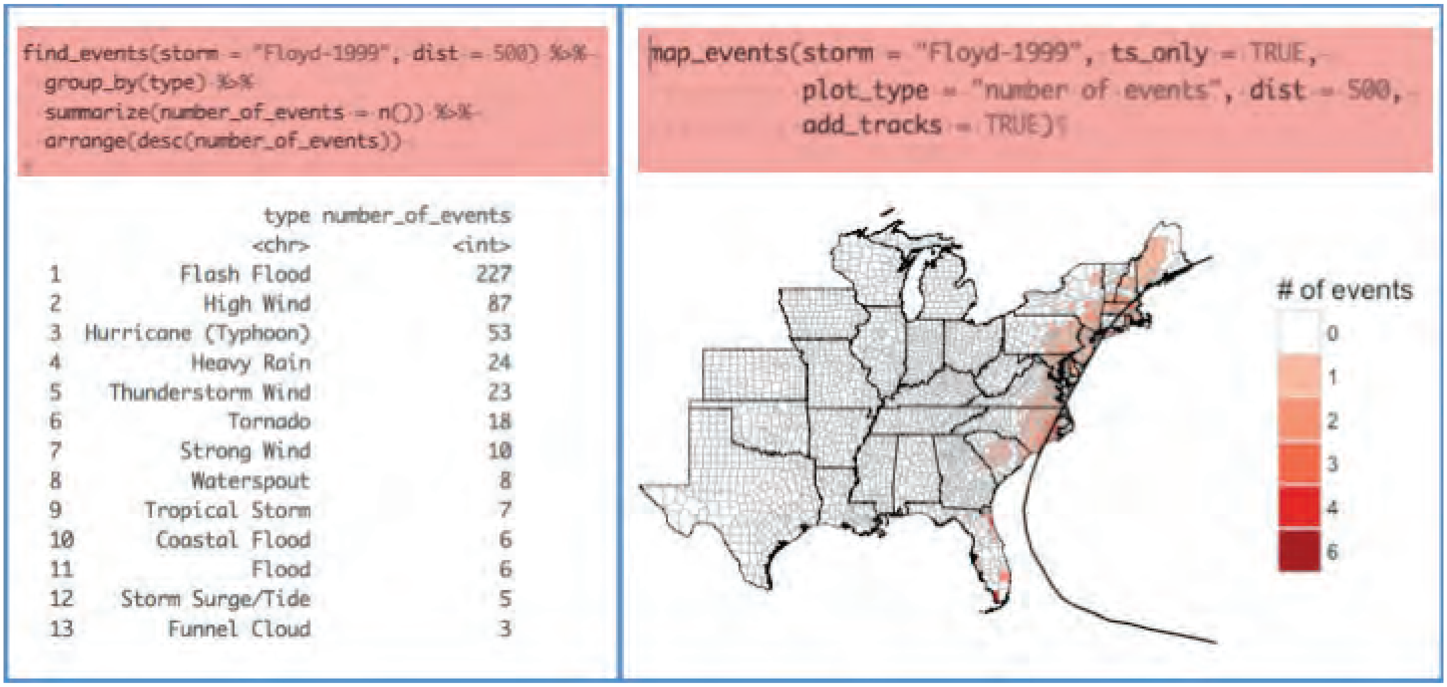


Figure 2. This figure illustrates the use of the `noaastormevents' R package to map the track of Hurricane Floyd (1999), which caused devastating flooding along the East Coast. 'Noaastormevents' was developed by undergraduate student Ziyu Chen and PI Brooke Anderson.

the county level, while surface observations of weather conditions are typically monitor-based. The software will automatically query the NOAA web-based databases to:

1. find all monitors within the county;
2. pull all available weather data from those monitors for any weather variables requested (e.g., precipitation, wind speed, temperature);
3. filter out any monitors with a coverage over the study period that is below a user-specified threshold (for example, a researcher could choose to filter out any monitors with less than 75% non-missing data over a study period);
4. average across monitors to generate a county-level average for the relevant time period (currently, the package can pull either hourly or daily measurements, so this step creates either an hourly or daily county-wide average); and
5. write out exposure datasets, describing the stations included in that exposure dataset, and maps of the locations of the stations used.

Because this is all coded as a simple function, it is straightforward for a researcher to write a loop to collect and save data for many counties in an efficient way, and it is easy to later update and re-run the code to collect exposure data if the study size increases in the future.

In addition to this package, a package was also created (`countytimezones', available on GitHub and CRAN) for converting weather data timestamps to local time. This package includes a dataset created with Oleson time zones for every U.S. County, and it captures day light savings time, including changes over the years in day light savings practice in different counties. This package allows us to convert weather observations to a time zone appropriate for aggregating with health data, which is typically given based on local time. We also have begun developing software that can use USGS streamgage data to assess flood-based exposures for U.S. counties. Furthermore, undergraduate researcher Ziyu Chen, who was supported by an undergraduate research program and advised by PI Dr. Brooke Anderson, developed a package (`noaastormevents', available on GitHub; Figure 2) that can pull, sort, and map data from NOAA's Storm Events database and can pair this data with hurricane tracking data. This package allows researchers to identify events, including floods and flash floods, which occurred the same time and within a certain distance of a tropical storm path.

Several of these software projects are spin offs of ideas and code generated during the Spring 2016 Hackathon (Figure 3) and involve students or researchers who attended the Fall 2015 Hydro-Epidemiology workshop series (described below), two other activities supported by this grant.

Fall 2015 Hydro-Epidemiology Workshop Series

PIs Brian Bledsoe and Brooke Anderson and researcher Joel Sholtes coordinated and led a workshop series funded by this grant on hydro-epidemiology. These workshops were held during four Fridays in October and November 2015 and brought together students and postdoctoral researchers in epidemiology and engineering to talk about water-related research topics and to help us explore potential areas of future collaboration. Other professors from engineering and epidemiology (Sybil Sharvelle and Sheryl Magzamen) also joined for parts of the workshops.

Sessions were divided into hour-long segments lead by students or professors and included a combination of research talks, describing current research projects, or in-depth analysis of journal articles. The topics covered included: flood hazards and related health risks, watershed hydrology, Opportunistic Premise Plumbing Pathogens (OPPPs) including Legionella, gray water and health risks associated with its use, and disinfection by-products. Based on the interest from the students, we might explore expanding this idea in the future years into a 1-credit seminar course jointly listed for engineering and epidemiology students. Several of the people who attended these workshops were later involved in our spring 2016 hackathon (described below) and in some of the open-source software development (described above).

Spring 2016 Weather Data Hackathon

On April 20 and 21, 2016, PI Brooke Anderson led a Weather Data Hackathon. Around 15 people participated in this hackathon, including undergraduate students, graduate students, postdocs, and professors. While some hackathons have teams compete against each other, this hackathon was a collaborative effort. With the help of Co-PI Sheryl Magzamen, we developed two weather data challenges, each focused on environmental health-related exposures, and hackathon participants worked together to develop code and find tools for these challenges. The first challenge was to find and explore as much weather exposure data as possible for three major hurricanes (Andrew in 1992, Cyclone Tracy in Australia in 1974, and Tropical Storm Bilis in China in 2006). Participants looked for existing R packages and online weather data APIs that would allow them to create datasets characterizing precipitation, wind, and flooding during these events, with an aim to creating code and tools that can generalize to any tropical storm. The second challenge had similar goals, but for wildfires in Alaska, and included collecting data on lightning strikes and weather conditions before and during fires.

One key challenge was to ensure that the code developed could serve as a seed for developing future software. Therefore, all the participants used GitHub to fork the same repository locally to their computers and then pushed completed code to a central repository at the end of each hackathon session. This introduced many of the participants to GitHub (and version control more generally) as a tool for collaborative scientific research. Using some of the ideas and code developed during this Hackathon, we have implemented into our open source software projects described above.

Following the submission of this research grant, the researchers discussed with professionals at the Centers for Disease Control (CDC) who study water-related health risks the potential for future research. They advised future research should explore the links between Legionnaires' disease, weather, and water infrastructure. Therefore, the researchers shifted their focus on the pilot project to explore these connections, rather than a relationship between flooding and gastrointestinal disease. To be able to continue the research initiated under this grant, the researchers plan to submit a grant to the National Institute of Environmental Health Sciences (NIEHS).

Figure 3. Students participating in the spring 2016 Weather Data Hackathon.

Western Water Symposium and Barbecue in Review

Patricia J. Rettig, Head Archivist, Water Resources Archive, Colorado State University Libraries

Speakers at this year's Western Water Symposium and Barbecue emphasized that understanding past decisions and actions helps in achieving solutions to present and future challenges. Four speakers participated in the July 25th event at Colorado State University's Morgan Library, held to support the Water Resources Archive.

In taking up the day's theme, the politics of water, the speakers avoided the partisan debates present in the media and instead looked at more subtle political realities that have significant impact on water issues.

Lafayette College History Professor DC Jackson discussed a 1928 dam failure, which provided plenty of reality for those proposing and planning more and bigger dams, including one of the most famous, the Hoover Dam. Jackson's talk, "Engineering Politics in the American West: The St. Francis Dam Disaster and San Francisco's Hetch Hetchy Dam," focused on the scenario and people surrounding the St. Francis Dam collapse, which killed more than 400 people. The disaster's political outcomes included improvements in California dam safety laws. Simultaneously, the catastrophe was being swept under the rug to cause as little impact as possible on the Congressional passage of the Hoover Dam legislation. Californians had a great stake in promoting the massive unprecedented dam for the energy and water benefits it would ultimately provide.

The next speaker lived his own political reality during five terms in the U.S. House of Representatives and one in the U.S. Senate. Hank Brown, bringing the day forward in time and closer to Fort Collins, discussed his experiences in the passage of the legislation designating the Cache la Poudre River both a wild and scenic river and a national heritage area. He clearly stated his self-identified bias in his talk "Water: The Key to Improving Colorado's Environment" as being the belief that "a great environment is the product of action, not inaction." He discussed working with both pro and con groups on the wild and scenic legislation, stating that either side could have killed the bill, but it took both sides to pass it.

A break for a barbecue lunch gave attendees a chance to discuss what they heard during the morning before more provocative presentations. Starting the afternoon was Denver Water's CEO/Manager Jim Lochhead with his talk "Can Western Water Politics Avoid a Zero Sum Game?"—the "game" being the typical water reality where gains are directly offset by losses. Lochhead discussed how this plays out locally and across the Colorado River Basin, and how it has been exacerbated by 1960s and 1970s federal legislation. He explained that the "water development community didn't get the memo" and took several decades to alter the way they were doing projects.

(Above) More than 130 guests joined the Water Resources Archive for the Western Water Symposium and Barbecue. Photo courtesy of the CSU Libraries.

(Left) DC Jackson, Pat Mulroy, Jim Lochhead, and Brad Udall have a spirited discussion. (Right) Guests enjoy political humor in the Water Resources Archive. Photos courtesy of the CSU Libraries.

In Colorado, change was evidenced in how the water community came together in the late 1980s to design and implement an endangered fish recovery program on the Colorado River. This practice was later extended to the three-states agreement on the Platte River. Such negotiated solutions are more likely to provide more gains and fewer losses across the board, Lochhead explained, and went on to describe a new operational paradigm negotiated with Grand County and others: "learning by doing."

Lochhead enumerated the current challenges for the water community: growth, dependence on a Colorado River in decline, and a warming climate. His suggested solution involves visionary leadership and honest discussions. Ideas and initiatives are needed from various venues, not just the traditional ones. Lochhead also praised forums such as the symposium to allow such discussions to take place, but says they need to move to the policy arena. He also gave credit to the environmental community for moving past mitigation and bringing credible solutions to the table.

The final speaker returned the discussion to California, while showing the reality that water issues across all the Colorado River Basin states are connected. Pat Mulroy, non-resident Senior Fellow at the Brookings Institution and Practitioner in Residence at the William S. Boyd School of Law at the University of Nevada Las Vegas, discussed "The Politics of the California Bay Delta: Shaping the Future of the Colorado River." While southern California diverts and uses significant portions of the Colorado River, water issues in the northern part of the state are impacting the river system. The Metropolitan Water District of Southern California (aka, "Met") sits at the crux of this, getting half its water supply from the Bay Delta, but switching to Lake Mead after a judge shut down the Bay Delta pumps, in what Mulroy called a "fallacious" decision to protect fish. With Met tapping into an already low Lake Mead, river system conditions were exacerbated. Mulroy contends that all parties need to be willing to share risk voluntarily.

Added to political issues within California is the "regulatory paralysis" in the federal government. Mulroy calls it "insanity" for regulations to require predicting how systems will operate in perpetuity. With a more uncertain future than ever, predicting river flows forty years out is nearly impossible. Systems cannot necessarily be operated the same way every year and need more flexibility. She believes that regulators and legislators have to adapt to this uncertainty and change the way they are regulating.

Mulroy argued that dialogues are needed to find common solutions and that coexistence equals shared risks. "The sooner we start the conversation, the better off we can all be."

The presentations concluded with the day's emcee Brad Udall, Senior Water and Climate Research Scientist/Scholar at CSU's Colorado Water Institute, leading a panel discussion with Jackson, Lochhead, and Mulroy. Audience questions ranged from water storage to agriculture to Mulroy's forthcoming book.

To wrap up the day, guests attended a reception to keep discussing politics and visited the Water Resources Archive for exhibits and tours. Proceeds from the symposium benefit the Archive to fund its preservation, digitization, and outreach work.

While both water and politics can produce some wildly different opinions, the symposium guests generally had good comments about the day. One of the more than 130 attendees commented, "I really enjoyed it and found it to be insanely interesting."

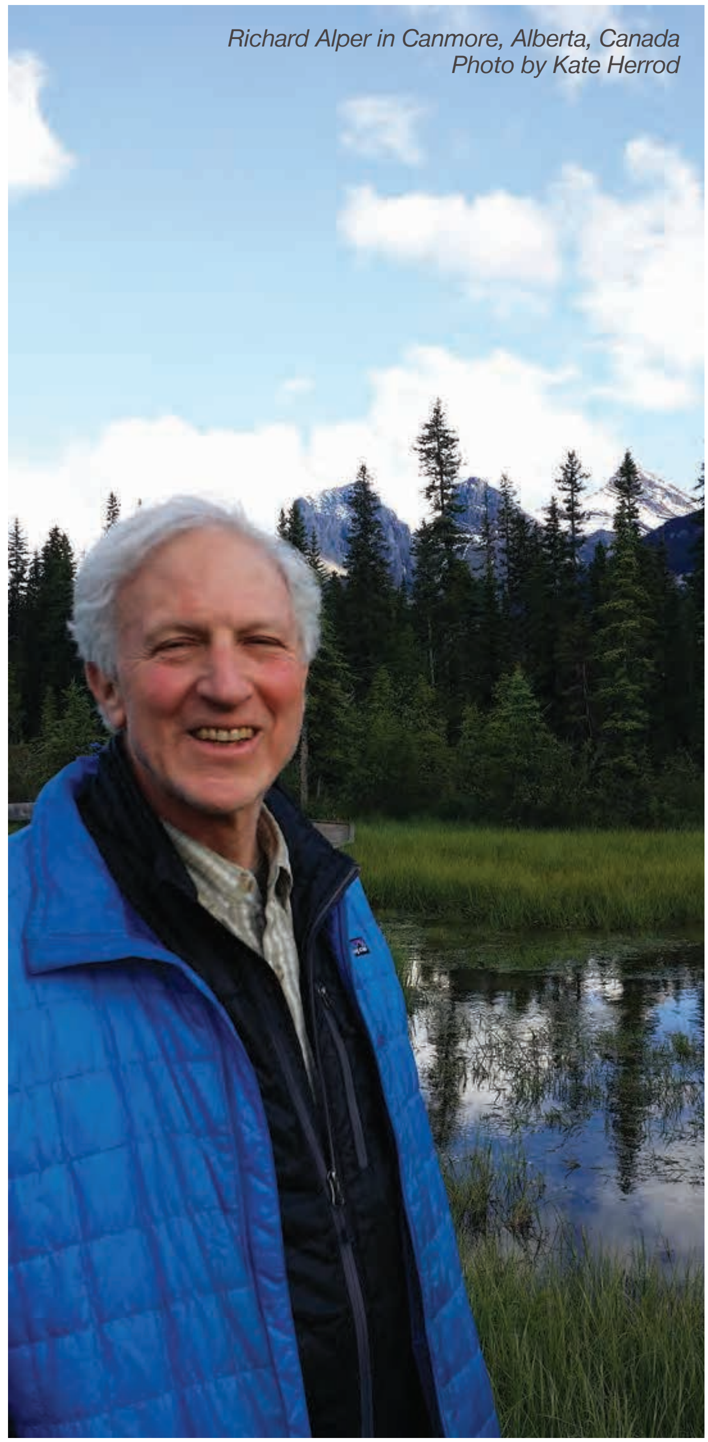
For more information about the Water Resources Archive and its other events and activities, see the website (http://lib.colostate.edu/water/) or contact the author (970-491-1939; Patricia.Rettig@ColoState.edu) at any time.

Whisky is for Drinking; Water is for Values-Based Negotiating

Tradeoffs and Tensions in the Colorado Water Plan A Study in Values

Richard Alper, Environmental and Sustainability Studies, University of Northern Colorado

This article is the second in a two part series. Part 1 can be found in the July/August 2016 Issue of Colorado Water.



Richard Alper in Canmore, Alberta, Canada
Photo by Kate Herrod

SYNOPSIS

Part two of this article offers insight into the values of the Colorado Water Plan, assessing cognitive bias, and provides insight into how individuals may address specific wicked and tame problems within the realm of water resources.

Values and the CWP

After conducting nine public meetings around the state about the CWP in the summer of 2014, the Interim Water Resources Review Committee (IWRRC) of the Colorado Legislature advised Director Eklund of the CWCB that: (1) there is universal support for the doctrine of prior appropriation and the existing market based system for allocating scarce water resources and (2) citizens also support innovative and flexible approaches toward conservation and sharing water among agricultural, M&I, and environmental/recreational values.

What does this tell us about the values incorporated in the CWP as it is perceived by the public? On the content side, there are values expressed of:

1. Preserving the tradition, but using flexibility and innovation to tweak or refine it so the tradition may adjust to an era of finite water supply and projected water gaps
2. Embracing conservation so that water may be shared across three sectors—agriculture, M&I, and environmental/recreational health

These values underscore the tensions between tradition and innovation, and the difficulty of conserving enough additional water to reasonably share between three sectors. Hence, we are again in the world of tradeoffs and working through the consequences of various options illustrated above with respect to grazing and buy and dry. Now that we have looked at some of the values represented in the CWP as a whole, we can turn to the wicked problem contained in the issue of TMD, which is mentioned above. One practitioner scholar of environmental conflicts believes that the reason many environmental conflicts are not adequately resolved is that the parties treat them as purely resource conflicts when in most cases, they also contain important values conflicts which, if not addressed, can lead to disappointing outcomes. Let us see if this is this the case with the TMD topic.

It has been said that one of the most glaring disagreements in the entire CWP is where one basin's plan identifies water from another basin, usually across the Continental Divide, as a target for its own supply. Let's briefly review the kinds of concerns that first the West Slope and then the Front Range interests have.

Summary of West Slope Concerns

One commenter from the West Slope observed, "What seems to be missing from the discussion is the fact that if one basin is short water and goes looking for it in another basin, [which] constrains the ability of the affected basin to develop its own future." Another commented, "Each basin must find ways to exist and thrive within the limits of their own water supplies" and the West Slope has historically provided to the Front Range more than 500,000 acre-feet per year, so it is not obliged to do more. In particular, a TMD would harm river, stream and ecosystem health, which would cause damage to recreational and environmental resources; damage the ability of the West Slope to maintain healthy rural communities and meet its development needs; and reduce the ability of the West Slope to meet a Colorado River Compact deficit for surrounding states. So long as the Front Range does not engage in high levels of urban and agricultural conservation and reuse prior to such a project, the West Slope should not allow "de-watering" to fuel Front Range urban population growth. This concern can be seen as stating a ladder of priority actions beginning with conservation and re-use and ending, if necessary, with a TMD for new supply. It is reflected in Principle 6 of the Conceptual Framework in Chapter 8 of the CWP.

Summary of Front Range Concerns

Here is a sampling of comments from the Front Range during the IWRRC hearings:

"Water and land use planning ought to take place in conjunction with one another."

"Far more can be done to directly encourage conservation among urban users."

"Conservation should be incentivized. This requires a revision of the current 'use-it-or lose-it' provision in Colorado water law."

"Population growth will eventually outstrip the environment's carrying capacity, including water."

"Identified Projects and Processes, conservation, new supplies and ATM's all merit inclusion in the CWP."

"Any new water projects should be multi-purpose so they will serve agriculture, urban utilities and the environment."

"While the need for conservation is acknowledged, too little is being done in this regard and too much emphasis is given to additional water storage."

As can be seen from these statements during the hearings, many Front Range people are concerned that a) stricter conservation measures need to be put in place on the Front Range and b) to meet the projected growth in urban and industrial consumptive use needs by 2050, it does not have adequate resources within its own basins. According to the CWP, there is a projected water gap of 200,000 to 304,000 acre-feet by 2050. Front Range people tend to believe that if the water gap is not met through a) new supply comprised of multi-purpose TMD's, b) the no-low regrets strategy, and c) low to moderate conservation strategies, which must include a high rate of customer adoption, then the Front Range will lose one-third of its irrigated land and the ability to manage its' future water demand. There is a concern to protect productive agriculture on the eastern plains from buy and dry by M&I demand. There is a need to streamline permitting processes for new supply and to capture the full compact entitlement of Colorado Rivers, before they flow in to surrounding states, particularly Kansas and Nebraska.

What Are the Next Steps?

Having briefly reviewed one version of the TMD concerns of the West Slope and the Front Range, what needs and value are truly at stake? Why does the TMD issue matter so much to each slope? What needs or values are threatened by this conflict? Is this purely a resource issue?

At its core the West Slope is saying it wants beauty partially expressed through conservation and ecosystem health, control over its destiny, well-being, freedom and self-reliance. The Front Range seems to be saying that better conservation is good, but it is not enough: Its' well-being depends on some help with providing water for the expected population explosion. It is fair to say that the TMD issue is not purely a resource allocation issue, but also contains difficult values issues, some of which have been approached in the CWP.

The Conceptual Framework in Chapter 8 of the CWP represents important progress on the TMD issue. It is a significant benchmark in acknowledging the interdependence of the basins and of collaboration between water representatives at several levels and from both slopes. Harris Sherman, a former chair of the Inter Basin Compact Committee observed, "Colorado is more than an amalgam of eight separate river basins. In reality each basin is dependent upon the other basins. The interdependence is more pronounced today than at any point in our history." John Stulp, an aide to the Governor makes a similar point with respect to the Front Range and the concern on the West Slope about a compact deficit on the Colorado River: "We are all tied together by the Colorado River Compact. That's been part of the educational effort to make people on the Front Range realize that they're tied into that compact every bit as much as people in the far reach of the Western Slope are."

Treating the TMD issue as a wicked problem which is interconnected with other water supply and demand management issues, let us make some tentative assumptions about a water gap scenario, which may lead to further examination of our values about water. Suppose that: (a) a large population increase occurs and that much of the projected water gap will exist, (b) successful ATMs are developed and implemented to prevent significant loss of acreage to buy and dry, (c) conservation and re-use are implemented with a high degree of consumer adoption on the Front Range, (d) future land use decisions are effectively linked to water use and (e) following the ladder of priority actions stated in the Conceptual Framework, Colorado still needs a multi-purpose TMD. Here are some guidelines to help navigate the remaining values issues between the stakeholders on this topic:

1. **Clarify what the value conflict is about**
2. **Try to rank the values of each interested party and notice any common values**
3. **Research additional useful facts**
4. **Develop practicable alternatives which reflect these useful facts and common values**
5. **Examine long term and short term major consequences of each alternative**
6. **Research evidence to determine the probability of each major consequence occurring for each practicable alternative**
7. **Examine the desirability, tensions and tradeoffs between the set of probable consequences for each alternative**
8. **Make a judgment about which alternative is the best fit with then existing values, useful facts, major consequences and available resources**
9. **Kick back and enjoy a cold brew made in Colorado!**

As many participants in the IBCC and the Basin Round Tables know, these guidelines are easier said than done, but as noted above, a remarkable shift toward recognizing the value of collaboration has occurred in the past several years.

Cognitive Bias: Do You Have Some?

In addition to identifying values that are in play beneath our water debates, there is another hidden barrier called cognitive bias, which is mentioned above. A cognitive bias is a simplified rule of thumb we automatically use which leads us to a) making routine errors in processing information, b) missing our blind spots and c) falling in to decision traps. Two of the most common "blind spots" are *confirmation bias*, where we select out and only see the information which supports our already established opinions and *ego-centrism bias*, where we tend to believe that our perceptions, judgments and abilities (even our driving skills) are superior to, and/or more accurate than, those of the other persons we are negotiating with. While not using the current terminology of blind spots or cognitive bias, one of our Founding Fathers noticed this state of mind in himself and his colleagues at our nation's Constitutional Convention in the summer of 1787. On the last day of that Convention, Benjamin Franklin encouraged his colleagues to consent to the then unsigned Constitution with the following reflection:

"Mr. President, I confess that there are several parts of this constitution which I do not at present approve, but I am not sure I shall never approve them: For having lived long, I have experienced many instances of being obliged by better information, or fuller consideration, to change opinions even on important subjects, which I once thought right, but found to be otherwise. It is therefore that the older I grow, the more apt I am to doubt my own judgment, and to pay more respect to the judgment of others. Most men indeed as well as most sects in Religion, think themselves in possession of all truth, and that wherever others differ from them it is so far error… But though many private persons think almost as highly of their own infallibility as of that of their [religious] sect, few express it so naturally as a certain French lady, who in a dispute with her sister, said "I don't know how it happens, Sister but I meet with no body but myself, that's always in the right ...In these sentiments, Sir, I agree to this Constitution with all its faults, if they are such;… I doubt too whether any other Convention we can obtain may be able to make a better Constitution. For when you assemble a number of men to have the advantage of their joint wisdom, you inevitably assemble with those men, all their prejudices, their passions, their errors of opinion, their local interests, and their selfish views. From such an assembly can a perfect production be expected? It therefore astonishes me, Sir, to find this system approaching so near to perfection as it does; and I think it will astonish our enemies, who are waiting with confidence to hear that our councils are confounded like those of the Builders of Babel; … Thus I consent, Sir, to this Constitution because I expect no better, and because I am not sure, that it is not the best. The opinions I have had of its errors, I sacrifice to the public good. … On the whole, Sir, I cannot help expressing a wish that every member of the Convention who may still have objections to it, would with me, on this occasion doubt a little of his own infallibility, and to make manifest our unanimity, put his name to this instrument".

As we move forward with protecting Colorado's water future, let us i) bear in mind what it takes to tackle wicked problems, ii) examine the tradeoffs and tensions between our underlying values and iii) try to learn from Benjamin Franklin about noticing our biases, passions, errors of opinion, local interests and values.

The author wishes to thank the following people for their contributions to this article: Larry MacDonnell, Martin Carcasson, Mara MacKillop, John Stulp, Sean Cronin, Reagan Waskom, Patricia Rettig, Kate Herrod and Ara Azhderian. Have questions? You can reach Richard Alper at richard.alper@unco.edu

Colorado Climate Center Water Year Wrap-Up

Nolan Doesken, Colorado State Climatologist, Colorado Climate Center, Colorado State University
Peter Goble, Colorado Climate Center, Colorado State University
Zach Schwalbe, Colorado Climate Center, Colorado State University

SYNOPSIS

No two years are ever alike. For the year as a whole, this past water year was not exceptionally wet or dry in Colorado. Snowpack this past winter was fair to good and spring brought additional water. This summer provided enough humidity east of the mountains to fuel many afternoon and evening storm opportunities. Some areas like Colorado Springs and parts of the eastern plains of Colorado had relatively frequent and sometimes heavy storms. Other areas, like the northern Front Range, were largely missed by everything. While surface water supplies held out OK, soil moisture is now largely depleted in some unirrigated locations.

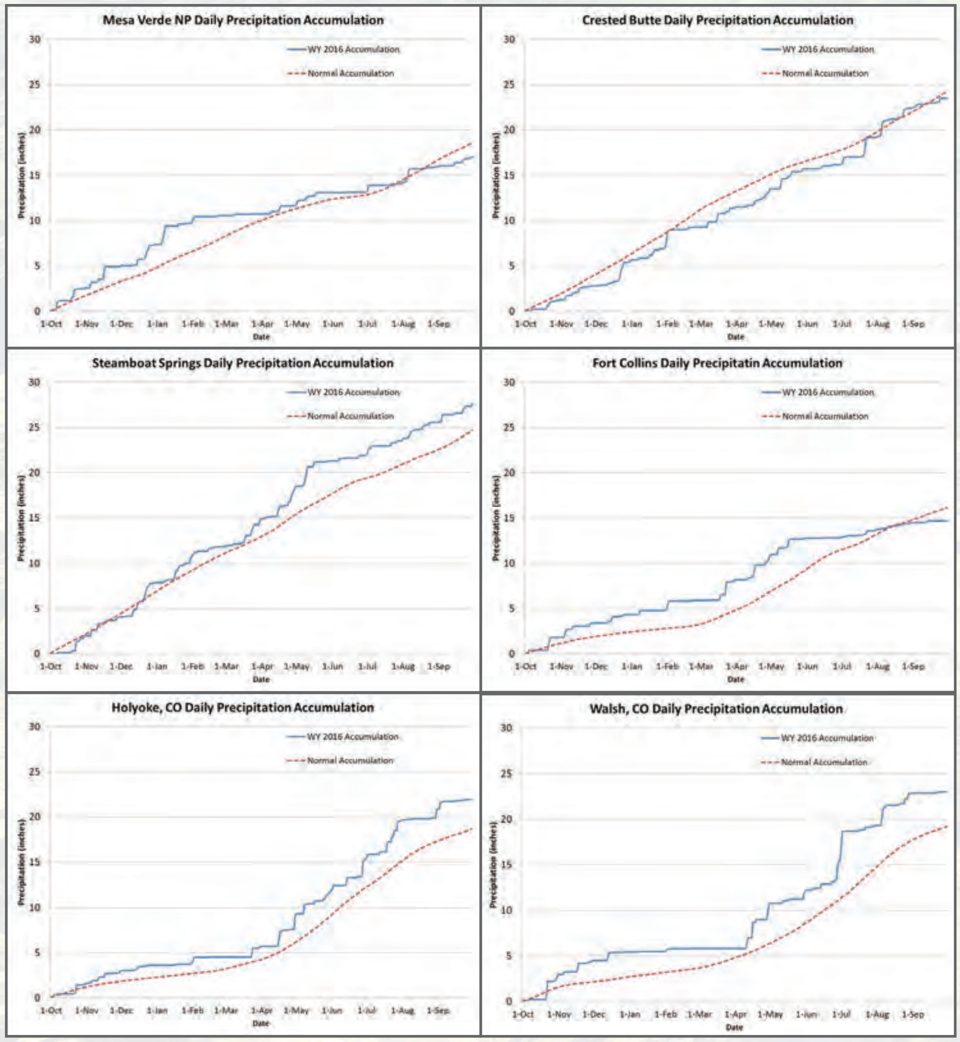


Figure 1. Accumulation of daily precipitation for the 2016 water year, (October 1, 2015-September 30, 2016) for selected stations in Colorado (Mesa Verde National Park, Crested Butte, Steamboat Springs, Fort Collins, Holyoke (NE plains), and Walsh (SE plains)). Courtesy of Colorado Climate Center.

Defining the "Water Year"

The October 1–September 30 "Water Year" calendar is often used in the West to track many aspects of climate and water resources. This calendar fits the climate of Colorado very well as it aligns nicely with the winter snow accumulation season that often begins in the mountains in October followed by the snowmelt and summer irrigation season that wraps up in September. This summary describes the general weather conditions experienced in Colorado during the 2016 Water Year—October 1, 2015 through September 30, 2016.

The Climate Situation

The climate of the Southwest received much fanfare and media attention going into the 2016 water year. The reason for this hubbub was the "super El Niño"—much above average ocean surface temperatures across the eastern and central tropical Pacific Ocean. The pattern of anomalously warm sea surface temperatures was predicted to peak in early winter and then collapse quickly during the spring. Based on similar very strong El Niño situations in 1982 and 1997, some bold forecasts were made for a very wet winter over southern California, possibly extending inland to Arizona, New Mexico, and southern Colorado. The El Niño features over the Pacific Ocean behaved very much as predicted; peaking in early winter and then cooling quickly back to more normal levels by late spring and early summer. The precipitation forecast for Colorado and the southwestern U.S., however, was more problematic. The variable

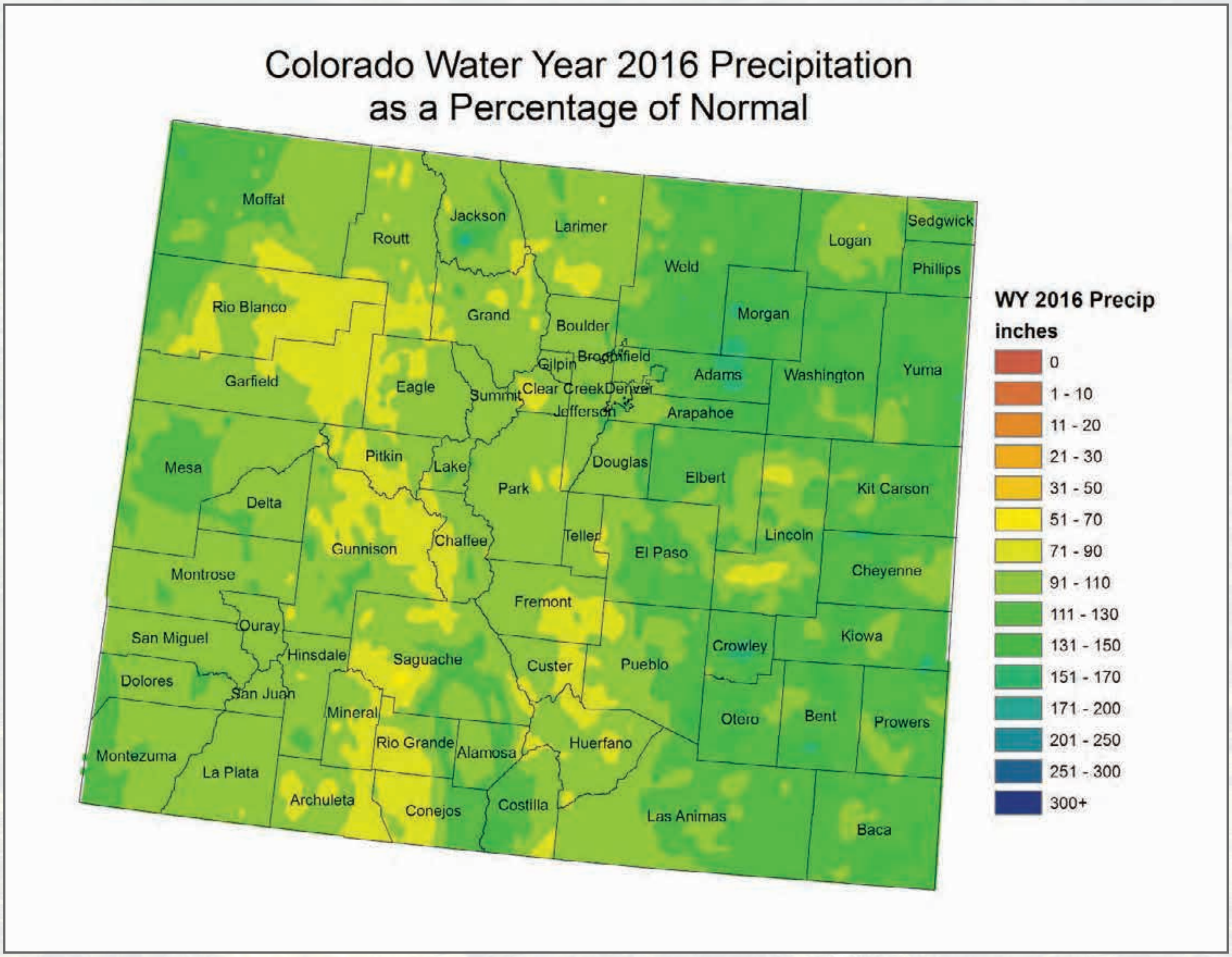


Figure 2. Precipitation for the 2016 water year, October 1, 2015-September 30, 2016, expressed as a percent of the 1981-2010 average. Graphic credit: Copyright © 2016, PRISM Climate Group, Oregon State University, http://prism.oregonstate.edu. Map created by Colorado Climate Center 4 Oct 2016.

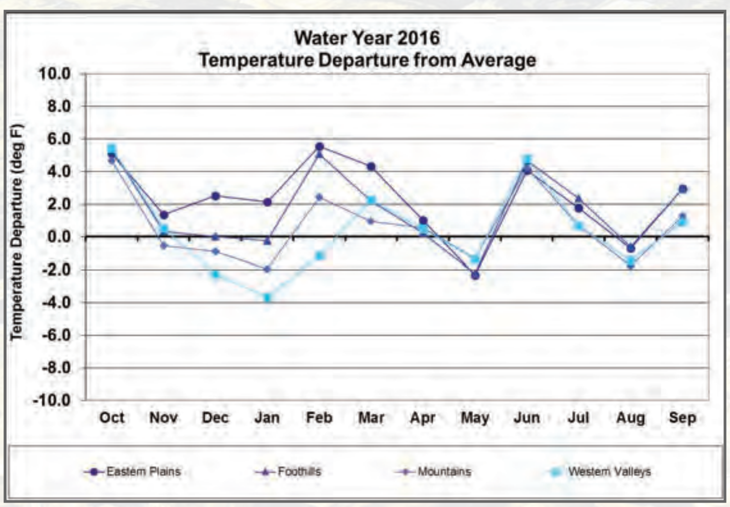


Figure 3. Monthly temperature departures (degrees F) from the 1981-2010 averages for Colorado by region of the state for the 2016 water year. Courtesy of the Colorado Climate Center.

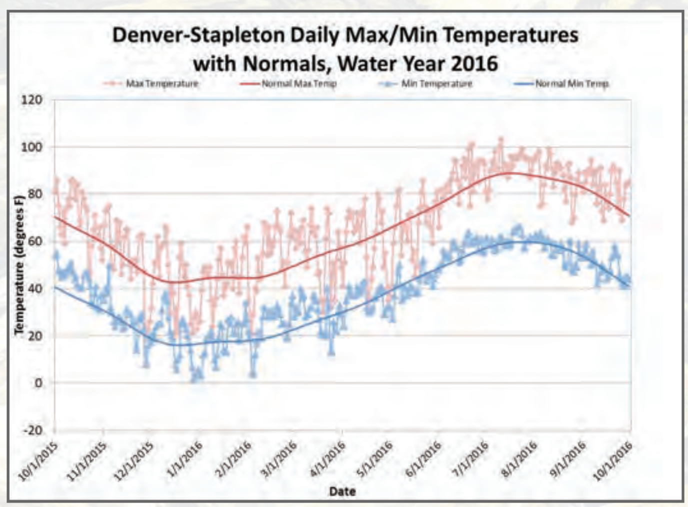


Figure 4. Daily maximum and minimum temperatures for the 2016 water year compared to 1981-2010 averages for the Denver-Stapleton climate station. Courtesy of the Colorado Climate Center.

nature of our climate does not always lend itself to successful prediction. Southern California, for example, did get off to a wet start. But the southern storm track soon fizzled resulting in yet another dry year there. Farther north and east in Colorado, there was some increase in fall and winter storminess that may have been associated with El Niño. Likewise, winter and early spring temperatures were also quite warm over the Northern Great Plains, which also aligned well with the El Niño pattern.

Precipitation

For most of Colorado, water year 2016 will not be remembered as exceptional – either on the wet or dry side. However, many areas had a good year for water resources with near to above average water year precipitation totals. As usual there were wetter regions, drier areas, some prolonged dry episodes, and a few impressive storms. For much of the Front Range, it was a snowy winter with seasonal snowfall totals exceeding 100 inches near Boulder and over 160 inches within portions of the eastern foothills. Colorado State University, for example, had two separate campus-wide snow closures – February 2 and March 23. Figure 1 shows the daily accumulation of precipitation for the year at selected locations across the state.

All areas of Colorado experienced beneficial moisture but not all at the same time. Storms first hit southwest Colorado in October. Early and mid-November brought substantial storms with rain and snow to most of the state except the Arkansas Valley. December was seasonally dry east of the mountains but quite snowy in the mountains, especially the days preceding Christmas. January brought modest snows but no major storm until the end of the month. A widespread major snowstorm hit Colorado January 31–February 2. When that storm departed on Ground Hog Day, most of the rest of February was dry. March was dry in southern Colorado, but March and April brought several storms with beneficial moisture farther north in the state. Nearly five inches of rain in one day (April 16) was measured in Kit Carson County near Burlington. Widespread storms in early and mid-May helped bolster the late season snowpack and increase water supplies but then retreated giving way to more spotty local precipitation later in the month. June was primarily dry in western and northern Colorado but quite stormy on our southeastern plains. Other than a week of concentrated monsoonal precipitation in early August, summer precipitation was light and spotty in the mountains and western slope, while frequent storms, some heavy, raked eastern Colorado. Finally, the water year ended with more summer-like storms, some bearing hail in eastern Colorado, dry along the Front Range, and fairly average on the western slope.

> **"Colorado made it through another year relatively drought free."**

For the year as a whole, most of the state was near or above average with the wettest areas, as a percent of the 1981-2010 average, on the eastern plains (Figure 2). Drier than average conditions were observed in a few areas of western and southwestern Colorado. North central Colorado and the Fort Collins area had been well on their way to a very wet year. Then, patterns changed mid-May and the final 4 ½ months were among the driest on record for the area going back over 125 years. For parts of eastern and southeastern Colorado it was just the opposite. A slower start to the year was followed by a wet summer.

Temperature

Monthly temperatures for the state expressed as departures from the 1981-2010 averages (Figure 3) show that the year began with a much warmer than average October. The eastern plains remained warmer than average throughout the winter months but with occasional seasonally cold episodes (Figure 4). Note that the minimum temperature never dropped below zero degrees Fahrenheit at any time last winter – not common but not unprecedented. Meanwhile the mountains and western valleys experienced colder than average December and January weather. Several locations in mountain valleys experienced low temperatures of -30° F or colder at the end of December and the first few days of January. February was warmer than average except in some mountain valleys where cold pockets lingered. March was also above average as was early April. Late April and May however, were chilly, helping to slow the mountain snowmelt and delay the need for irrigation water. Summer came on hard and fast with hotter than average temperatures statewide. July, the climatologically hottest month of the year, lived up to expectations but did not include any extreme heatwaves. August brought cooler relief to late summer, and September was again warmer than average as it has been now for several years in a row.

Soil Moisture

We are working to build a Colorado soil moisture monitoring network, but it is not yet complete. Based on a few existing stations, areas of Colorado enjoyed excellent soil moisture conditions going into the winter within areas that received plentiful fall moisture. Winter snowpack and April-early May precipitation further bolstered soil moisture conditions. As expected, warm temperatures and plant growth quickly depleted soil moisture in the mountains in June and July, while storms on the plains continued to replenish moisture used for evapotranspiration. As of late September, however, soil moisture had dropped again to the wilting point in some areas of northern Colorado such as Larimer County and the northern mountains. Much of the eastern plains had dried near the surface but still had good root zone soil moisture. One of the outcomes of this progress was a very good winter wheat crop in eastern Colorado followed also by good summer dryland crops. Some areas had dried out for fall planting of the 2017 winter wheat crop resulting in some angst in the agricultural communities.

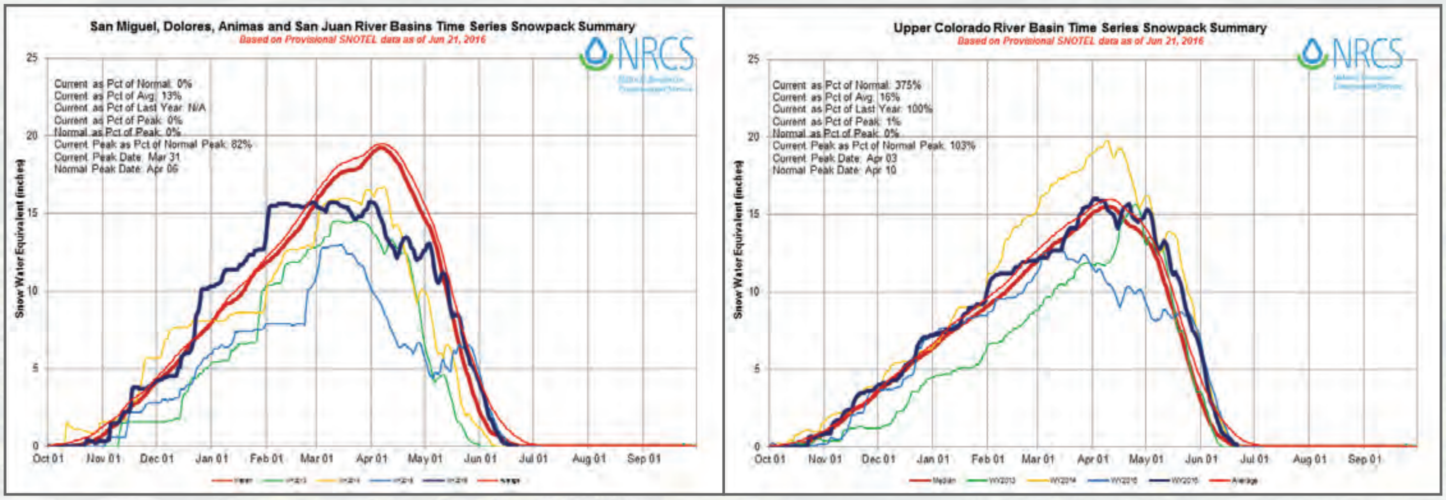


Figure 5. Daily accumulation and melt of snow water content for the 2016 water year compared to average and recent years for Colorado's Southwestern Mountains (left) and for the headwaters of the Colorado River (right). Credit: NRCS Colorado Snow Survey Program.

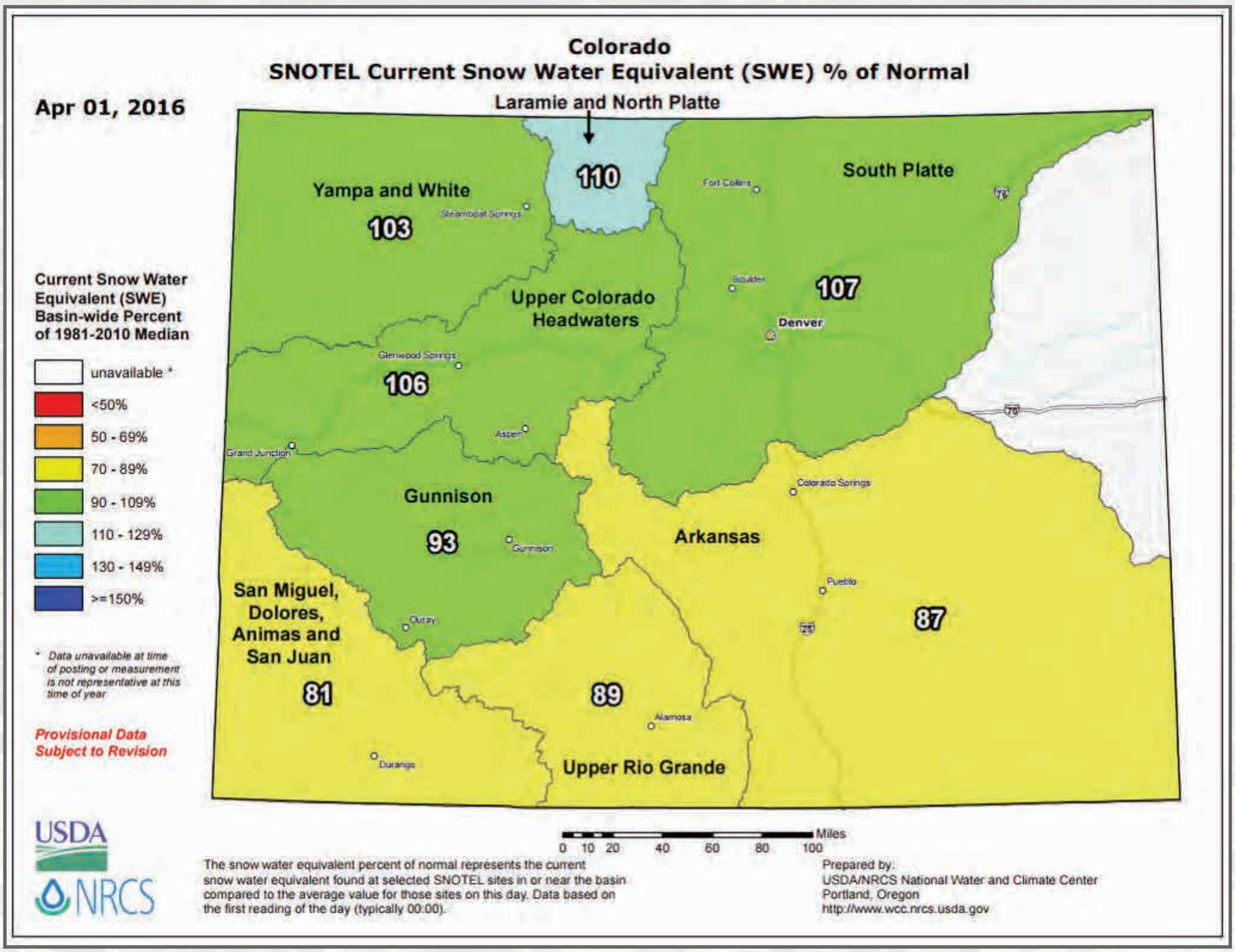


Figure 6. April 1, 2016 snowpack water content as a percent of average by drainage basin. Credit: NRCS National Water and Climate Center, Portland, Oregon.

Snowpack Accumulation and Snowmelt

Colorado's southern mountains got off to a typical start to the snow season and by November and December seemed to be following the "super El Niño" forecast for a big snow year for that region. After a few modest early winter snows, a timely pre-Christmas week-long snowy period coated nearly all the mountain resorts and made for a post-card perfect start to the holiday season. Regular but smaller storms arrived in January. One brief but potent storm January 31-February 2 gave the mountains a huge boost. This was followed by several weeks of drier weather, especially for our southern mountains. By April 1st, the southern mountains had fallen to only about 80-90% of the seasonal average snowpack water content while northern Colorado continued to track above average (Figure 6). Colorado's northern mountains tracked surprisingly close to their long-term average snow accumulation all winter. April and early May contributed additional beneficial precipitation. Snowpack reached peak levels for the year and began melting out earlier than historic averages in southern Colorado but at fairly typical times for the northern and central mountains. There were dust layers deposited this winter on the snowpack, but this appeared to only be a major factor for snow hydrology in the southwestern-most mountain ranges.

Streamflow

Streamflow volumes for the year ended up surprisingly close to the long-term average over most of the state – both east and west of the mountains (Figure 7). Going into the spring snowmelt, base flows were below average in southwestern Colorado, near average in western and northwestern Colorado, and still above average in northeast Colorado–continuing a trend that started with the September floods of 2013. As expected for a snowmelt driven region, the bulk of the annual streamflow was compressed into about two months starting in late March and April in extreme southern Colorado and running from mid-May through mid-July in streams coming out of northern mountains and highest elevation mountain ranges. Summer rains usually contribute, but not greatly to annual flows. This year, one monsoonal surge of moisture in early August was sufficient to increase streamflow, especially in southwestern Colorado.

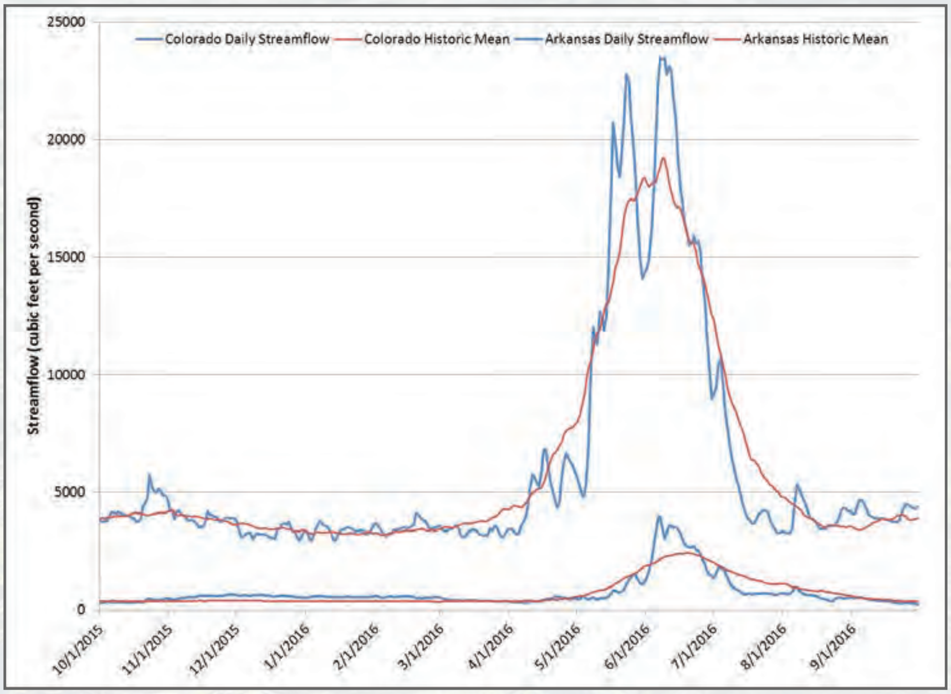


Figure 7. Daily streamflow for the 2016 water year for the Colorado River near the Colorado-Utah state line (top group) and for the Arkansas River at Canon City (bottom group). Data source: U.S. Geological Survey (Colorado River at Stateline) and Colorado Division of Water Resources (Arkansas River at Canon City). Graphic created by Colorado Climate Center.

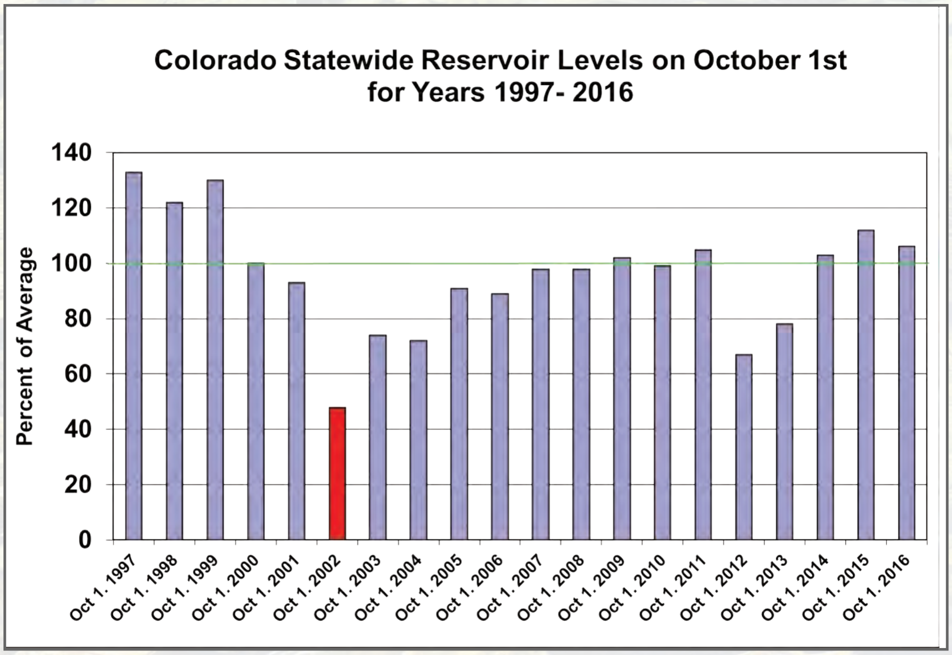


Figure 8. Time series of statewide reservoir storage in Colorado as a percent of average, 1997–2016. Data source: NRCS Colorado Snow Survey Program. Graphic created by Colorado Climate Center.

Evapotranspiration

Evapotranspiration (ET) rates from fully watered grass and alfalfa fields in 2016 were near average to a bit less than average this summer. This assessment is based on weather stations from the Colorado Agricultural Meteorological

Network (CoAgMet). While temperatures were above average in June and July, especially east of the mountains, this was offset by higher summertime humidity and afternoon cloud development. This is the second consecutive year with higher than average summer temperatures but below average reference ET rates. Lower reference ET rates mean that irrigation water demand was not stressed.

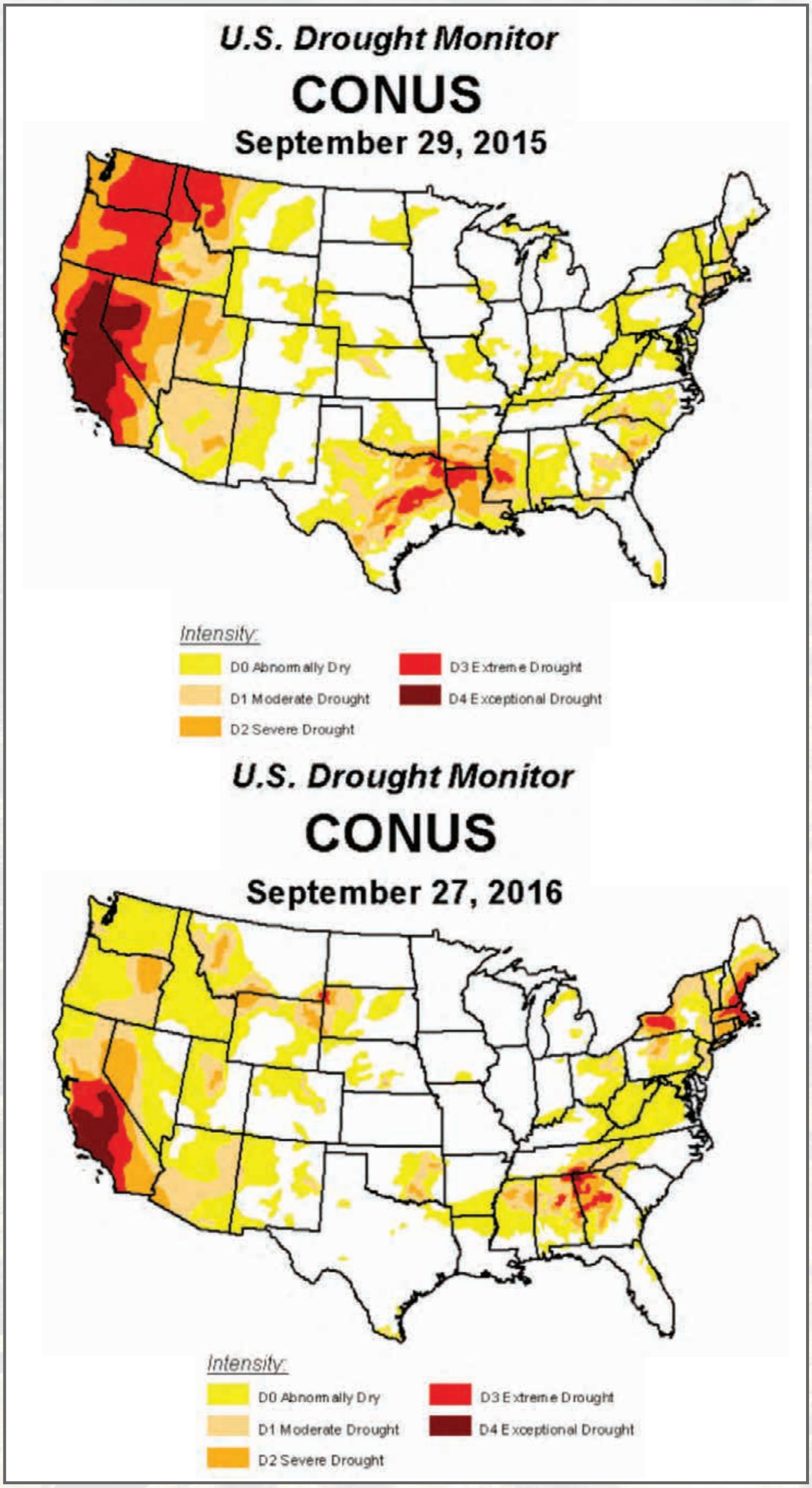


Figure 9. U.S. Drought Monitor at the beginning (top) and end (bottom) of the 2016 water year. Weekly update maps, 1999–present, are available from the National Drought Mitigation Center at the University of Nebraska, Lincoln at http://droughtmonitor.unl.edu. Courtesy of the National Drought Mitigation Center.

Reservoir Storage

2016 was characterized by healthy amounts of reservoir storage. This continues a trend that began with the floods and subsequent high stream flows since September 2013. Reservoirs are not all managed the same way or for the same purposes, making it hard to generalize. Reservoirs used primarily for municipal uses are managed differently than reservoirs used primarily for irrigated agriculture. Overall, the year started with more reservoir storage than average for October. Snowmelt was sufficient, along with spring rains, to fill most of the state's reservoirs in May and June. Then, although summer demand was modestly high, most reservoirs ended the water year near or still a bit fuller than average. After bottoming out after the 2002 drought (Figure 8), it took several years for Colorado's larger reservoirs to recover. Reservoir levels since the fall of 2013 have been in good shape. 2016 year-end storage averaged across the state is again above average and nearly the best they have been since the late 1990s. Since drought may be lurking right around the corner at any time, maintaining strong reservoir storage provides water managers a satisfying margin of safety for an uncertain future. That is certainly the case again this year.

The Year in Historical Perspective

Colorado made it through another year relatively drought free. The year started with some dryness, mostly on the eastern plains (Figure 9). Fall rains and winter/spring snows erased most of that minor dryness. As summer 2016 progressed, dryness increased in the

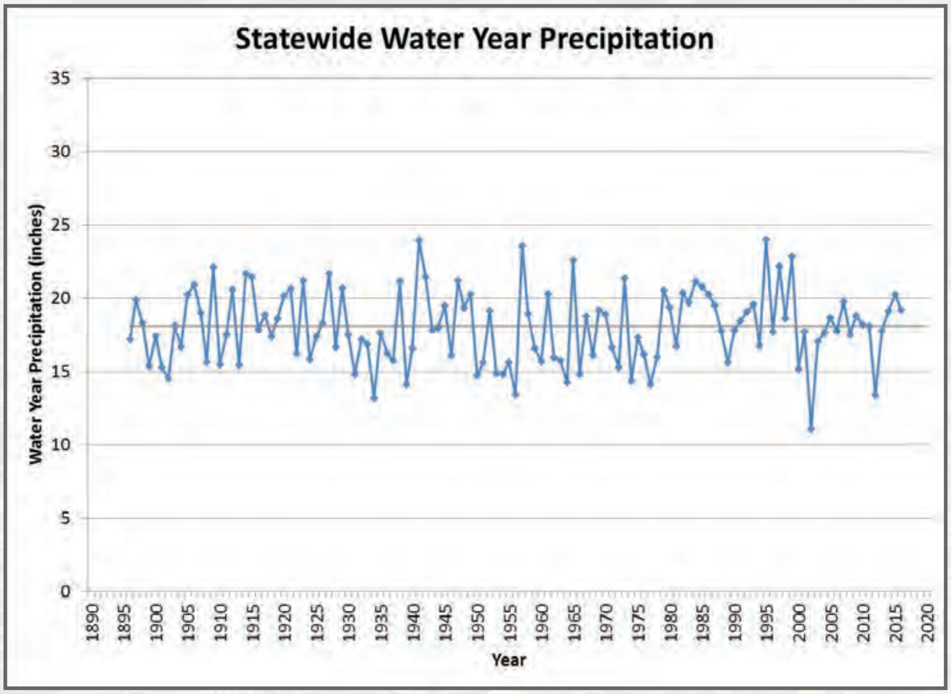


Figure 10. Water year precipitation average across the state. The light grey line is the 1901-2000 average, 18.10 inches. Data source: National Centers for Environmental Information, Climate at a Glance: U.S. Time Series, Precipitation, published October 2016, retrieved on October 6, 2016 from (http://www.ncdc.noaa.gov/cag/). Graphic created by Colorado Climate Center.

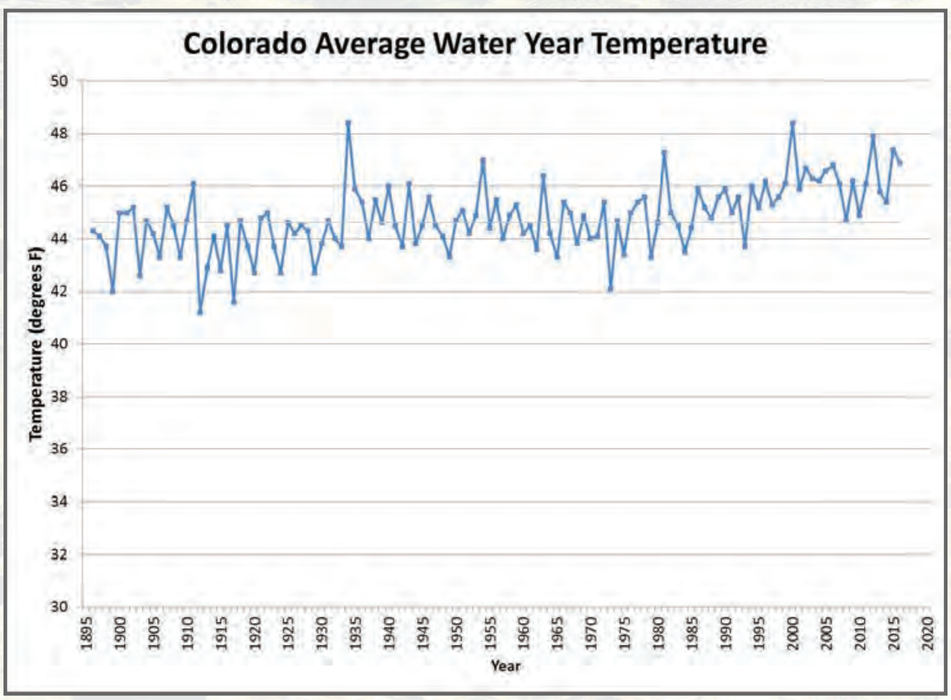


Figure 11. Average water year temperature average across the state. The light grey line is the 1901-2000 average, 44.6°F. Data source: National Centers for Environmental Information, Climate at a Glance: U.S. Time Series, Temperature, published October 2016, retrieved on October 6, 2016 from (http://www.ncdc.noaa.gov/cag/). Graphic created by Colorado Climate Center.

northern mountains, the Front Range and parts of northwestern Colorado. A small band of D1 (moderate drought) developed by late summer along the Colorado Front Range urban corridor. While concerning, compared to recent dry years such as 2012, when drought conditions were severe and widespread, this recent dryness is minor. It does open the door, however, to water resources challenges if snows this coming winter (2017) falls short in the Colorado high country.

Temperatures statewide ended up higher than average for the year despite some very cold mid-winter temperatures in Colorado's western valleys (Figure 11). It is not equally apparent at each individual weather station in Colorado, but these composite annual temperature statistics continue to show a noticeable warming trend. It has now been over 20 years since a year has been cooler than the 1901–2000 average in Colorado. Statewide, the past two decades have been about two degrees Fahrenheit warmer than the pre-1990s period based on this temperature index. Precipitation for water year 2016 when averaged across the state totaled 19.19 inches. This is one inch greater than the long-term statewide mean (Figure 10) and is now the 3rd year in a row that has ended up on the wetter side of average.

Summary

Water year 2016 did not break any records. It was unique as are all years, but not exceptional in terms of anomalies and extremes. Every year where water supplies are adequate and year-end reservoir storage is near average, is a good year. So let us celebrate a good year.

Acknowledgement

The Colorado Climate Center at Colorado State University is supported by the Colorado Agricultural Experiment Station through the CSU College of Engineering. The Colorado Climate Center was established with CAES support in 1974.

Faculty PROFILE

Steven Fonte

Steven Fonte, Soil and Crop Sciences, Colorado State University

Agricultural systems around the globe face increasingly complex challenges as they are pushed to keep pace with growing demands on food production, while up against increasing climate variability and associated limitations in water. At the same time, farmers are under pressure to improve resource use efficiency to remain competitive and limit the negative impacts of excess nutrient, water and energy consumption. While these varied and growing demands on agriculture are daunting, they are not insurmountable. However, to address these challenges we need to develop new approaches for managing and evaluating the performance of agroecosystems that consider a range of productive and environmental functions within agricultural landscapes and meet the diverse needs of farmers and society.

Since joining the Department of Soil and Crop Sciences at CSU just over a year ago, I have been working to build a research program that broadly addresses issues of farm management and agricultural sustainability. More specifically, my research focuses on managing soils, nutrients and water to support long-term productivity and other ecosystem services expected from agricultural lands. This work began during my PhD at UC Davis, where I examined the effect of different soil management options (e.g., organic vs. conventional agriculture, mulching vs. burning of residues) on earthworms, soil structure, and nutrient cycling, both in high-input tomato farms of California as well as in subsistence farming systems in the mountains of Honduras. I then moved to the International Center for Tropical Agriculture (or CIAT, based on the acronym in Spanish) in Cali, Colombia, where I worked closely with farmers across diverse agricultural contexts and in multiple continents to improve yields and the provision of ecosystem services on their farms. In one example, I worked with smallholder farmers in Uganda on nutrient management strategies that enhance the profitability of market vegetable production, while helping to restore soil organic matter and long-term soil fertility.

Recognizing water as the most important constraint for agriculture globally, much of my research focuses on how farm management impacts the movement, capture and availability of water in soils. For example, I'm currently working on projects in El Salvador and Peru to understand how different smallholder management practices (e.g., agroforestry, improved pastures) within hillside farming systems impact soil biodiversity and a range of ecosystem services, including water capture and erosion control. Closer to home, my lab is involved in efforts to explore the impact of cover crops/forages on soil quality in dryland wheat systems of Colorado, and potential tradeoffs in water storage and availability. In addition to rainfed agriculture, we recently embarked on a new project (supported by the CSU Water Center) to examine the influence of limited irrigation strategies on soil microbial communities, C sequestration and greenhouse gas emissions. A common theme through all of my research is to understand linkages between management, soil organisms (earthworms, microbes, plants, etc.) and key soil processes associated with carbon and nitrogen cycling, water dynamics and impacts on soil structure.

Involvement of students and diverse stakeholders in the research process is a priority in my work. This translates into participatory research with land managers at various levels of involvement, so as to facilitate the development of more relevant research objectives and greater impact from this work. I also strive to engage students in agricultural and ecological research - in the laboratory, field and classroom, as this offers an important means to share key lessons and promote interest in a variety of agricultural contexts. Strong and effective engagement helps to better train the next generation of land managers, researchers, and policy makers in scientific literacy and, ultimately, results in better informed decision making across multiple sectors of society.

While still relatively new at CSU, I am very excited by all the great work I see going on around me and am thrilled to be part of this institution. I look forward to meeting with many of you in the future and collaborating across multiple colleges on campus and beyond.

Steven Fonte

Assistant Professor

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Colorado State University

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Water Research Awards June 13, 2016 - September 13, 2016

Cooper, David Jonathan, Forest and Rangeland Stewardship, U.S. Department of the Interior, National Park Service, Seeps and Springs of Colorado National Monument: Ecology and Visitor Impact Assessment, $10,000

Evangelista, Paul H., Natural Resource Ecology Laboratory, U.S. Department of the Interior, U.S. Geological Survey, Mapping, Forecasting, and Simulating Invasive Species and their Impacts on Natural and Social Systems, $281,042

Kendall, William L., Cooperative Fish and Wildlife Research, U.S. Department of the Interior, U.S. Geological Survey, Fish Population Models for the Little Colorado River from Integrated Data Sources, $62,567

Rathburn, Sara L., Geosciences, U.S. Department of the Interior, National Park Service, 2016 Electrical Resistivity Imaging for Phase 1 Effectiveness Monitoring: Upper Colorado River, Rocky Mountain, $2,401

Ronayne, Michael J., Geosciences, Vorra Companies, Investigating the Influence of Lined Sand and Gravel Pits on Shallow Aquifers with Application to Alluvial Deposition, $20,207

Sale, Thomas C., Civil and Environmental Engineering, Hemenway Groundwater Engineering Inc., Fort Collins Bedrock Subsurface Water Storage Opportunities, $25,000

Photo by Stacy Lynn

This photo is from Research Scientist Stacy Lynn's trip to Turkana, Africa. For more information please refer to the article on page 2.

Water Calendar

December

12-16 **2016 AGU Fall Meeting; San Francisco, CA**
fallmeeting.agu.org/2016/

14-16 **Colorado River Water Users Association Annual Conference; Las Vegas, NV**
crwua.org/

January

12-13 **Colorado Water Well Contractors Association Annual Conference; Denver, CO**
cwwca.org/

25-27 **Colorado Water Congress Annual Convention; Denver, CO**
cowatercongress.org/annual-convention.html

31-Feb. 1 **29th Annual High Plains No-Till Conference; Burlington, CO**
highplainsnotill.com/conference/registration.html

February

3 **Poudre River Forum; Greeley, CO**
cwi.colostate.edu/ThePoudreRunsThroughIt/forum_2017.shtml

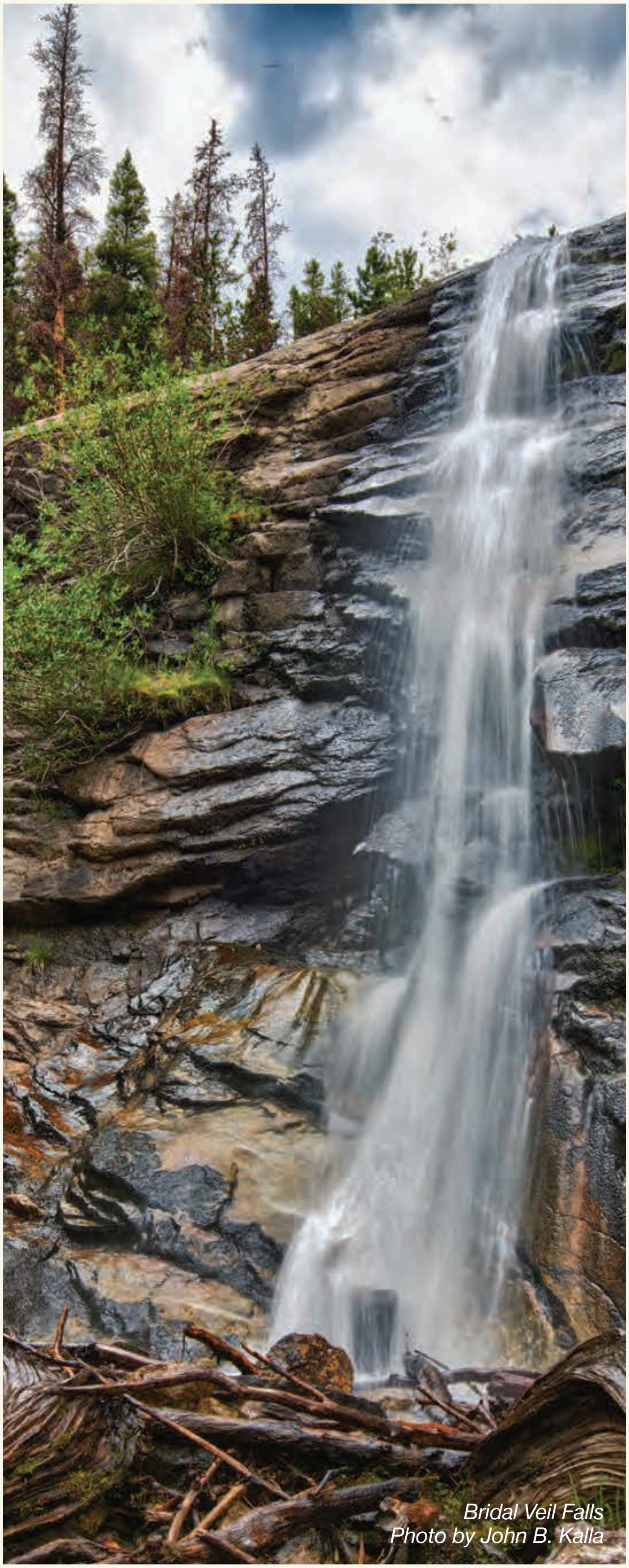
8 **Thirsty Land Film Screening; Fort Collins, CO**
http://watercenter.colostate.edu/calendar.shtml

7-9 **Tamarisk Coalition's 14th Annual Conference; Fort Collins, CO**
tamariskcoalition.org/about-us/events/2017-conference-call-papers

13-16 **Colorado Rural Water Association Annual Conference and Exhibition; Denver, CO**
coloradoruralwater.sharepoint.com

22 **Colorado Governor's Forum on Colorado Agriculture; Denver, CO**
governorsagforum.com/

For more events, visit www.watercenter.colostate.edu



Bridal Veil Falls
Photo by John B. Kalla

Colorado State University

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Colorado Water is financed in part by the U.S. Department of the Interior Geological Survey, through the Colorado Water Institute; the Colorado State University Water Center, College of Agriculture, College of Engineering, Warner College of Natural Resources, Agricultural Experiment Station, and Colorado State University Extension.

Lizard Lake
Photo by John Fowler