Colorado Water

September/October 2017

CSU WATER CENTER
2017 PROJECTS

Colorado State University

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Photo by Michael Levine-Clark

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COLORADO **WATER**

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Director's LETTER

The goal of every issue of the *Colorado Water* newsletter is to communicate current water research to a broader audience. It is not enough to conduct sound scientific research; to have real impact we must effectively communicate our results to other scientists and stakeholders. Yet, it has been said that we are now living in a post-truth world where opinion is valued over fact. Others have observed there is a war on science underway, evidenced by recently discontinued federal research projects and appointments of people with limited credentials to important scientific jobs. The legitimacy and objectivity of scientists and the scientific process is under fire from some quarters.

The benefits of scientific discovery permeate modern society. But the public and many decision makers misunderstand the process of science. Science is a systematic search for deeper knowledge of our world. Single experimental results are interesting, but it is the iterative process of systematic observation, measurement, and experimentation that builds the body of evidence that moves us along the continuum from hypothesis to established principle.

We are in a time of fake news and alternative facts where various spokespersons often with little scientific background discount research findings that do not fit their world view, undermining public trust in scientific research. It seems you can find an authoritative opinion on the Internet or cable news that provides "factual" support for almost any stance you choose to take. Part of the cause of this post-truth phenomenon may simply be the overload of crowd-sourced information in the digital age. Disbelief in established scientific principles and the spread of alternative facts is not a new phenomenon. It was not long ago that certain corporations hotly debated whether smoking was harmful. Today we debate the greenhouse gas effect, safety of pipelines, benefits of vaccines, fluoride, and genetically modified organisms, among other things. While civil discourse and debate are healthy, sizeable fractions of the public persist in holding views that are contrary to the weight of considerable scientific evidence. Why? And what role does the research community play in this credibility gap?

Social science research shows that facts do matter and that they do have persuasive power—but only if they are well framed. In his book, "Thinking, Fast and Slow", Nobel Laureate Daniel Kahneman explains that humans process facts in the fast and semi-automatic way that the brain takes in new information, fitting unframed facts into their existing worldview or simply ignoring them if deemed irrelevant. Kahneman argues that framing facts around values or solutions can move people toward the slower, more conscious way of thinking that may allow integration of new or even contradictory views. The more highly charged or politically polarized the debate, the greater the challenge in communicating scientific findings. When emotions are high, human hearing and comprehension are compromised. Arrogance, real or perceived, seldom improves communication.

To overcome the current trend of subjective selection of facts, researchers must improve their ability to communicate beyond their discipline. It is not effective to simply dismiss science deniers as ignorant; we must understand that most of the public is not trained to understand science or the scientific process. And we all tend to take in new information and assimilate facts in a way that supports, or at least does not threaten, our existing worldview and values.

I submit that we are not in a post-truth world. Proven, objective facts still matter and researchers must work to communicate effectively and objectively. Communications research has shown that simply reciting the facts in polarized debates is seldom effective in changing minds. Subject matter experts must bring objective information to the public dialog, but they should also bring humanity and empathy, particularly in politically charged debates. It is through sustained engagement, listening and seeking to understand that we build relationships and trust. Public trust for science hinges on whether the public trusts scientists.

Reagan Waskom
Director, Colorado Water Institute

2016 - 2017 CSU Water Center Competitive Grants Recipients

Each year the CSU Water Center funds Interdisciplinary Research Teams, Faculty Fellows, and Symposium Planning grants which catalyze transformative water research, teaching, and engagement through collaboration and creative scholarship among CSU faculty and students. These awards provide unique opportunities to accelerate progress in research and enable the academic and experiential realm of water resources for faculty and researchers. A request for proposals is released at the beginning of each spring semester.

Visit www.watercenter.colostate.edu for more information.

Multi-Disciplinary Research/Proposal Teams

- *New Frontiers in the Nexus of Food, Energy, and Water Systems: Exploring Food Crop Uptake of Contaminants from Oil & Gas Wastewater*
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- *Evaluating Alternative Water and Nutrient Management Strategies as Climate-Smart Agricultural Options for Colorado and Beyond*
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- *Evaluating the Energy Cost of Groundwater Production in the Denver Basin Sandstone Aquifers*
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- *One Health Surveillance of Antimicrobial-Resistant Bacteria in Fort Collins, CO*
  Elizabeth Ryan, Richard Bowen, Susan De Long, and Charles Henry
- *Investigation of the Effects of Whitewater Parks on Native Fishes in Colorado: A Novel Two-Dimensional Modeling Approach*
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Faculty Fellow

- *Toward a Quantitative Estimate of Organic Carbon Storage in River Corridors of the United States*
  Ellen Wohl

Fall 2016 CSU Campus Symposium

- *Subsurface Water Storage*
  Tom Sale, Michael Ronayne, Ryan Bailey, and Sally Sutton

Evaluating the Energy Cost of Groundwater Production in the Denver Basin Aquifers

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Tom Sale, Department of Civil & Environmental Engineering, Colorado State University;
Jordan Suter, Department of Agricultural & Resource Economics, Colorado State University;
Daniel Shugert, Natural Resources Management, Colorado State University

SYNOPSIS

Groundwater is a crucial resource across the semiarid landscapes of the western U.S. Constant pumping of groundwater can result in depleted aquifer levels, requiring further energy to extract the water to the surface. This research study focused on assessing the energy use for municipal groundwater pumping within the Denver Basin Aquifer System and indicating which best management practices can help reduce the amount of energy needed for groundwater pumping. We discovered that the energy intensity values in the Denver Basin wells were higher than published energy use rates related to groundwater pumping.

Introduction

Groundwater pumping can be a substantial source of energy expenditure during water production, particularly in semiarid regions like the western U.S. where large depths to groundwater are commonly encountered. Persistent pumping from wells causes aquifer water levels to decline, requiring greater lifts and thus heightened energy input to bring the water to the surface. This project investigated the energy requirement for municipal groundwater pumping in the Denver Basin Aquifer System (Figure 1), an important water resource in Colorado. There are over 800 active municipal wells in the Dawson, Denver, Arapahoe, and Laramie-Fox Hills aquifers (the four

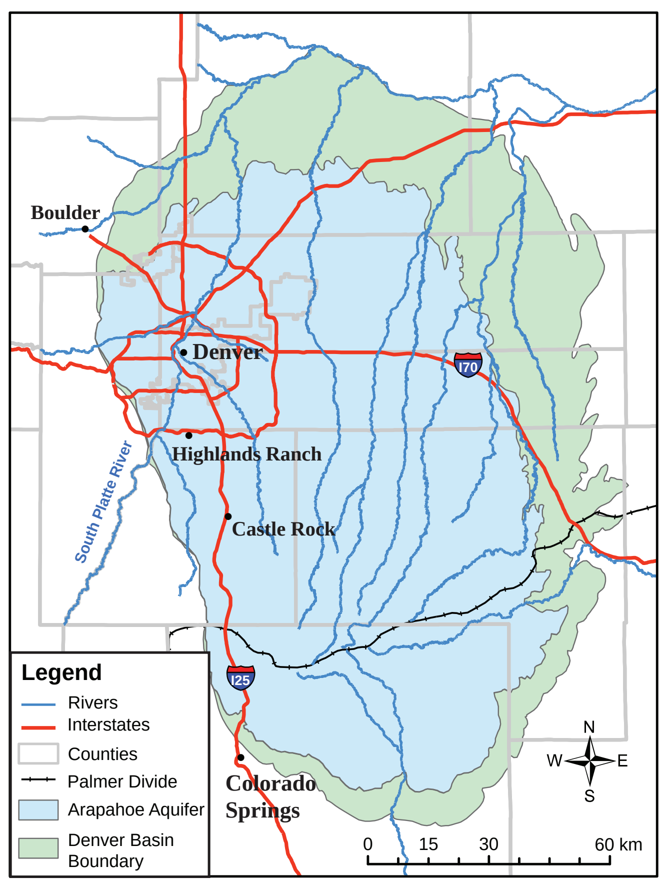

Figure 1. Map of the study area.

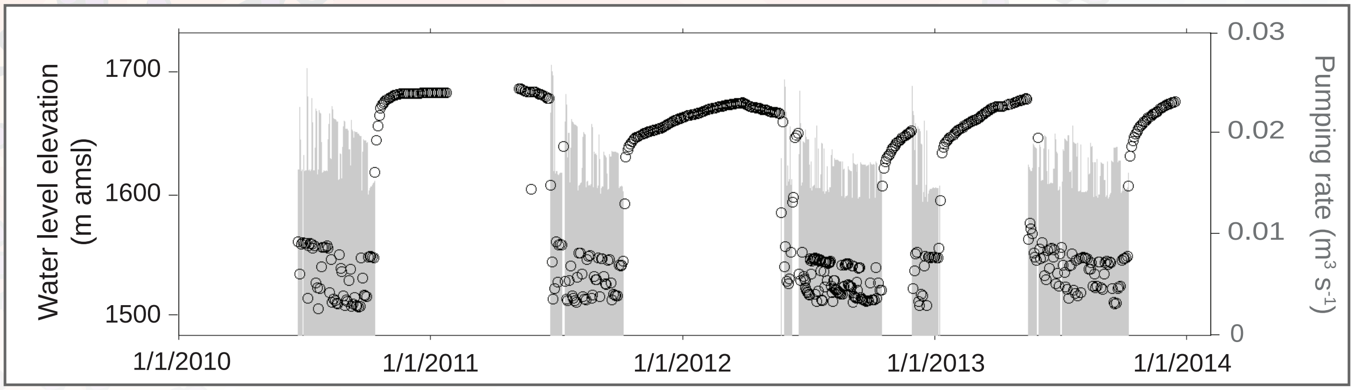

Figure 2. Example data for a municipal well in the Denver Basin. The wellhead elevation is 1,920 meters above mean sea level (m amsl), indicating water depths ranging from 230 to 420 m below ground surface. Measured water levels are shown as open circles; pumping rates are shown as grey bars.

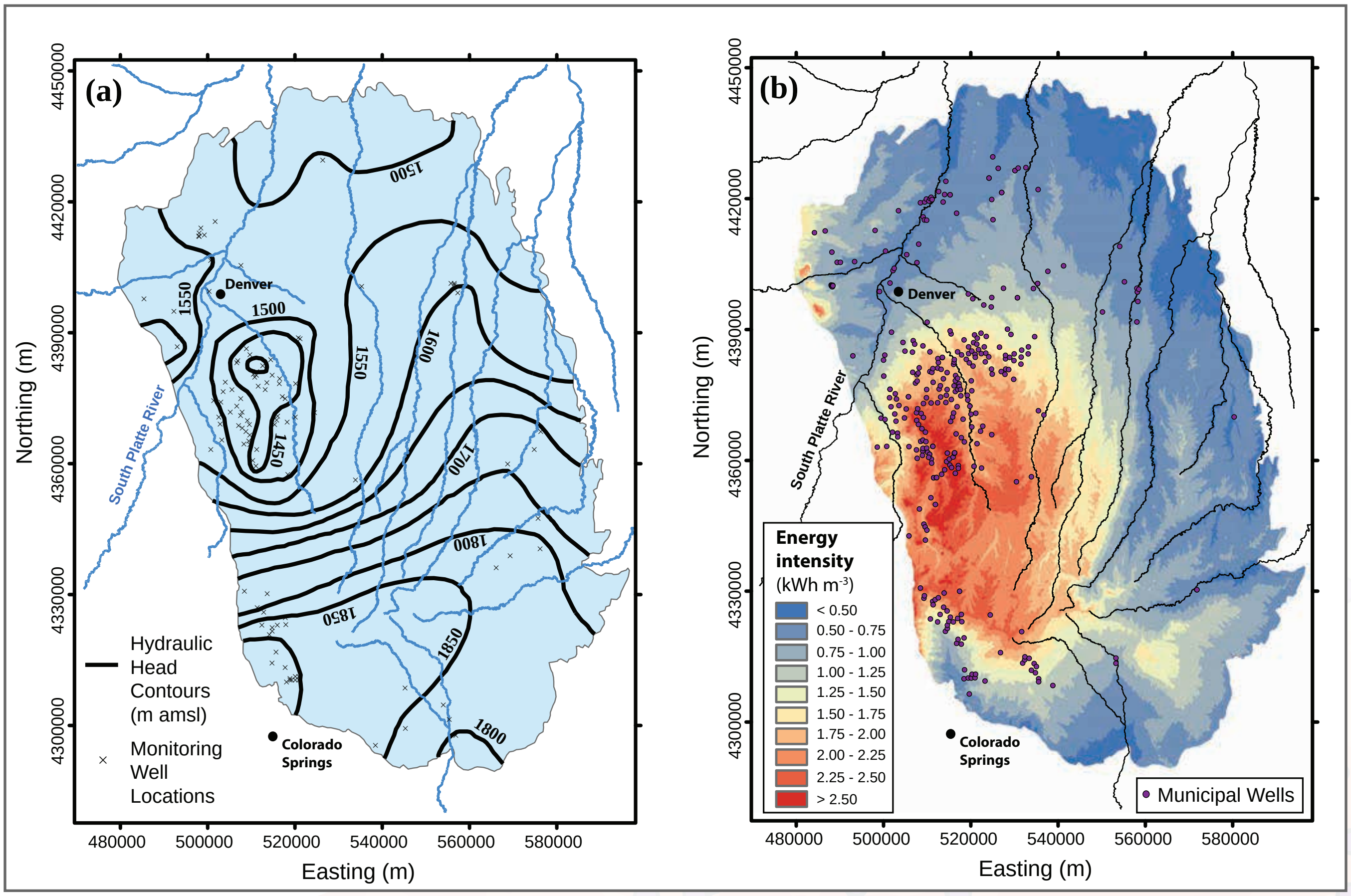

Figure 3. (a) Arapahoe Aquifer potentiometric surface map and (b) estimated energy intensity for groundwater pumping in the Arapahoe Aquifer. Circles represent active municipal wells.

sedimentary rock aquifers that comprise the Denver Basin Aquifer System). Decades of pumping from these aquifers has resulted in falling water levels and a coincident increase in the amount of energy required to produce water. The objectives of this study were as follows: (i) to quantify spatially variable energy intensity and estimate total energy use for municipal groundwater pumping in major aquifers of the Denver Basin; and (ii) to identify management strategies that can be used to reduce lifts and therefore decrease the amount of energy required for groundwater pumping.

Methods and Data Sources

Municipal well data were obtained from the Colorado Division of Water Resources HydroBase database. Although we analyzed data from multiple aquifers, this article focuses on the Arapahoe Aquifer, which is characterized by the highest groundwater withdrawals.

The energy required for groundwater pumping is proportional to the lift, which can be approximated as the difference between the land surface and the water level elevation in the well. Specifically, the lift is the non-pumping depth to water (DTW) plus the total pumping-induced drawdown in the well. Figure 2 illustrates how the drawdown during pumping can exceed 100 m for a typical municipal well. During periods of active pumping, the water level elevation is ~1525 meters above mean sea level (m amsl) at this well. The water level recovers to near 1700 m above mean sea level when the pump is shut off. To analyze spatially variable DTW, we interpreted the aquifer hydraulic heads using (nonpumping) monitoring well data. The resulting potentiometric surface (Figure 3a) was subtracted from the land surface elevation to estimate DTW across the aquifer. We calculated the energy required to produce a unit volume of groundwater (energy intensity in kWh m^{-3}) using a standard relationship that considers the lift, weight of water, and pump efficiency.

Results and Discussion

Hydraulic heads in the Arapahoe Aquifer range from 1,400 to 1,900 m above mean sea level. The potentiometric surface map (Figure 3a) reveals a large cone of depression in the South Metro area, a consequence of historical pumping in that region. Estimated energy intensity across the aquifer is shown in Figure 3b. In the area between Denver and Colorado Springs, where most municipal pumping occurs, energy intensities typically range from 1.0 to 2.5 kWh m^{-3}. For a single well producing at a pumping rate of 0.017 m^3 s^{-1} (265 gpm, the average for Arapahoe Aquifer municipal wells), an energy intensity of 2.0 kWh m^{-3} translates into 1.06×10^6 kWh yr^{-1}. Given that this example well provides enough water to supply 540 households in this part of Colorado, the energy cost associated with lifting water is 5.4 kWh day^{-1} per household, approximately 25% of the average electricity consumption for household end uses. Summed over all active wells in the Arapahoe Aquifer, the total energy required for municipal groundwater pumping was approximately 1.1×10^8 kWh yr^{-1}, which is comparable to the average annual electricity use for 15,000 households. We note that these values only consider the energy required to lift water. Other factors, such as frictional losses within each pipe, further increase the energy cost during groundwater production, and additional energy is required for treatment and distribution of water.

The energy intensity values estimated for Denver Basin municipal wells are significantly higher than other published energy use rates for groundwater pumping. Previous studies of energyforgroundwater in the agricultural sector have reported intensities below 0.8 kWh m^{-3} for irrigation wells, despite lower pump efficiencies for those wells. A study of municipal wells in Ontario, Canada, found a median energy intensity of 0.63 kWh m^{-3}, with less than 20% of wells having values above 1.0 kWh m^{-3}. The large lifts that generate high energy intensity in the Denver Basin Aquifer System are primarily attributable to two factors: (i) the relatively low transmissivity and storativity of these bedrock aquifers produces large drawdowns during pumping (e.g., Figure 2), and (ii) decades of groundwater pumping has resulted in lowered hydraulic heads. Prior to 1950, high pressures in some areas of the Arapahoe Aquifer supported flowing artesian wells. Since then, groundwater pumping has caused substantial reductions in hydraulic head (and therefore heightened lift) throughout much of the basin.

Given the large energy requirements associated with groundwater pumping documented in this research, it is important to consider the financial cost and greenhouse gas emissions associated with groundwater production. Considerable financial savings could potentially be achieved if groundwater pumping could be shifted away from times when the marginal cost of electricity generation is highest, for example, during peak-load times on hot summer afternoons. Similarly, it may be possible to reduce the carbon footprint associated with groundwater use in the region by explicitly considering spatial and temporal differences in the greenhouse gas intensity of the electricity generation mix. Although the current fuel source mix for electricity generation in Colorado is dominated by coal and natural gas, increasing groundwater use during times and locations where the electricity grid is more likely to be powered by renewable sources may offer opportunities to reduce the overall carbon intensity of groundwater use in the region. The financial and greenhouse gas savings associated with reduced electricity use also offer another benefit associated with municipal water conservation that reduces the demand for pumped groundwater.

Importance of Well Maintenance and Rehabilitation

Well efficiency is a key factor that influences energy expenditure during groundwater pumping. No well is perfectly efficient. Disturbance of the aquifer formation during drilling, along with potential turbulent flow through the well screen, results in additional drawdown (well losses) at the well during pumping. Figure 4a shows example modeling results for a municipal well in the South Metro region. To reproduce observed water levels in the well, the model requires inclusion of a well-loss effect, indicating that the water level in the well is significantly lower than the hydraulic head in the adjacent aquifer formation. For this example, the well-loss effect generates ~ 50 m of additional drawdown during pumping (Figure 4a). This is 15% of the total lift and therefore 15% of the total energy required to bring water to the surface.

Over time, well efficiency inevitably declines, often a result of physical, chemical, or biological clogging. Well rehabilitation maintains the pumping capacity and can reduce the drawdown due to well-loss effects. Our work emphasizes that timely well rehabilitation can also promote energy conservation.

Managed Aquifer Recharge – A Water Management Strategy with Energy Benefits

Managed aquifer recharge (MAR) is another strategy that can be used to reduce energy intensities for groundwater pumping. MAR has been used for a variety of purposes, including enhanced water storage, drought resilience, and streamflow augmentation (e.g., Tamarack recharge project on the South Platte River). In deep aquifers with large lift requirements, MAR has the potential to reduce the amount of energy required for groundwater pumping. Recharge that produces a net increase in groundwater storage is accompanied by higher hydraulic heads, thereby reducing the necessary lift during subsequent pumping.

Centennial Water and Sanitation District conducts MAR in the Denver Basin aquifers near Highlands Ranch, Colorado. During wet years, available surface water is piped from the McClellan Reservoir and is used to recharge the Denver, Arapahoe, and Laramie-Fox Hills aquifers via wells. Figure 4b shows example data for one of the recharge wells screened in the Arapahoe Aquifer. The longterm dataset with multiple pumping and recharge periods illustrates the impact of MAR. During 2001-2005, prior to recharge, the hydraulic head at this well was declining at a rate of approximately 6.5 m yr^{-1}. The rate of decline slowed to 1.5 m yr^{1} between 2007 and 2015, during and after multiple periods of recharge (Figure 4b). This example illustrates the potential of MAR to not only replenish groundwater storage in historically depleted aquifers, but also to stabilize or increase hydraulic heads, which may translate into substantial energy savings during future groundwater pumping. Again, explicit consideration of the variation in the financial cost and greenhouse gas emissions associated with energy use for groundwater pumping could help to optimize where limited surface water resources are used for MAR in the region.

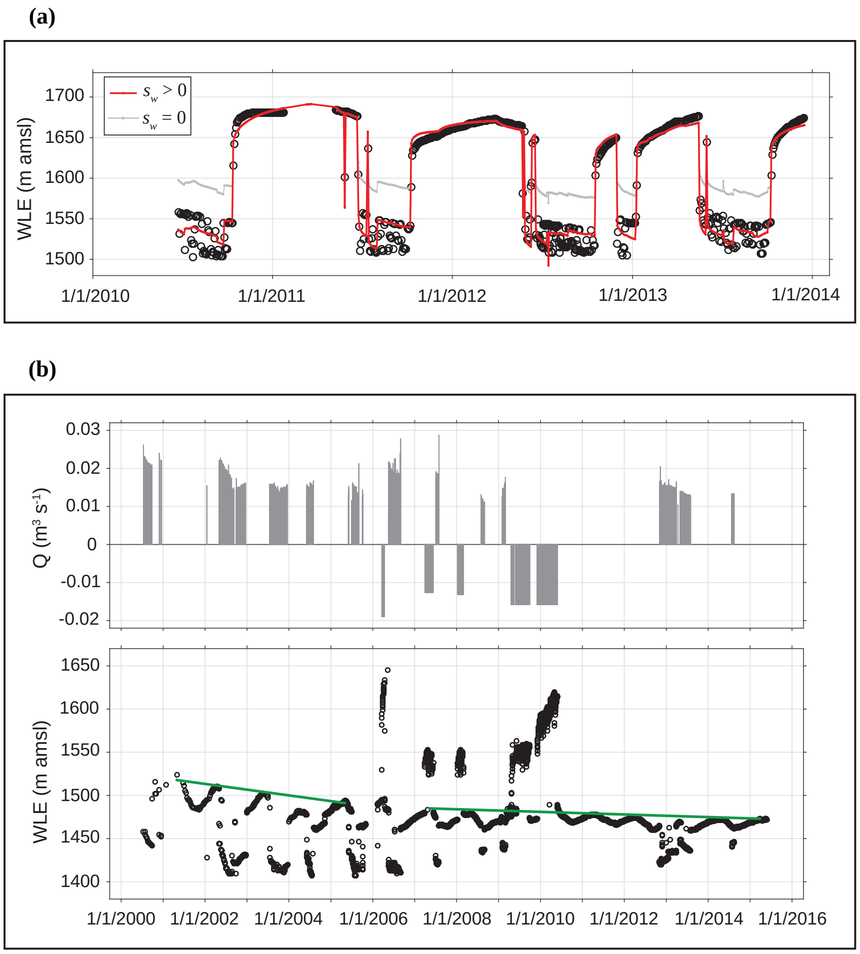

Figure 4. Water level behavior at selected wells in the Denver Basin. WLE = water level elevation. (a) Denver Aquifer municipal pumping well operated by Castle Rock (pumping rates for this well are shown in Figure 2). Solid lines in (a) are simulated water levels using our analytical wellfield model. The red line is the best fitting model that accounts for drawdown due to well-loss effects (sw > 0); grey line is the modeled water level without well-loss effects (sw = 0) and (b) Arapahoe Aquifer MAR well near Highlands Ranch. Wellhead elevation is 1,926 meters above mean sea level (m amsl). Pumping rate (Q) is shown in the upper panel and the measured water level is shown in the lower panel. A positive Q represents groundwater extraction, while a negative Q represents recharge. Green lines illustrate approximate linear trend during 2001-2005 and 2007-2015.

Impacts of Oil & Gas Produced Water Discharges on Surface Water Quality

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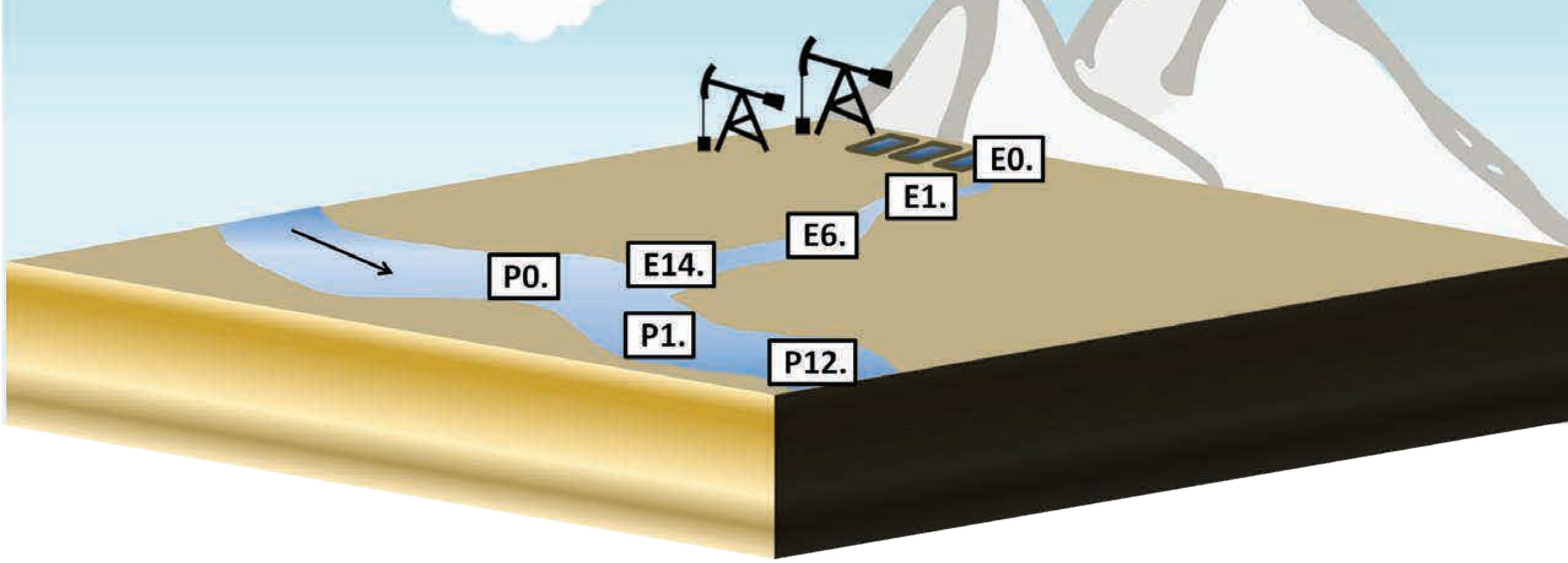
J. Lucas Argueso, Environmental & Radiological Health Sciences, Colorado State University;
Molly McLaughlin, Civil and Environmental Engineering, Colorado State University;
Bonnie McDevitt, Civil and Environmental Engineering, Pennsylvania State University;
Nathaniel Warner, Civil and Environmental Engineering, Pennsylvania State University



SYNOPSIS

Within oil and gas producing regions, produced water is common and often extracted to the surface. In portions of the western U.S., such as Wyoming in this research study, there is very little treatment applied to the produced water and in some situations, is discharged to streams, providing drinking water for livestock. The chemical composition of collected water samples was analyzed to determine if any contaminants from produced water were present. The research study also focused on assessing potential health implications as a result of the water releases within the watershed and downstream areas for humans, livestock, as well as the environment. Our investigation found chemicals (petroleum hydrocarbons and naturally occurring radioactive materials) related to oil and gas extraction within the Wyoming watershed. These results can help regulators efficiently and effectively mitigate produced water discharges.

Produced water is naturally present in oil-and gas-producing formations and is brought to the surface during resource extraction. It is generated for the lifetime of the well (typically a few decades) and is the largest waste stream associated with oil and gas (O&G), with over 3 trillion liters produced annually in the United States. Because of its origins in O&G reservoirs, produced water contains elevated levels of petroleum hydrocarbons, total dissolved solids, metals, and naturally occurring radioactive materials (NORMs). Additionally, this wastewater may contain any remaining

(Above) Figure 1. Schematic of the investigated watershed, which is composed of an ephemeral stream (E) that drains into a much larger perennial stream (P). These sites are located immediately downstream of the discharge (E0), one mile downstream (E1), six miles downstream (E6), and 14 miles downstream (E14). On the perennial stream, sampling sites are located a half mile upstream (P0) and downstream (P1) of the junction between the two streams as well as 12 miles downstream (P12) of the first sampling site on that stream. Sample E14 was dry during all the sampling trips, but has previously been flowing at times of greater produced water generation.

chemicals that are used during the drilling, hydraulic fracturing, and well maintenance processes.

The 98th meridian roughly runs through the center of the Continental United States. In water-scarce areas west of it, such as Colorado and Wyoming, operators can take advantage of the federal National Pollutant Discharge Elimination System (NPDES) exemption. According to U.S. Code of Federal Regulations 40 CFR § 435.51(c), O&G produced water can be released into the environment if it is "of good enough quality to be used for wildlife or livestock watering or other agricultural uses." However, the requirement "of good enough quality" is not clearly defined through permissible chemical concentrations. Produced water composition is highly variable between different O&G formations and may be altered by differing treatment techniques used prior to release. As a result, the environmental and health impacts of produced water and NPDES produced water releases are largely unknown.

At the field site for this study, located in Wyoming, produced water is minimally treated through a series of settling ponds prior to discharge into surface waters and dry streambeds. These flows combine with other natural streams and eventually flow into a much larger river, which is used for cattle irrigation and as source for drinking water downstream in two nearby towns with populations totaling 20,000 people. In 2010, at the height of production, there were 50 wells releasing produced water, resulting in some 10 million liters of produced water generated per day.

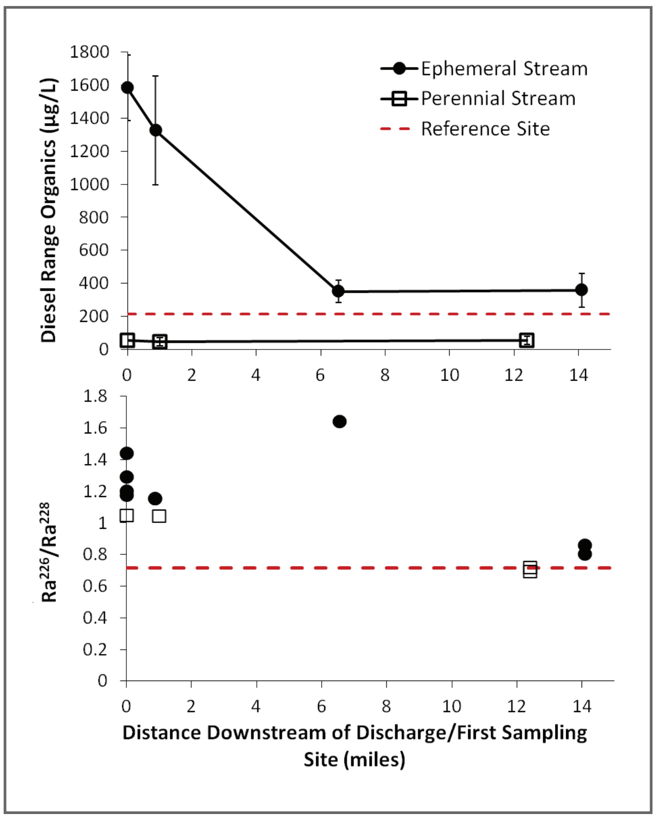


Figure 2. Plots showing how the concentration of Diesel Range Organics (DRO) in the water (top) and the ratio of Radium-226 to Radium-228 in the sediment (bottom) change with distance from the discharge point. The x-axis shows distance downstream, where mile 0 is the discharge point into the ephemeral stream and mile 0 is the first sampling point in the perennial stream. The red dotted line is the DRO concentration at the reference site.

To determine the potential impact that discharges of this minimally treated produced water (MTPW) may have on downstream water quality, our team collected surface water samples at 30 different locations throughout the field site on three occasions (June, August, October 2016). From these 30 samples, one watershed was chosen as the focus for this study (Figure 1). This watershed is composed of an ephemeral stream (a stream that flows only during and briefly following rainfall), which drains into a much larger perennial stream. A discharge point is located at the start of this ephemeral stream. Due to lack of precipitation, this ephemeral stream is composed almost entirely of produced water. A sampling site that is located upstream of all NPDES discharges and outside of this watershed was selected as a background site for comparison.

The first goal of this study was to characterize the chemical composition of the water samples and identify any contaminants of concern. In collaboration with the United States Environmental Protection Agency (EPA) Region 8 and Dr. Nathaniel Warner at Pennsylvania State, we applied state-of-the-art analytical techniques for chemical characterization. Petroleum hydrocarbons, surfactants, NORMs, and various other chemical species were detected in these complex waters, details of which are given below. The second major goal of our collaborative research was to understand potential health impacts of these water releases on the watershed and downstream users including people and livestock. For this purpose, a novel toxicity test developed in Dr. J. Lucas Argueso's laboratory at Colorado State University (CSU) was used to analyze rates of mutation in yeast cells exposed to these water samples. Increased mutation rates are indicative of increased potential for diseases such as cancer. Thus, the results from our study are critical to determine if the practice of releasing MTPW is safe for humans, livestock, wildlife, and the environment.

Results show that a variety of chemicals associated with O&G are present in the stream samples, with concentrations generally decreasing with distance from the discharge point. Figure 2 (top) shows that there are elevated levels of Diesel Range Organics (DRO) in the ephemeral stream and that the concentration decreases with increasing distance from the discharge point. DRO are an indicator of O&G activity, and were found in the sample closest to the discharge point along with a range of other species related to O&G, many of which are known endocrine disruptors. This includes, but is not limited to, BTEX (Benzene, Toluene, Ethylbenzene, and Xylenes), naphthalene, phenanthrene, 2- butoxyethanol, acetone, and isopropyl benzene. DRO concentrations remain relatively steady in the perennial stream and are slightly elevated in the reference site, most likely due to the fact that this site is located beneath a bridge and influenced by cars.

Figure 2 (bottom) shows how the Radium-226 (Ra^{226}) to Radium-228 (Ra^{228}) ratio in the sediment changes in both the ephemeral and perennial streams. This analysis was done by Dr. Nathaniel Warner and Bonnie McDevitt at Pennsylvania State. Higher ratios of Ra^{226}/Ra^{228} are associated with produced water, so the decrease in this ratio with distance downstream from the discharge is very indicative of O&G impacts. The DRO and Ra^{226}/Ra^{228} results show that concentrations of chemicals associated with O&G decrease with distance from the discharge and are lower in the perennial stream, as was expected. Surfactants, which are commonly used in O&G operations, have also been observed in these water samples. Analysis and quantification of these species is yet to be completed.

We then used bioassays to quantify the effect of the water samples on mutagenic activity in yeast. These tests are conducted by growing yeast in at two different produced water concentrations (25% and 50%) and then plating those cultures on both non-selective and selective plates. The number of colonies that grow on the non-selective plate is the total number of cells in that culture, while the number of colonies with mutations can be determined by counting the number of colonies on the selective plate (Figure 3). These results can then be used to calculate a mutation rate. Haploid yeast strain JAY 2087 was used to measure four different types of mutations including chromosomal duplications, chromosomal deletions, and two types of point mutations. Diploid yeast strain JAY 685 was used as an additional way to measure chromosomal duplications.

Results from the bioassays conducted in 50% produced water showed increased rates of chromosomal duplications and deletions in the sample collected immediately downstream of the discharge point (E0). Chromosomal duplications remained elevated in sample E1, while chromosomal deletions did not (Figure 4). Point mutations in the trp1-289 gene were also elevated in all three samples collected from the ephemeral stream. No significant change was observed for point mutations in the CAN1 gene. Results from the bioassays conducted with the diploid strain also showed increased levels of chromosomal duplications. A larger increase in mutation rate was observed in the diploid strain, as was expected. To conclude this project, all six sites (excluding E14) will be analyzed for mutagenic activity. Additionally, a few other samples of interest will be analyzed including samples collected near a separate discharge site, from a domestic water well and from the background site.

In summary, our investigations show that chemicals related to O&G extraction activities such as petroleum hydrocarbons and NORMs are present in this Wyoming watershed. While concentrations of these chemicals decreased with distance from the discharge point, mutation rates remained elevated. These findings raise an important point: to evaluate the risks and impacts associated with current environmental discharge practices, chemical analyses for select indicator compounds may not be sufficient, and a more integrative toxicological assessment of these complex waters may be needed. Thus, the outcome of our study will ultimately help regulators and industry to effectively and safely manage produced water discharges for beneficial use.

This project is co-funded through an Environmental Defense Fund (EDF) grant and the CSU Water Center.

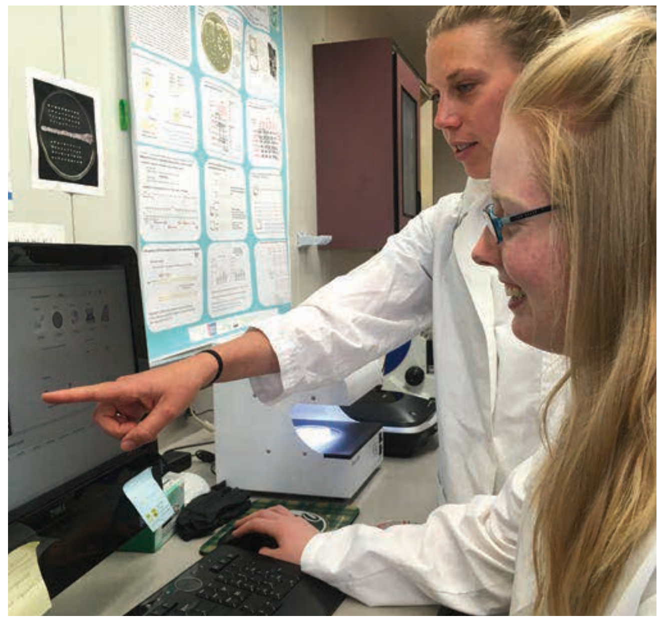


Figure 3. When the bioassay is complete, the number of colonies on each plate are counted using a plate counter. In this photo, Molly McLaughlin, a PhD student, shows Baylee Schell, an undergraduate student, how to count colonies in order to determine mutation rate for each sample. Photo by Nadia Sampaio.

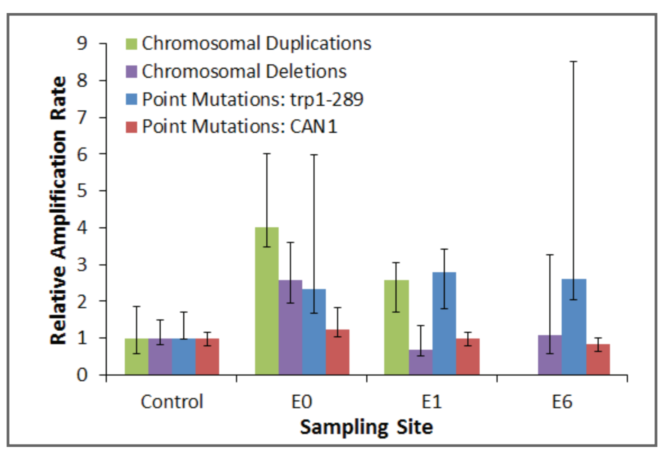


Figure 4. Mutation rates in the samples from the ephemeral stream relative to a control culture made without produced water. Samples were made with 50% produced water.

Smoothed-Particle Hydrodynamics

A New Fluid Modeling Technique Applied to Analyze Fish Passage Opportunities in Whitewater Park Structures in Lyons, Colorado

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Christopher Myrick, Department of Fish & Wildlife & Conservation Biology, Colorado State University

SYNOPSIS

Whitewater parks are increasingly common recreational attractions, especially for kayakers. However, they can impact the natural life cycles of fish. It can be challenging to assess the stream velocity at various depths within whitewater parks to truly determine the impacts they have on fish. Thus, we used smoothed-particle hydrodynamics (SPH) to model hydraulic forces in whitewater parks in Colorado. This research study assessed fish passage opportunities through whitewater park structures and provided guidelines on how to analyze fish passage for future studies. We found possible flow paths for fish larger than 175 mm at every structure during all flows. However, each structure had at least one flow that did not permit smaller fish to pass through.

◀ *(Opposite) Figure 1. A whitewater park structure on the North St. Vrain Creek near Lyons, Colorado. Photo by Travis Hardee.*

Introduction

Whitewater parks are increasingly popular recreational features where structures are built into a stream channel to create standing waves for kayakers. Waves form where fast moving water, created by accelerated flow through either a constriction or a sudden drop, meets slow moving water, caused by a deeper pool. Although whitewater parks provide recreational and economic benefits to their communities, the modified flow patterns may be detrimental to the natural life cycles of fish. Fish must be able to migrate up and down a river to find spawning habitat, escape unsuitable temperatures, and seek refuge during high and low flows, but whitewater parks have the potential to create flows that are too fast and flow depths that are too shallow to allow fish to freely migrate during certain times of year.

Because it is difficult to obtain velocity and flow depth measurements in and around whitewater parks at a high spatial resolution for different flows, researchers use hydraulic modeling to analyze how whitewater parks affect fish passage opportunities. Typically, fluid flows are modeled using techniques that rely on solving a set of two- or three-dimensional governing equations for fluid flow at points on a fixed grid. An alternative modeling approach called smoothed-particle hydrodynamics (SPH), which solves the same governing equations for a set of 'particles' that move freely and interact with each other, is gaining popularity in other fluid dynamic fields. SPH's recent surge in popularity comes from advances in computer graphics processing units (GPU), driven largely by the video gaming industry, which allow faster computation times than a computer's central processing unit (CPU). SPH has not, however, been applied to natural river channels. In this project, we investigated the applicability of SPH techniques to simulate flows through whitewater parks. The predicted velocities and flow depths were then used to determine fish passage opportunities through existing whitewater park structures, and we outlined a methodology for analyzing fish passage opportunities for future whitewater parks.

Methods

Three whitewater park structures (Figure 1) on the North St. Vrain Creek in Lyons, Colorado were modeled for fish passage opportunities. We collected topographic data for the structures using three different methods: a survey-grade real-time kinematic global positioning system (GPS), terrestrial laser scanner (TLS) scanning, and Structure-from-Motion (SfM) photogrammetry. We used the GPS to collect cross sections every 2-5 meters along the channel, with a cross-stream spacing between measurement points of about 1 meter. More dense GPS points were collected within and around the structures because of the less uniform nature of the topography. The TLS was set up at multiple locations

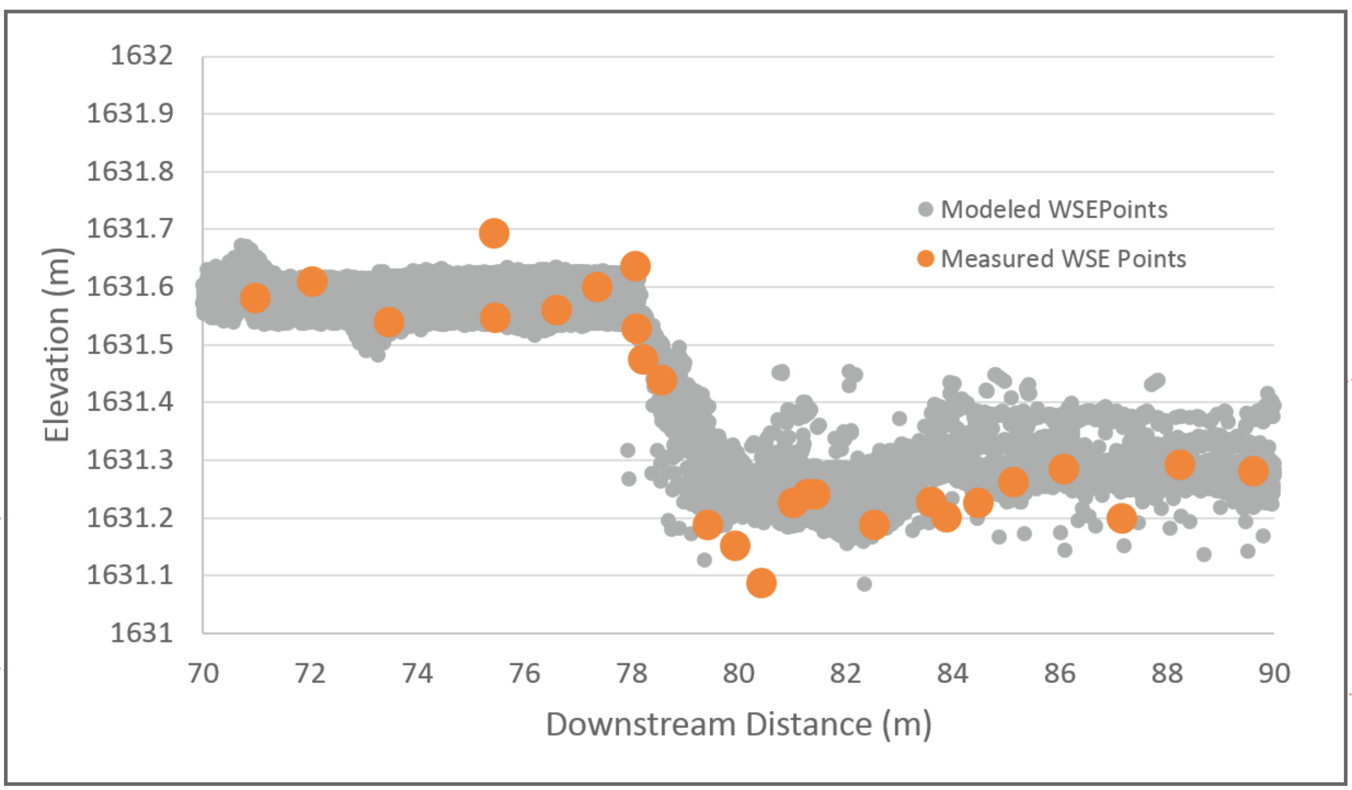


Figure 2. Comparison of model-predicted water surface elevations (gray) to measured field conditions (orange).

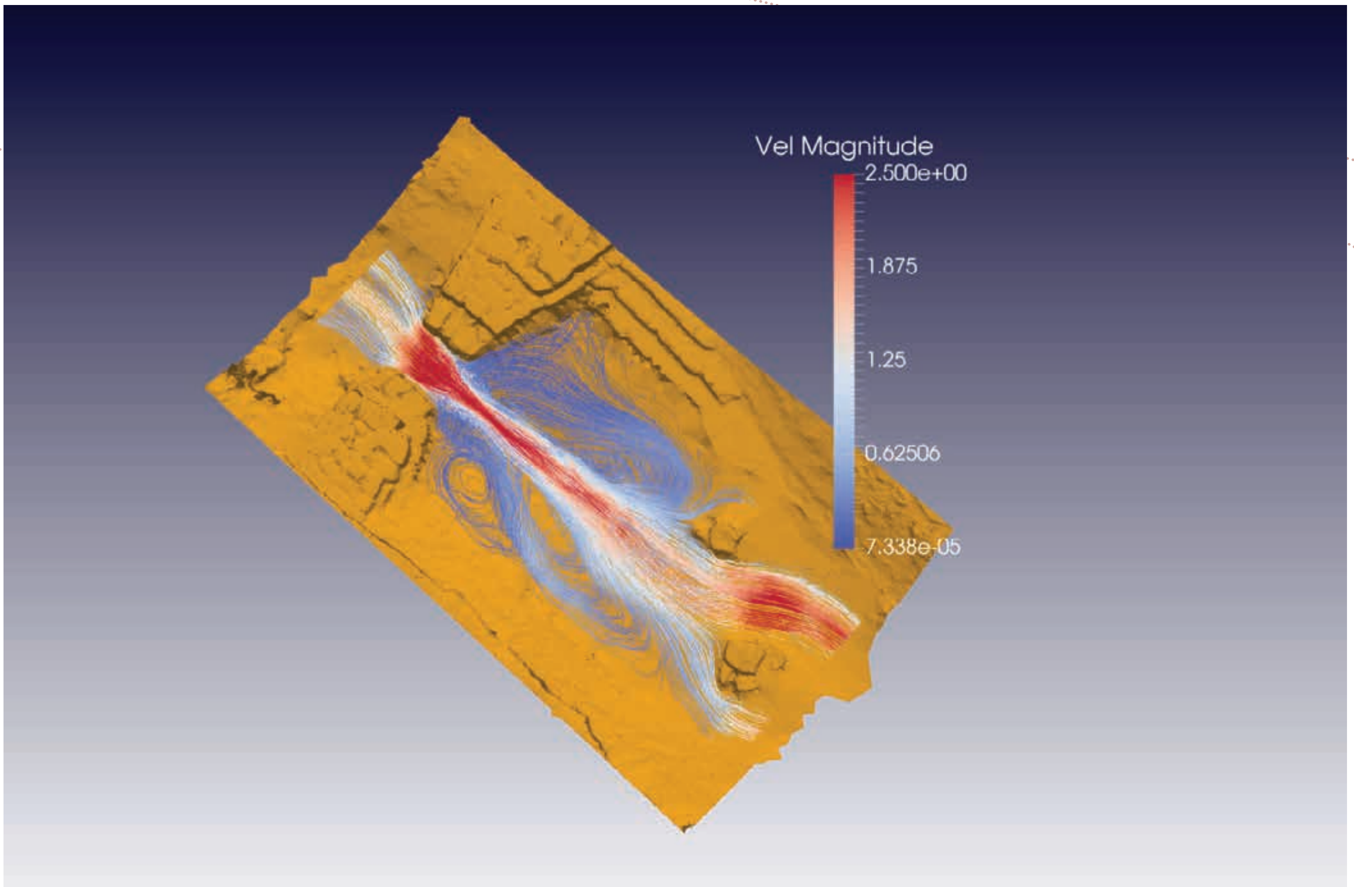


Figure 3. Example of streamlines created to analyze fish passage opportunities. The colors refer to velocity with red representing fast moving water and blue representing slow moving water. Flow is from left to right.

along the channel, and overlapping scans were merged. Photographs used for SfM were taken with a digital SLR from many locations along the channel, and the commercial software Agisoft PhotoScan Professional was used to generate a point cloud from the photo sets. Both the TLS and SfM datasets were aligned using control points measured with the GPS, and all three types of data were merged into a single topographic point cloud. The TLS and SfM methods produced very dense point clouds (multiple points per square centimeter), but the GPS was the only method that could collect topography data under the water.

In addition to the topographic data, we used the GPS to collect water surface elevation measurements at each of the structures for several different flows. Simultaneously, we collected velocity measurements along the structures with a field acoustic Doppler velocimeter (ADV). These measurements were used to calibrate the model and evaluate the accuracy of the SPH simulations.

The SPH modeling was performed in DualSPHysics, a free, open-source software package. Since SPH has not been previously used to model flows in natural channels, one of our primary goals was to determine the best methods for applying SPH to model a natural channel with complex topography. We generated fixed boundary particles from the topography datasets, and we filled this model domain with fluid 'particles' to an elevation close to the expected water surface elevation. Additional fluid particles were initially placed in an upstream reservoir that introduced a steady flow throughout the simulation. Parameters built into the governing equations within the software allowed us to modify several properties including the fluid viscosity, particle size, and boundary roughness to calibrate the model to measured field conditions. Our setup allowed for a 5 cm particle spacing resulting in about 5 million 'particles' per simulation. To analyze fish passage opportunities, we simulated four different flows covering the expected range of flows for the river during a typical year.

Results and Discussion

We found that DualSPHysics could model the flows through the whitewater parks with varying levels of success. The boundary topography exerted a large control over the accuracy of the predicted water surface elevation. Much of the model domain was below the water surface, so the boundary geometry was primarily determined from the relatively sparse GPS points. While this was not a major issue for most of the channel, within the whitewater park structures we found it was necessary to generate the boundary within DualSPHysics using prisms based on the GPS data, which gave a much better representation than a topographic mesh based on GPS points. Once this issue was solved, we were able to model water surface elevations to within 8 cm of the measured values for most structures and flows (Figure 2). The model accuracy decreased to 10-15 cm when flows were shallow and the model had a flow depth of only a few 'particles'.

The model produced a high resolution, three-dimensional output of the fluid flowing through the channel, which we used to create three-dimensional streamlines (Figure 3) to analyze fish passage opportunities. Velocity and flow depth along individual streamlines (or potential fish swimming paths) have been shown to be the main controls on fish passage through whitewater park structures. A streamline was considered passable if the maximum velocity along it was less than 10 times the fish body length per second and if the flow depth everywhere along the streamline was greater than 18 cm. This analysis showed that some potential flow paths existed for passage of fish larger than 175 mm at all structures during all flows, but all structures had at least one flow that would not allow smaller fish to pass through the structure. One structure at the upstream end of the channel showed that, due to shallow depths, only 10% of the possible swimming paths allowed for passage of larger fish at low flows, indicating that this structure may be a barrier to all fish migration at these flows. This structure did allow for 70% of the streamlines to be passable by larger fish at higher flows (Figure 4), but did not allow for the passage of fish smaller than 175 mm at any flow analyzed.

We have created an instruction manual that provides guidance on how to apply DualSPHysics to natural channels. This manual walks the user through the process of turning field data into a usable form for boundary particles, setting up the fluid particles and upstream reservoir, varying the parameters to calibrate the model, and running the model in an efficient manner. The instruction manual also goes through an explanation of the relevant parameters for natural channels, common problems associated with setting up the model, and tips for modifying the model to obtain useful data for different projects.

Conclusions

We have shown that SPH may be a powerful new method of modeling flows through natural channels. Using free SPH software, we modeled flow through whitewater parks, producing results as accurate as more traditional mesh-based modeling techniques, while generating velocity fields in three dimensions at a high spatial resolution. We developed a methodology that can be used to determine the impacts of future whitewater park structures on fish passage opportunities, and we found that current whitewater park structures in Lyons, Colorado generally allow for larger fish to migrate up and down the channel over a wide range of flows, but these structures likely act as a migration barrier to smaller fish. Overall, this work shows that SPH is an exciting new method for simulating dynamic flows in rivers with complex topography, such as that associated with whitewater park structures.

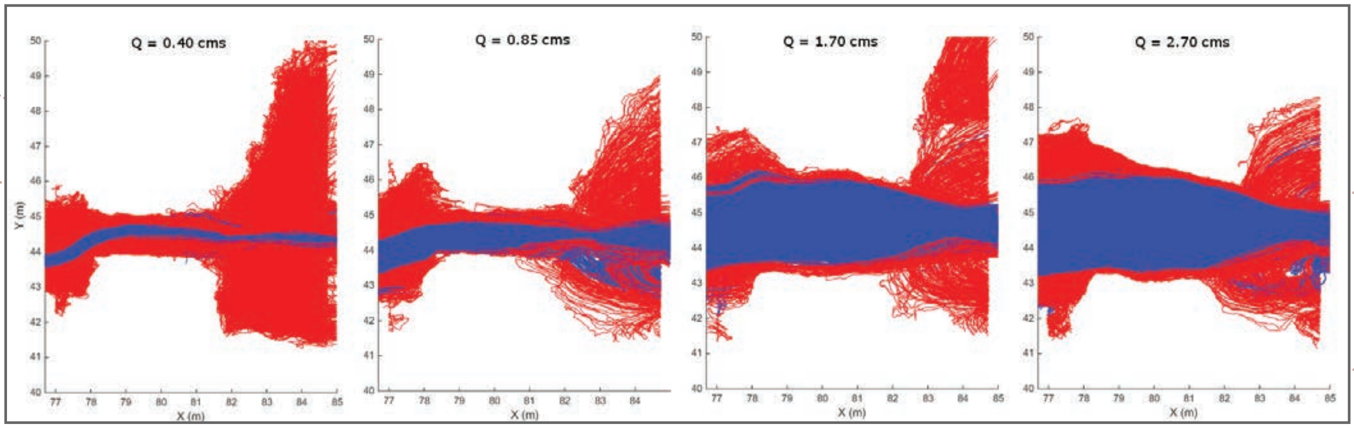


Figure 4. Fish passage analysis for the largest fish size at four different flows through a whitewater park structure. Blue lines indicate conditions that a 400 mm fish can swim along, while red lines either have depths that are too shallow or velocities that are too high for a fish to pass through. Flow is from left to right.

Organic Carbon Storage Along River Corridors of the U.S. Prairies

Ellen Wohl, Department of Geosciences, Colorado State University

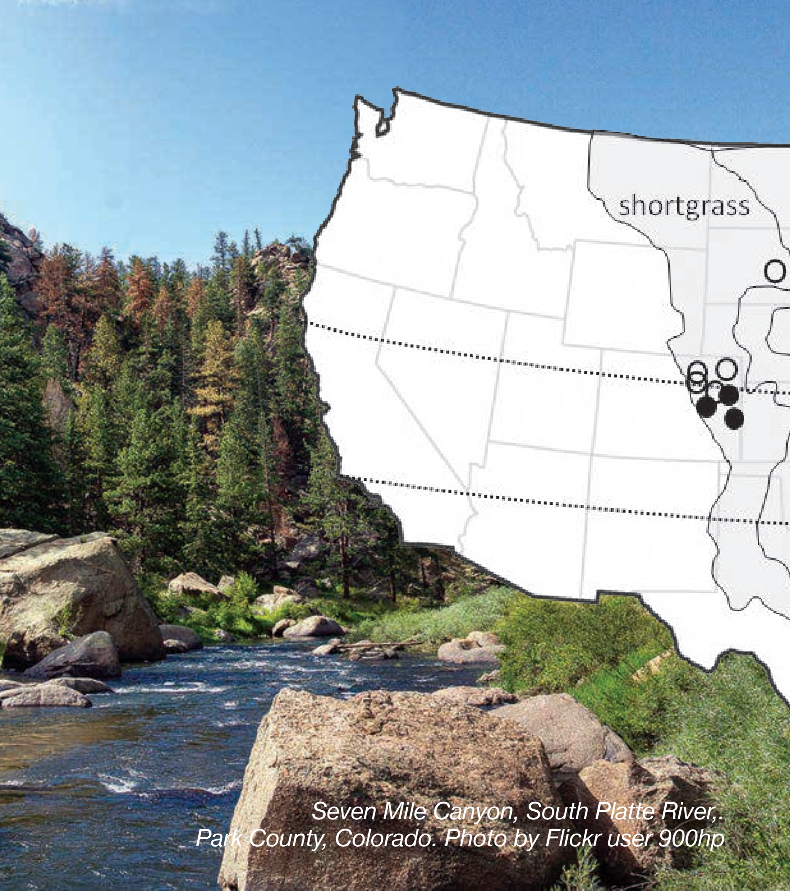
SYNOPSIS

Rivers transport substantial volumes of terrestrial organic carbon stemming from soils as well as vegetation. They also store organic-rich sediment in floodplains and throughout river networks. For this research study, emphasis was placed on evaluating organic carbon losses from river 'pipes' as a result of gas exchanges, determining stream metabolism, as well as assessing sediment storage which is a dynamic part of the global carbon cycle. The field sampling revealed significant spatial heterogeneity in organic carbon concentrations, with higher values representing abandoned channels or wetlands. Specifically, river corridors within prairie regions had considerable stocks of organic carbon in floodplain soil.

Rivers and Organic Carbon Storage

Research during the 1970s and 1980s demonstrated that rivers deliver significant amounts of terrestrial organic carbon (OC) derived from soils and vegetation to the ocean, but rivers were only included in early conceptual models of the carbon cycle as neutral or passive pipes for OC transport. Ecologists have explored transformations and losses of OC within river networks, demonstrating that more terrestrial OC enters rivers than is transferred to the oceans. This work, however, focused on losses of OC from river 'pipes' via gas exchange. Rivers can also store organic-rich sediment in floodplains and other portions of the river network dominated by deposition and storage from decades to millennia. Together, the research on stream metabolism, gas exchange, and sediment storage suggests that rivers are an active component of the global carbon cycle, rather than neutral pipes, and that river process and form can significantly influence partitioning of terrestrially derived OC among the atmosphere, geosphere, and ocean.

Although we are in the early stages of understanding the details of how rivers form and process influence carbon dynamics, human activities have clearly altered and continue to alter most aspects of carbon dynamics within river corridors. Carbon dynamics refers to inputs, storage, transformations, and outputs of OC that occur within a river corridor. A river corridor includes the active channel, hyporheic zone of shallow subsurface flow that underlies channels, floodplain, riparian zone, and river depositional landforms such as deltas and alluvial fans. People indirectly alter carbon dynamics within river corridors by changing inputs of OC to river networks from the uplands through changes in land cover and by changing outputs of OC to the atmosphere (via CO_2 emissions from reservoirs) and ocean through flow regulation. People



Seven Mile Canyon, South Platte River, Park County, Colorado. Photo by Flickr user 900hp

Figure 1. Location map showing the conterminous United States; the extent of tallgrass, mixed grass (within the band located between tall- and shortgrass), and shortgrass prairies in gray shaded area; field sampling sites (solid black circles) and remotely sampled sites (open black circles).

also directly alter the ability of river corridors to process, store, and release OC via river engineering that simplifies channel geometry, disconnects channels from floodplains, hyporheic zones, alluvial fans and deltas, and alters the natural downstream fluxes of water, sediment, and nutrients. Although these human-induced alterations are ubiquitous throughout river networks in temperate latitudes, they have received very little attention in the context of carbon dynamics.

OC is stored within river corridors primarily in floodplain soil, in downed, dead wood, and in riparian vegetation. Quantities of OC per unit area stored in floodplain soil are disproportionately large relative to upland soils in temperate latitudes, although the details of where most OC is stored (small vs. large rivers, floodplains vs. deltas, high vs. temperate or low latitudes) remain poorly constrained.

Research Objectives and Hypotheses

An overarching goal of the activities within my research group is to quantify OC storage in downed wood and sediment within diverse natural and human-altered river corridors. To this end, we are engaged in quantification of OC storage in subalpine lake deltas and small mountainous rivers of the Southern Rocky Mountains (PhD student Dan Scott); in beaver meadows of the Southern Rocky Mountains (PhD student DeAnna Laurel); in large, lowland rivers of interior Alaska (PhD student Katherine Lininger); and in mountainous rivers of the Cascades and Olympic Peninsula (PhD student Dan Scott). Comparable quantitative estimates of OC storage in river corridors have been published for several other regions of the U.S., but some important gaps remain in the diversity of rivers within the U.S. for which OC storage has been characterized.

Thus far, my research group has focused exclusively on river corridors with minimal human alteration and we have begun to constrain the characteristics of rivers that facilitate OC storage. The research summarized here targeted data collection along natural and human-altered river corridors in regions of the U.S. for which OC storage has not yet been estimated, including tallgrass and shortgrass prairie rivers. Data obtained from these regions is currently being used to develop a first-order estimate of OC storage in river corridors throughout the United States.

The primary objectives were to (1) quantify OC stocks (megagrams of OC per hectare of floodplain surface; Mg C/ha) in floodplains of prairie rivers and (2) use these field data to test hypotheses related to OC storage in prairie river corridors. I hypothesized that OC stocks are significantly higher in rivers of the tallgrass prairie than in rivers of the shortgrass prairie, but prairie river corridors generally contain lower stocks of OC than those in forested watersheds of comparable size and latitude. I expect carbon stocks to be higher in the tallgrass prairie because of the more continuous grass and the associated greater net primary productivity, as well as the more extensive floodplain wetlands present in tallgrass river corridors. Rivers of the tallgrass prairie are also more likely to have spatially extensive bottomland forests than are rivers in the shortgrass prairie. Rivers of the shortgrass prairie are more likely to be intermittent or ephemeral than those of the

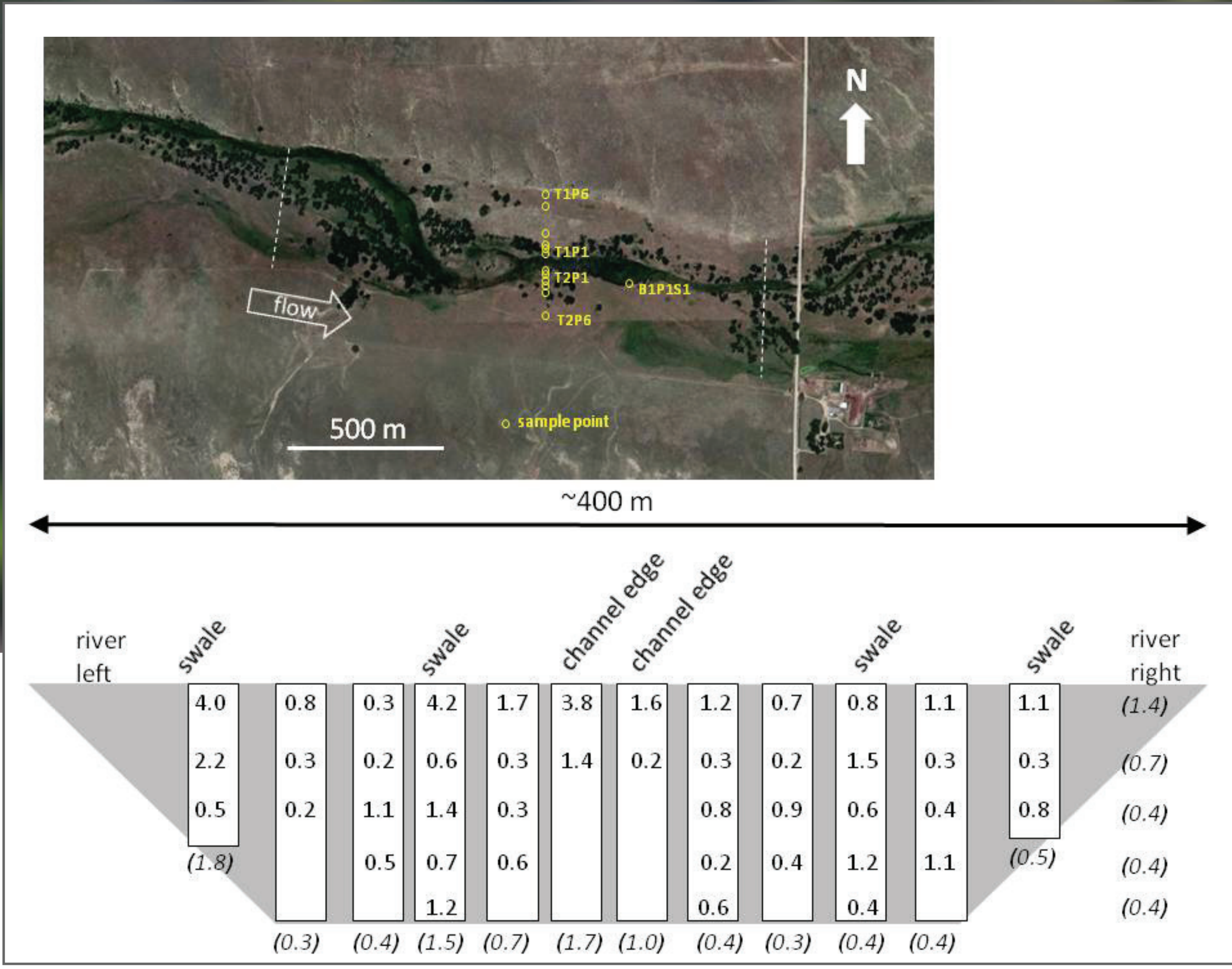


Figure 2. (Top) Aerial view of the sampling locations along the Arikaree River corridor in eastern Colorado. Yellow circles indicate sample points; white arrow indicates flow direction; dashed white lines indicate lateral extent of the river corridor. Base imagery from Google Earth. (Bottom) Schematic illustration of spatial variation in organic carbon concentrations among samples at the Arikaree River. Relative depth and lateral position of carbon concentration values are correct, but lateral distances and depths are not to scale. View is downstream, as indicated by river left and right labels. Samples at the edge of the active channel, which contained water at the time of sampling, are shallow. Surface location of swales indicated by text at top of idealized channel cross section. Valley bottom width indicated by arrows at top of each figure. Values of standard deviation among vertical samples below each column in parentheses and italics. Values of standard deviation at a depth across the valley at right in parentheses and italics.

tallgrass prairie, and perennial rivers have greater productivity than intermittent or ephemeral rivers.

I expect prairie rivers to contain lower OC stocks than rivers of similar drainage area and latitude within forested watersheds for at least three reasons including (1) watersheds that are primarily grasslands have lower net primary productivity in upland sites and may have smaller carbon fluxes to river corridors than forested watersheds. Although tallgrass prairies can have high rates of accumulation of plant detritus, periodic fires remove much of this material, (2) instream wood loads can be much greater in forested catchments. Instream wood obstructs flow and facilitates overbank flows that deposit particulate organic matter on floodplains, potentially creating higher OC stocks in floodplain soils of rivers with more abundant instream wood, and(3) beaver-created wetlands contain high carbon stocks, as do other forms of floodplain wetlands. Although beavers can build dams along prairie rivers that have only woody shrubs rather than trees, beaver population densities are likely to be higher along rivers in forested watersheds.

Study Areas

Field sampling was conducted along tallgrass prairie rivers in the Flint Hills of Kansas, the Tallgrass Prairie Preserve of Oklahoma, and Prairie State Park in Missouri (Figure 1). Additional soils data were obtained from the Natural Resources

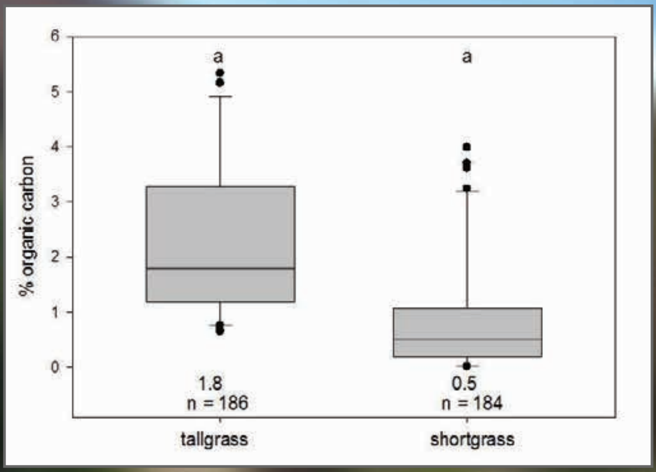


Figure 3. Percentages of organic carbon content in floodplain soils at different locations within the tallgrass and shortgrass river corridors sampled in the field. Median value in the box, with standard deviation in parentheses and sample size listed below box.

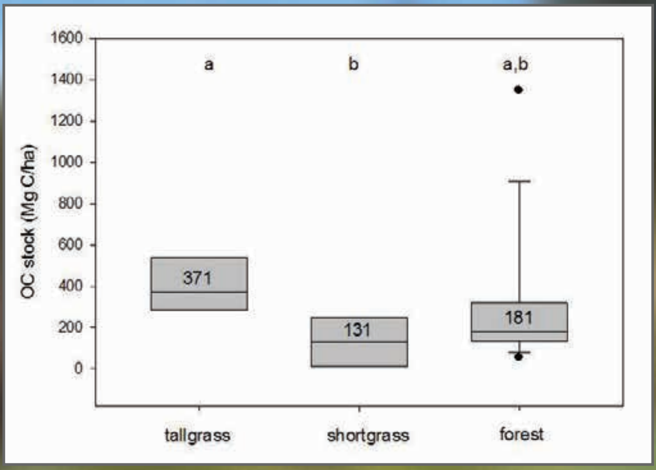


Figure 4. Organic carbon stocks for three types of river corridors. Letters at the top of the plot indicate significantly similar and different median values.

Conservation Service Soils (NRCS) Soil Survey Geographic Database (SSURGO) in the Illinois River drainage basin for larger rivers with greater human alteration. Field sampling for shortgrass prairie sites focused on eastern Colorado, with SSURGO data from the South Platte and Missouri River drainages. Field sampling involved coring floodplain soils to collect samples analyzed in the CSU Soil Testing Laboratory for OC by weight. These values were used with bulk density and field-estimated volume of floodplain sediment to quantify floodplain soil OC stock.

Results

Field sampling across a valley cross section and depth indicates substantial spatial heterogeneity in OC concentrations, with buried pockets of higher values that likely represent abandoned channels or wetlands (Figure 2). Prairie rivers historically had braided, meandering, or anastomosing planforms and substantial lateral mobility, creating numerous cutoff and abandoned secondary channels and floodplain wetlands.

Statistical analyses indicate that median values of OC concentration at both field-sampled and remote sites in the tallgrass prairie are significantly higher than those of the shortgrass prairie (Figure 3), as hypothesized. Median values of OC stock at field-sampled sites are largest at tallgrass prairie sites relative to forested and shortgrass prairie sites and values of forested sites tend to be intermediate (Figure 4). No statistically significant difference exists between forest and shortgrass or between forest and tallgrass sites. A significant difference exists between tallgrass and shortgrass sites. The results thus do not support the second hypothesis that prairie rivers would have lower OC stocks than comparable forested rivers: only the shortgrass prairie rivers have lower OC stocks.

Relevance to Current Issues

An important implication of this research is that river corridors in prairie regions, especially in tallgrass prairie, can contain substantial stocks of OC in floodplain soils. Some process concentrates OC in floodplain soils sufficiently to create higher median values than found in forested floodplain soils, despite lower net primary productivity in prairies than in forested environments. I speculate that the primary process acting here is the presence of wetlands in prairie river corridors. Although such floodplain wetlands are now rare after more than a century of beaver trapping, flow regulation, levee construction, removal of instream wood, and land drainage, historical records from tallgrass prairie regions indicate the ubiquity and long duration of bottomland flooding in these regions. OC storage within river corridors of the tallgrass prairie has almost certainly been reduced through land use and river engineering, but may still remain unexpectedly high because of the past occurrence of wetlands. Although many efforts to increase carbon storage focus on afforestation or forest preservation in upland environments, greater attention to river corridors and floodplain wetlands can also form an important component of enhanced carbon sequestration.

This research was supported by a Water Faculty Fellow grant from the CSU Water Center and a research grant from the National Geographic Society.

One Health Surveillance of Antimicrobial Resistant Bacteria in Fort Collins, Colorado

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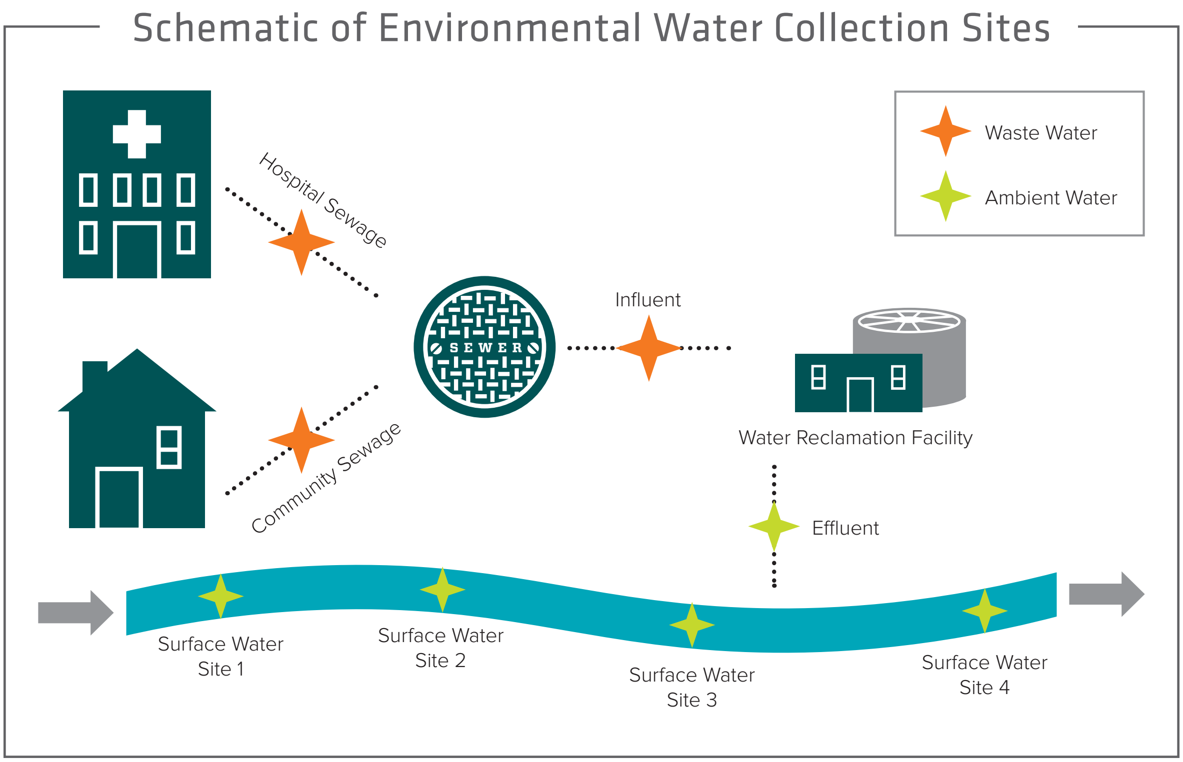
SYNOPSIS

Antimicrobial resistance (AMR) is an emerging issue for a suite of pathogens that have posed challenges for infectious outbreaks in humans and animals. Resistance develops due to natural and manmade pressures in their environment. Extended Spectrum Beta Lactamase (ESBL) and Klebsiella Pneumoniae Carbapenemase (KPC) represent two classes of resistance. E. coli is a relevant area of focus because of its role in enteric pathogenicity, including food outbreaks. Wastewater was sampled in and around Fort Collins, Colorado and analyzed for relative abundances of ESBL and KPC resistance at 12 sites. Over 30 strains of antimicrobial resistant bacteria were discovered, stemming from the environment, people, as well as animals. We created a surveillance methodology to help assess AMR microbes and provide a foundation for future research studies nationally and internationally.

Antimicrobial resistance (AMR) is an emerging issue for a suite of pathogens and it is challenging to predict the occurrence of outbreaks in humans and animals alike. Resistance can develop in microbes due to a broad spectrum of pressures from the environment. Global surveillance using standardized methodology is essential to understand how humans, animals, and the environment are exposed, and may provide important information about fluctuations in antibiotic resistance in promiscuous gene pools. Two major classes of resistance—Extended Spectrum Beta Lactamase (ESBL) and Klebsiella Pneumoniae Carbapenemase (KPC), both work by secreting enzymes that hydrolyze the beta lactam ring in certain antibiotics. The focus on *Enterobactericeae*, such as *E. coli* in our study, has important relevance to global and local water systems, regulatory practices, enteric pathogenicity, and emerging roles in food outbreaks that can threaten animal and human health.

The World Health Organization (WHO) notes that antimicrobial resistant bacteria (ARB) is an emerging water, sanitation, and hygiene issue, worsened by a lack of reliable, well-documented, and validated human health risk assessments. Surveillance for ARB and resistance genes from environmental exposures merits interdisciplinary attention, clear communication, and environmental health stewardship. This project addressed the increasing awareness of water's role in the spread and persistence of ARB and the need for coordinated domestic and international action in order to rapidly detect, diagnose, and contain ARB at their source. We completed work that is highly relevant and responsive to the CSU Water Center's strategic goals, as we facilitated multidisciplinary collaborations and

Figure by Hannah Haberecht and Jake Gilliand



engagements to enhance water research, scholarship, and potential for future funding. Three examples of how we accomplished this were by:

1. Submitting external proposals that address ARB across the food and water nexus with critical preliminary data on ARB in diverse human, animal, and water medias;
2. Enhancing water scholarship by cross-discipline training graduate students in chemistry, engineering, toxicology, veterinary medicine, and public health as it relates to ARB and water systems through research, journal club, and seminar.
3. Improving data sharing and innovation across disciplines, with internal/external partners, and research sites that linked local Colorado water authorities with international efforts.

Methods and Analysis

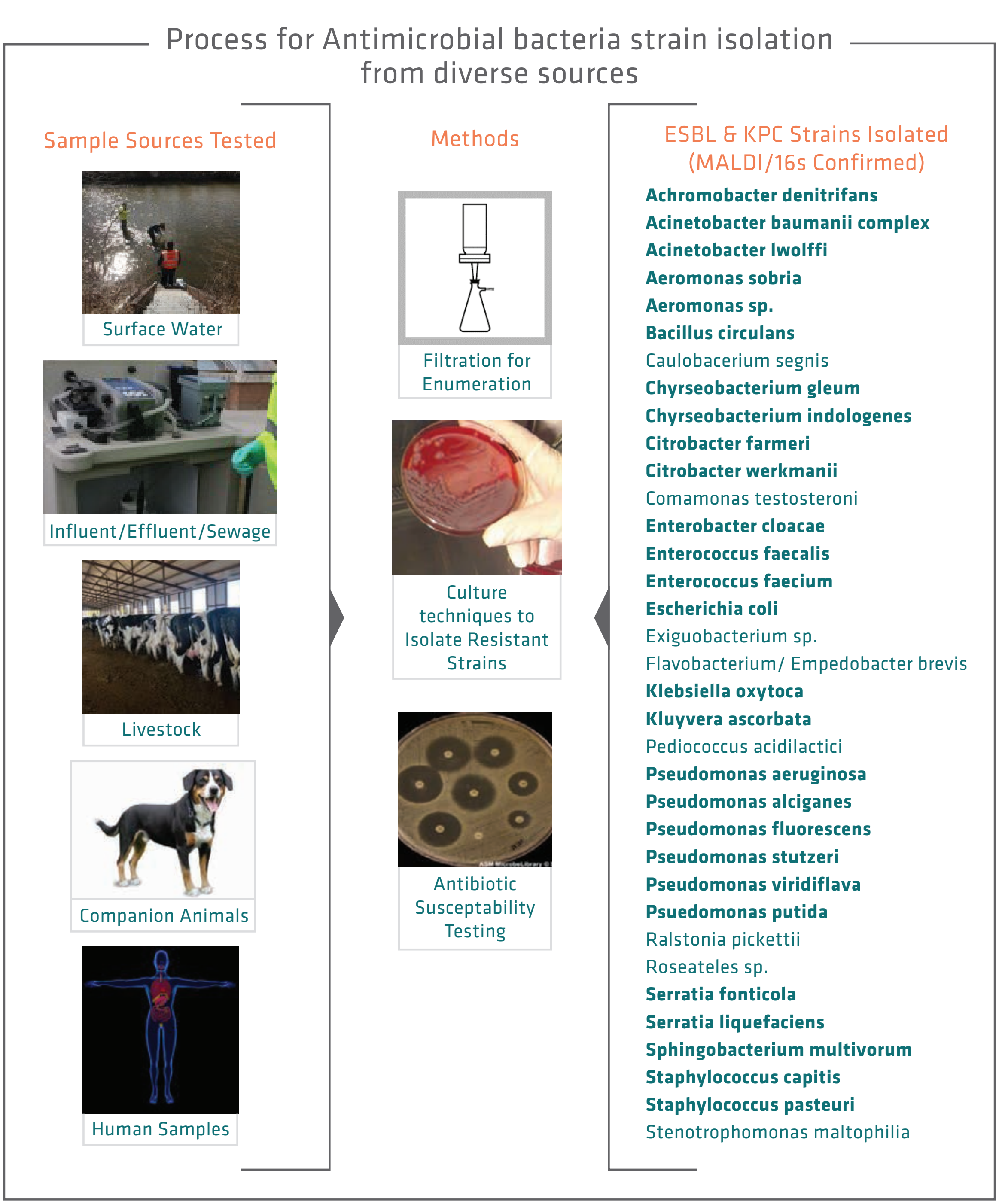
This research team applied a harmonized protocol using a simplified method for direct culture-based isolation, quantification, initial identification of ARB, and recognized urgent and serious threats including *Extended Spectrum Beta Lactamase Enterobacteriacea* (ESBL), *Carbapenem-Resistant Enterobacteriacea* (KPC).There were 28 sampling events which occurred from municipal and hospital raw sewage, waste water treatment plant (WWTP), such as the Drake Water Reclamation Facility (DWRF), influent and effluent, and sewage-impacted surface waters (i.e. Poudre River) were collected in Fort Collins, Colorado.

1. Isolated, culture purified, and characterized AMR bacteria for phenotypic and molecular properties, including clonal relationships across environmental media. We confirmed ARB identity with MALDI-TOF, measured phenotypically by Kirby-Bauer disk diffusion susceptibility methods and molecular analysis using PhenePlate and multiplex PCR assays.
2. Waste water, river water, and sewage water from the community and surrounding a hospital in Fort Collins, Colorado were sampled for total bacterial abundance of ESBL and KPC resistance mechanisms. 12 distinct sampling sites were selected to enumerate relative abundances of ESBL and KPC resistance. Bacterial strains were isolated using various selective agars and analyzed for antimicrobial resistance by disk diffusion on eight different classes of drugs.
3. ESBL and KPC resistant *E. coli* strains confirmed via MALDI-TOF were subjected to genetic screening using conventional PCR to screen for blaOXA, blaCTX-M, blaTEM, and blaSHV genes. These strains were also analyzed for functional biochemical fingerprinting (PhP-RE plate system) and assessment of clonal relatedness.

Results

Environmental waters sampled revealed a total relative abundance of ESBL at 2.58% and KPC at 1.17%. The relative abundance of ESBL in *E. coli* alone was 0.164% and 0.100% for KPC. Initial results show *E. coli* has resistance to ampicillin in 100% of the isolates, resistance to tetracycline in 28.6% of isolates

Poudre River, Poudre Canyon, Colorado. Photo by Flickr user Rich



One health approach for collection of AMR isolates includes utilization of harmonized methods for water, animals, and people.

and cephalosporin resistance in 57.1% of isolates. Whereas, all isolates were susceptible to three different aminoglycosides. Gene screening of isolates showed additional complexity in the patterns in resistance. These results and isolates from northern Colorado are being compared to other sites in North Carolina and Nicaragua that have been implementing similar laboratory protocols. Using a culture-based method that allowed for characterization of the functional antibiotic resistant landscape and focus on Escherichia coli, we provided a baseline pattern essential to future risk assessment and surveillance efforts.

When growing, resistance is observed in environmental bacterial isolates, we must consider their potential to spread between human, animal, and agricultural systems. Beta lactams antimicrobials are widely used in human and veterinary medicine and growing resistance will compromise patient treatment and can facilitate increased disease outbreaks. We have detected over 30 distinct types of antimicrobial resistant bacteria from animals, people, and the environment.

We identified AMR from 30+ bacterial strains (n=50 sampling events) located at:

- Surface waters along the Poudre River (5 sites)
- Sewage near Poudre Valley Hospital and community

access points before WWTP (5 sites)

- Drake Water Reclamation Facility—WWTP, influent, and effluent (3 sites)
- CSU Veterinary Teaching Hospital—companion animals, beef, and dairy cows (4 sites)
- Organic and non-organic dairy farms (3 sites, n=6)
- De-identified healthy adult (human) samples (1 site, n=6)

Through our academic collaborations and interactions with stakeholders in local government, we have developed a simple, yet robust surveillance method that has shown efficacy for determining the relative abundance of AMR microbes that includes the isolation and molecular characterization. Findings from our studies in northern Colorado merit extension to additional locations locally and globally and may help us prevent as well as better understand the relationships to AMR infections occurring in medical and health care settings.

Ongoing Research Utilizing Strains from this Research Study: *Investigations to Reduce Growth and Pathogenicity of Multidrug/Antibiotic Resistant Bacteria Isolated from Environmental Waters Using Synbiotics (Probiotics/Prebiotics)*

A growing body of research supports the broad-spectrum antimicrobial activity of gut-native probiotics, including the *Lactobacilli*, *Bifidobacteria* and *E. coli* Nissle, against multiple gram positive and negative human, and animal pathogens. Prebiotics, notably rice bran, which is produced globally during rice milling, have the potential to enhance the natural antimicrobial function of probiotics by modulating production of small, bioactive compounds. We have previously shown that rice bran enhances the growth-inhibitory function of *L. paracasei* against *Salmonella* Typhimurium (Nealon et. al. 2017), reduces *Salmonella* invasiveness in cell culture models (Rahman et. al. 2016), and increases native gut *Lactobacilli* while simultaneously reducing *Salmonell*a shedding in mice (Kumar et. al. 2012). Collectively, this warrants further examination into how probiotics and rice bran synergistically reduce the growth and virulence of other pathogens which contain antimicrobial resistance and emerging concerns for infectious outbreaks.

This project uses both gram positive and negative probiotics isolated from the human gastrointestinal tract. The spent, cell-free culture "supernatant" is harvested from these probiotics, fed in the presence and absence of rice bran, and are applied to various ARB species where it will be screened for growth-inhibitory potential. ARB species under investigation include *E. coli* and *Pseudomonas putida*, both of which are widely implicated in human and veterinary nosocomial infections. We hypothesize that some species of probiotics will be more effective than others at suppressing ARB growth, and that this effect will also depend on the ARB isolate. Furthermore, we predict that rice bran will potentiate the growth-inhibitory function of the probiotic species supernatant against ARB.

The Preliminarily tests against a KPC+ESBL resistant E. coli isolated from a water influent source (prior to waste water treatment) demonstrated efficacy to suppresses growth, and the effect was enhanced with rice bran. L. paracasei and E. coli Nissle (two additional probiotic strains) can differentially suppress the growth of ARB E. coli, supporting our initial prediction that probiotic species vary in their ability to suppress the growth of environmental ARB isolates. Future projects will integrate metabolomics, genomics, and proteomics approaches to understand how and which small bioactive compounds are responsible to reduce ARB growth and virulence.

Gram negative ARB, including Pseudomonas and E. coli, are among some of the biggest catalysts in the spread of antimicrobial resistance. Thus, a major goal of the 21st century will be to develop effective and sustainable methods that mitigate their spread through human, animal, and environmental systems. We have evidence to support that probiotics and rice bran may be effectively applied to ARB isolates from local environmental systems. Our goal is to reduce the spread of ARB through food and animal production systems, and have viable strategies to lower ARB prevalence in human/animal infections and avoid untreatable infectious disease outbreaks.

The CSU Water Center Grant provided funding support to identify and isolate Antimicrobial Resistant Bacteria in Environmental Waters in Northern Colorado.

Collecting community sewage samples for AMR isolations in the lab. Pictured: Adriana Romera, Masters of Public Health Student and Amethyst Holder, Masters Student in Toxicology.

Elizabeth Ryan

Investigating Deficit Irrigation

as a Climate-Smart Farming Option

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Louise Comas, U.S. Department of Agriculture, Agricultural Research Service;
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Nora Flynn soil sampling at the Limited Irrigation Research Farm. Photo by Lee Friesen

SYNOPSIS

Global water supplies available for irrigation are declining while food demand continues to rise. Deficit irrigation offers a promising strategy to reduce water use with minimal impacts to yields, but is likely to have a range of impacts on soil nutrient cycling processes and climate change mitigation potential. To address this issue, we examined deficit irrigation effects on microbial communities, C and N cycling and greenhouse gas emissions. With a focus on sustainability and economic feasibility, deficit irrigation was investigated as an opportunity for farmers to meet the growing challenges of irrigated agriculture. We discovered that deficit irrigation could be a useful management strategy to improve crop water efficiency and mitigation of greenhouse gases.

Water on the Front Range

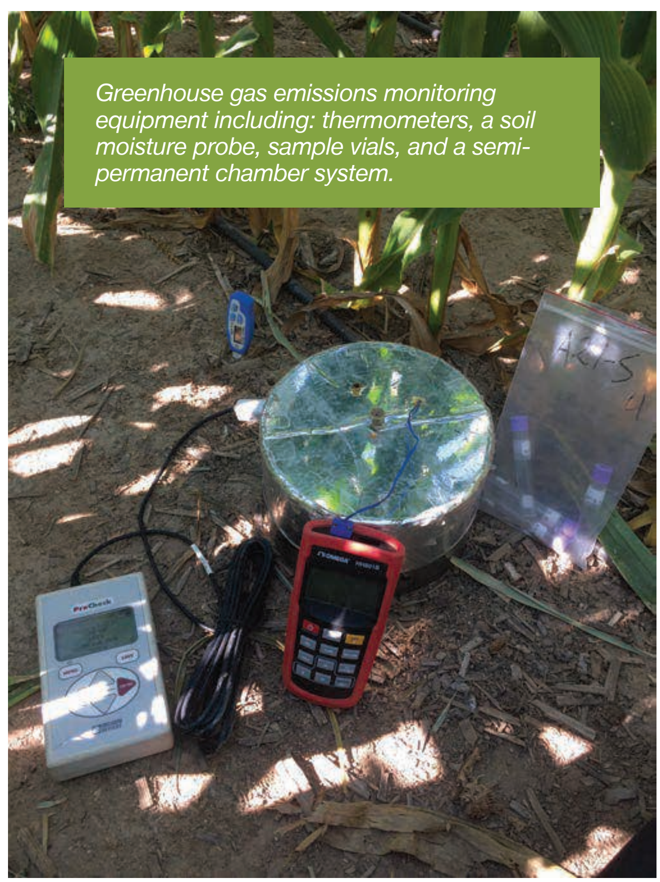
One fifth of corn produced in the U.S. is grown in the Great Plains under semiarid conditions and water is the most important limiting resource for corn production throughout the region. To avoid water stress, corn plants require approximately 24 in of water. In an average year, water in the soil profile at the beginning of the season is typically around 6.5 in in areas along the Front Range (e.g. Greeley, Colorado – where this study was conducted), leaving a difference of over 15 in to be provided by rainfall and supplemental irrigation (Schneekloth & Andales, 2017). This can represent a significant challenge for many farmers, particularly in dry years. Farmers in the region are accustomed to occasional high temperatures and low precipitation, decreasing yield and profit. However, the projected increase in severity and duration of drought will heighten the challenge of profitable production for farms and rural communities (Derner et al., 2015).

The booming population on the Front Range and demand for municipal water use puts further strain on Colorado water supplies. An encroaching water supply gap for 2.5 million new Coloradans by 2050 has caught the attention of producers and politicians alike. Agriculture is the dominant consumer of water in Colorado, comprising 85% of water use in the state. So naturally, municipal and industrial interests have pursued agricultural water to meet growing demands. The current status-quo practice of buy-and-dry implies the procurement of agricultural water rights and transfer to thirsty urban areas, thus threatening irrigated agriculture across much of the state.

Colorado's Water Plan recognizes growing municipal needs while striving to protect irrigated agriculture, which is important for the state's economy and cultural identity. Novel irrigation management practices in Colorado are needed to reduce water usage, allow for water sharing, support rural livelihoods and improve long-term farm sustainability. The goal of this research was to evaluate deficit irrigation as a climate-smart alternative to conventional irrigation management, by examining its impact on soil health and a range of important soil processes. Climate-smart refers to practices that allow farmers to better adapt to climate change and to mitigate drivers of global warming via carbon sequestration and reduced greenhouse gas emissions (Paustian et al., 2016). Additionally, we sought to gauge the economic viability of deficit irrigation with agro-econometric modeling.

Deficit Irrigation

Deficit irrigation is a promising management strategy for improving the efficiency of crop production per unit of water. By definition, deficit irrigation implies watering crops below what is required to replace the water used in photosynthesis and lost via evaporation from the soil and therefore induces crop water stress. To minimize the impact of water stress on yield, researchers as the U.S. Department of Agriculture (USDA) Agriculture Research Service (ARS) of Fort Collins are investigating how to optimize deficit irrigation with strategic watering regimes that are based on plant growth stage characteristics. Fully watering during the reproductive and grain-filling stages is crucial for realizing maximum crop yield, though it remains unknown how much stress plants can endure during less sensitive growth stages (late vegetative and maturation) before incurring unacceptable yield penalties. For



Greenhouse gas emissions monitoring equipment including: thermometers, a soil moisture probe, sample vials, and a semi-permanent chamber system.

Nora Flynn

Julia Young measuring plant water stress at the Limited Irrigation Research Farm. Photo by Nora Flynn

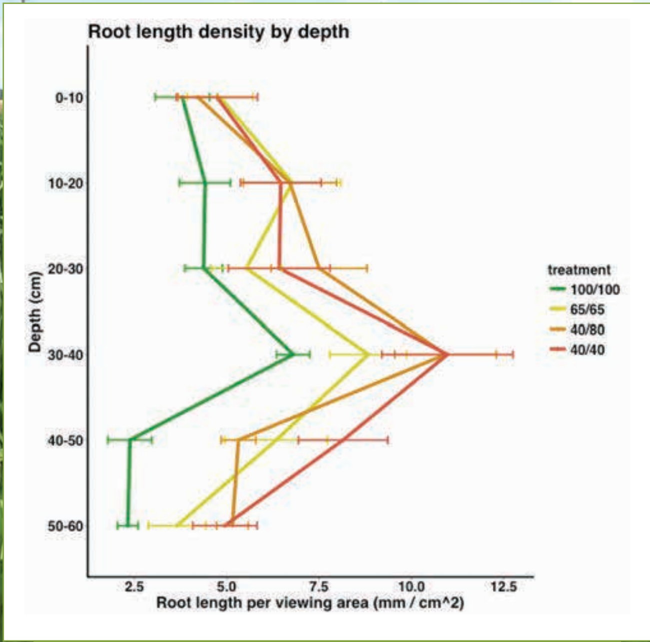


Figure 1. Root length density measured using a minirhizotron tube buried in the soil. Treatments varied with levels of irrigation and are named for the target percent of maximum crop evapotranspiration (ET) during vegetative and maturation growth stages respectively (e.g. a 40/80 treatment targets 40% of maximum ET during the vegetative growth stages and 80% of maximum ET during the maturation growth stages). All treatments are fully watered during the reproductive growth stage. Deficit irrigation treatments (65/65, 40/80 and 40/40) had greater rooting density than the fully irrigated treatment at all depths.

example, at the experimental farm where this research takes place near Greely, Colorado, a deficit treatment which uses 16% less water may suffer only a 6% decrease in yield, and in some environmental and economic scenarios, this could be optimal for producers.

Carbon Sequestration

Soils contain three times the amount of carbon found in vegetation and twice that found in the atmosphere. Understanding how agriculture impacts carbon cycling has large implications for the global carbon budget and associated impacts on climate. Soil organic carbon is also an essential element of soil health and fertility and offers numerous benefits for a growing crop (e.g., greater water and nutrient storage, improved drainage and tilth). Typically, carbon storage increases with higher plant biomass inputs to the soil. Corn plants under deficit irrigation have reduced aboveground growth which limits how much biomass can be incorporated into the soil. However, reduced growth of stalks and leaves under deficit irrigation is often associated with increased root growth, particularly at deeper soil depths. A deeper, denser root system is characteristic of plants grown under water shortages (Figure 1) because they expend more energy to mine water deep within the soil. This root growth trait helps corn plants survive times of drought, and has the potential to contribute to greater soil carbon sequestration in the long-term, since deep roots decompose (and release carbon back to the atmosphere) more slowly than aboveground residues. While our preliminary findings do not support the idea for greater carbon sequestration under deficit irrigation, we find it encouraging that soil organic carbon levels have not decreased under deficit irrigation, despite four years of reduced aboveground inputs.

Nitrous Oxide Emissions

Agricultural soils are a major source of greenhouse gas emissions. The majority of anthropogenic nitrous oxide, a greenhouse gas 300 times more potent than carbon dioxide, comes from agricultural activity. Nitrous oxide emissions are produced under common conditions found in irrigated agriculture: moist soils with an excess of nitrogen fertilizer. We found that deficit irrigation, because of its tight control over these two variables, tended to reduce emissions of nitrous oxide in comparison to fully irrigated systems (Figure 2). Monitoring greenhouse gas emissions over the growing season revealed that emissions were closely associated with irrigation and fertilizing events, further suggesting that close management of these activities offers great potential to reduce greenhouse gas emissions.

Economic Considerations

Deficit irrigation can improve crop water use efficiency in times of water scarcity and help to reduce agriculture's impact on the environment by mitigating greenhouse gas emissions, but still, there remain significant legal and economic barriers to implementation of this management practice in Colorado. Legal challenges exist in long-standing water court procedures which complicate handling and sharing of water rights. Our agro-economic analysis on deficit irrigation suggests that the price of water would have to be substantially higher than what it currently is to make deficit irrigation economically viable. This means that for the time being, water is a cheap enough input that limiting its application to save money does not result in increased net profit. In other words, to maximize expected profit, it is worth it to fully irrigate and realize full yields. This result holds as long as the opportunity for cost of leased water remains below $247 per acre-foot. As of March 2016, lease prices in the Colorado-Big Thompson regional pool were $93.75 per acre-foot. Therefore, deficit irrigation is not optimal at current water prices, but if water in the region becomes more costly, deficit irrigation may provide an opportunity to respond to water scarcity and sustain farms and rural communities through changing climatic and economic conditions.

Conclusion

Just as climate and the environment determine the success of a growing season, agriculture significantly impacts the climate variables and health of the environment. Developing climate-smart agricultural management is critical for the future of food production and in mitigating climate change. In these studies, we found that deficit irrigation may be a promising management strategy for improving crop water use efficiency in the future, mitigating greenhouse gases, and bolstering rural livelihood in certain economic conditions.

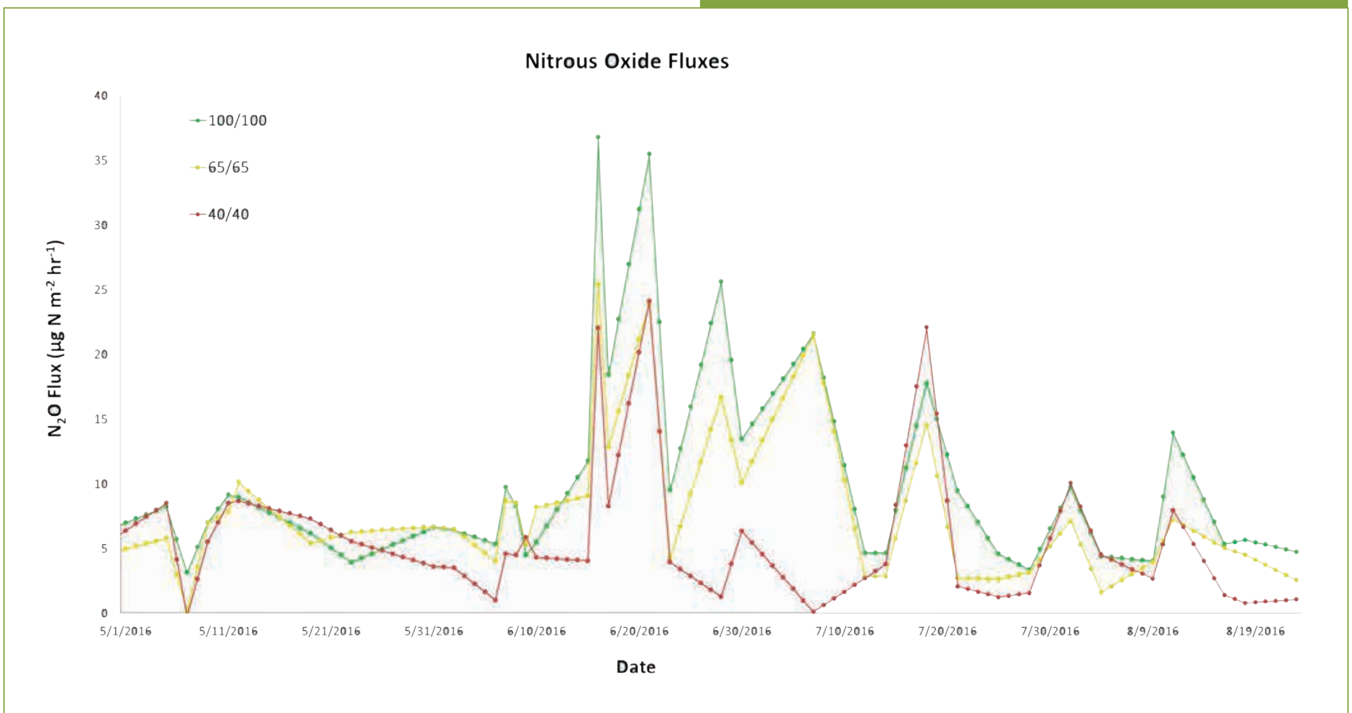
References

Derner, J.D., Joyce, L., Guerrero, R., & Steele, R. (2015) USDA Northern Plains Regional Climate Hub Assessment of Climate Change Vulnerability and Adaption and Mitigation Strategies.

Paustian, K., Lehmann, J., Ogle, S., Reay, D., Robertson, G.P., & Smith, P. (2016). Climate-Smart Soils. *Nature,* 532: 49-57.

Schneekloth, J. & Andales, A. (2017). Seasonal Water Needs and Opportunities for Limited Irrigation for Colorado Crops. Colorado State University Extension, Fact Sheet No. 4.718.

Figure 2. Nitrous oxide fluxes during the 2016 growing season. Treatments were varied by levels of irrigation and are named for the target percent of maximum crop evapotranspiration (ET) during vegetative and maturation growth stages respectively (e.g. a 65/65 treatment targets 65% of maximum ET during the vegetative growth stages and 65% of maximum ET during the maturation growth stages). All treatments are fully watered during the reproductive growth stage. The deficit irrigation treatments (65/65 and 40/40) tended to have lower fluxes of nitrous oxide emissions.



Colorado River Salinity, Then and Now

Steve Mumme, Political Science, Colorado State University

SYNOPSIS

Salinity is a major issue in the Colorado River, plaguing water resource managers. Irrigated agriculture along with municipal-industrial use further exacerbates the issue. A mini-symposium discussing the historical significance of the U.S.-Mexico Salinity Crisis was held in March 2017 to provide the opportunity for further discussion and understanding of this issue. One of the panel discussions provided a historical account of diplomatic water arguments in the U.S. and Mexico, as well as discussion on Minute 242, a binational water management standard. The second panel focused on present-day salinity problems.

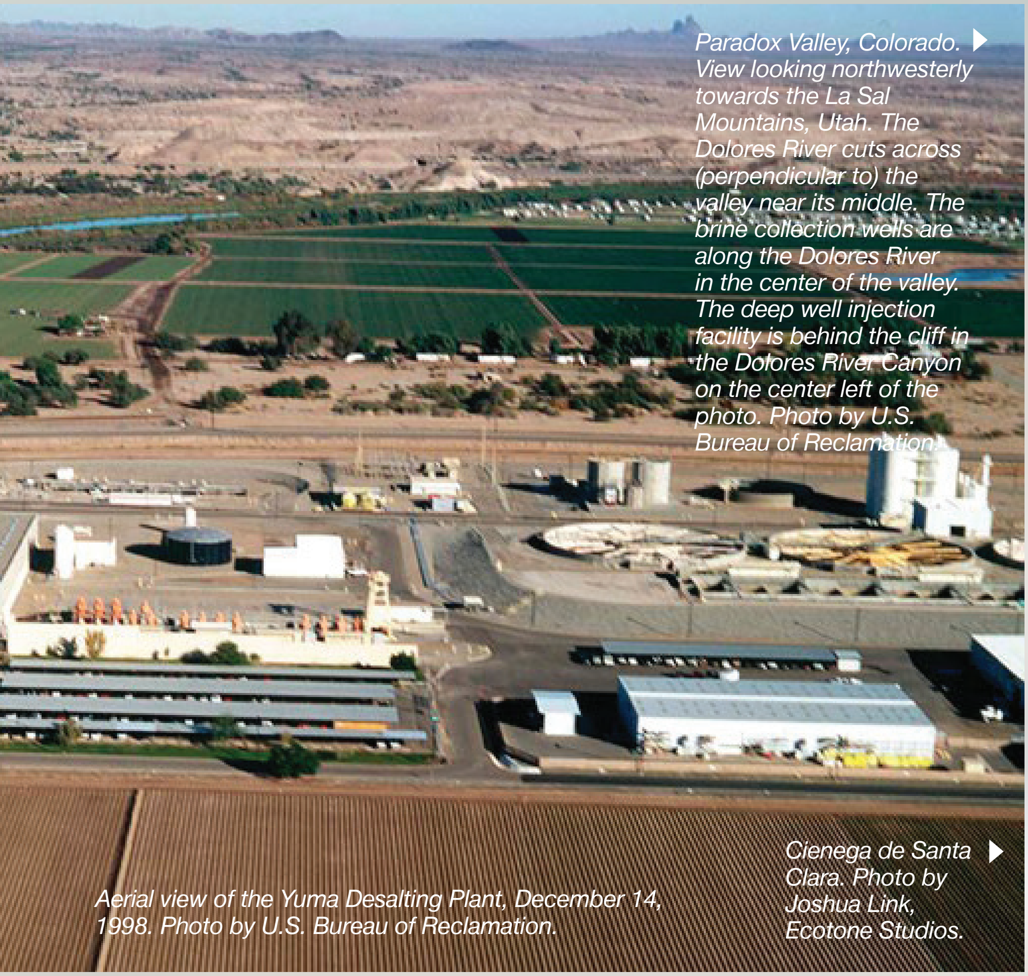
Mexicali newspaper depiction of the salinity problem in the Mexicali Valley, circa 1962. Courtesy of El Rio magazine and Ruben Castro Bojórquez

Of the serious challenges facing Colorado River managers, salinity ranks second only to drought. The Colorado River ranks among the most naturally saline rivers in North America. Human utilization in various forms, from irrigated agriculture to municipal-industrial use, only amplifies the river's salinity. Today, salinity is treated as a cultivation problem, a public health problem, an infrastructure problem, and an environmental problem. But it was not always so.

The Colorado River's salinity problem gained international prominence in October 1961, when, with the assistance of the U.S. Bureau of Reclamation (USBR), Arizona's Wellton-Mohawk Irrigation District on the Gila River began dumping highly saline effluent into river water bound for Mexico. That event triggered the most contentious water dispute in U.S.-Mexico history, and its resolution, International Boundary and Water Commission Minute 242, signed in August, 14, 1973, set a standard for binational water management that impacts all waters that cross the international boundary with Mexico, not just the Colorado River.

The history and implications of this historic agreement were examined in depth on March 24, 2017 at a Mini-Symposium on *The U.S.-Mexico Salinity Crisis, 1961-1973: History and Significance for Colorado River Management Today*, sponsored by the Colorado State University (CSU) School of Global Environmental Sustainability and the Colorado Water Institute (CWI). Organized in two panels, the symposium drew together a roster of Colorado River experts ranging from historians and social scientists to hydrologists and conservationists.

The first panel featured historical studies by CSU's political scientist, Steve Mumme, Brigham Young University (BYU)'s historian, Evan Ward, and Colegio de la Frontera Norte water specialist, Alfonso Cortez-Lara. Mumme's presentation traced the diplomatic arguments across three administrations in both countries showing how an initial U.S. defense of salinity, under provisions of the 1944 Water Treaty with Mexico, became less persuasive in the context of evolving ideas on public health and environmental protection, and the evolution of international rivers law. Minute 242, he argued, is the key agreement consolidating U.S. and Mexican commitment to the landmark 1944 Water Treaty allocating water on the Colorado River and



Aerial view of the Yuma Desalting Plant, December 14, 1998. Photo by U.S. Bureau of Reclamation.

Paradox Valley, Colorado. View looking northwesterly towards the La Sal Mountains, Utah. The Dolores River cuts across (perpendicular to) the valley near its middle. The brine collection wells are along the Dolores River in the center of the valley. The deep well injection facility is behind the cliff in the Dolores River Canyon on the center left of the photo. Photo by U.S. Bureau of Reclamation.

Cienega de Santa Clara. Photo by Joshua Link, Ecotone Studios.

the Rio Grande River. From a political perspective, Minute 242 remains the second most important water agreement we have with Mexico.

Ward emphasized the cultural and political importance of the salinity agreement for Mexico. Minute 242 not only improved water quality for the Mexicali Valley and the Colorado River Delta, it cemented international ties that ensured future cooperation in managing the River's salinity. He also noted that the salinity agreement was important for Mexico and Latin America, by establishing the principle of equity and fairness in bilateral water sharing, strengthening American hemispheric influence.

Cortez-Lara noted that salinity's legacy still haunts the Mexicali Valley. Mexican farmers were never compensated for their losses during the decade long salinity dispute. But, they take pride in the fact they are treated as equals under the 1944 Water Treaty, their water quality protected by an international agreement with their powerful neighbor to the north. Even so, salinity remains a serious problem in certain areas of the Mexicali Valley.

The second panel examined contemporary salinity issues on the River. Brad Udall observed that the salinity dispute was a wake-up call for Colorado River stakeholders, addressing one of the most serious and chronic problems associated with the West's most intensively utilized river. The 1974 Colorado River Salinity Control Act (CRSCA) ushered in one of the most important federal programs on the River, still ongoing. After 1973, water quality would match water quantity in river management.

Jennifer Pitt, Director of the Audubon Society's Colorado River Program, described how Minute 242 fortuitously helped forge Minute 319 —now up for an extension. Minute 242, she noted, required draining saline Wellton-Mohawk water to Sonoran mudflats in the Colorado River delta. The original idea was to purify this water at a newly authorized desalting plant in Yuma, reclaiming most of the water for U.S. beneficial uses and passing the brine to Mexico. The desalting plant was built but construction delays, high operating costs, and abundant river flows in the 1980s postponed operations. As saline groundwater flowed to the mudflats, the Cienega de Santa Clara was born. It is today the region's largest wetland, providing 70% of all bird habitat in the Delta.

When drought-driven conservation policies on the River threatened the Cienega's saline water supply, environmentalist sprang to action, driving much of the recent innovation in Colorado River management. State water agencies in the lower basin and the U.S. Bureau of Reclamation were persuaded to coordinate drought contingency planning with unprecedented new water storage, treatment, and transfer arrangements beneficial to Cienega and the Delta. The 2010 Mexicali earthquake, which led to temporary storage of Mexican treaty water in Lake Mead, gave water managers additional flexibility, facilitating agreement on Minute 319.

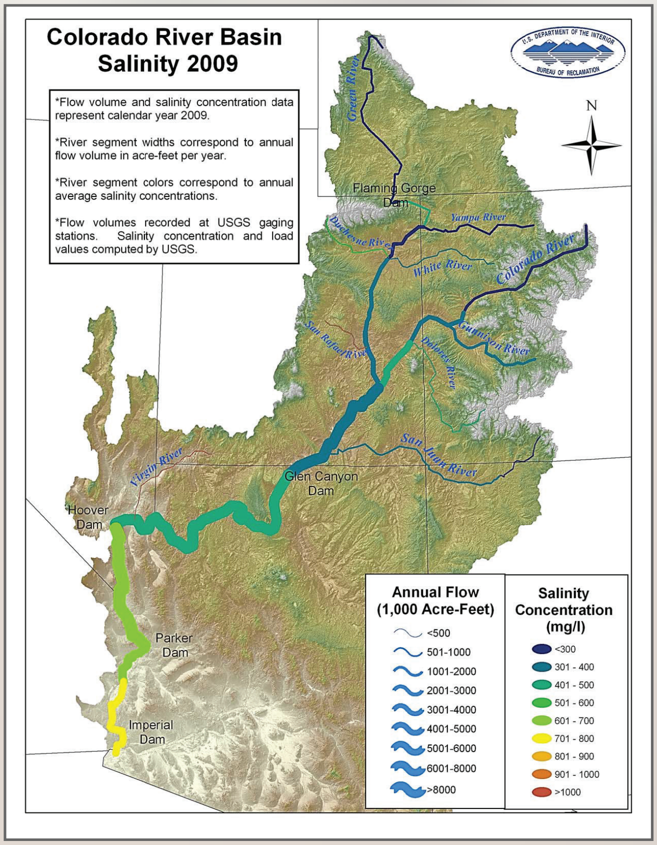
Complementing Pitt's assessment, Jennifer Gimbel, who was the director of Colorado's Water Conservation Board, Principal Deputy Assistant Secretary for Water and Science, and a participant in the bilateral negotiations for Minute 319, attested to the importance of Minute 242 in shaping contemporary discourse on the River. The 1974 Colorado River Salinity Control Act, she noted, established the Colorado River Salinity Control Program and the Colorado River Salinity Control Advisory Council, jointly funded by the U.S. federal government and the states, to advance salinity mitigation efforts basin-wide. These efforts are still vital for meeting the Minute 242 obligations to Mexico and other needs in the upper and lower basin.

And the Colorado River is facing serious challenges in this regard. The USBR's Paradox Valley Unit on Colorado's Dolores River alone accounts for upwards of ten percent of the total salinity abatement on the River but is about to exhaust its capacity.

Working with Mexico is essential, Gimbel noted. Minute 319 considers how to treat salinity when some of the conservation measures are implemented, like intentionally created Mexican surplus. Gimbel praised Mexican IBWC Commissioner Roberto Salmon for taking a "huge risk" and persuading his government to allow the participation of the U.S. basin states to join in the diplomatic negotiations on Minute 319. The basin states in both the U.S. and Mexico are involved in the negotiations for Minute 32X, which is another win-win for both countries, enabling both nations to better cope with reduced flows on the River while sustaining Minute 242's water quality aims.

Symposium participants agreed that the "Permanent and Definitive Solution" to the salinity dispute achieved in 1973 continues to shape water management practices in both the upper and the lower Colorado River basin. Brad Udall summed it up well when he said, "I like the idea that this is the first real commemoration of Minute 242. The historical specifics may have been lost but not the impacts."

International Boundary and Water Commissioners Roberto Salmon and Ed Drusina sign the historic Minute 319 in November 2012. Photo Credit: U.S. Bureau of Reclamation.



Map of Colorado River Salinity 2009. Map credit: U.S. Department of the Interior and U.S. Bureau of Reclamation.

In Memory of Professor Evan Vlachos

Panagiotis D. Oikonomou, Postdoctoral Fellow, Colorado Water Institute, Colorado State University

Left Photo by Panagiotis Oikonomou

Evangelos (Evan) C. Vlachos, Emeritus Professor of Sociology at Colorado State University (CSU) held a joint appointment in Department of Civil and Environmental Engineering. Dr. Vlachos, a renowned international expert in water resources and environmental planning and management, passed away on June 16, 2017 from complications of Alzheimer's disease. He was 82 years old, and had lived most of his life in Fort Collins, Colorado. He is survived by his wife Virginia, his daughter Irene, his son Dean, his four grandchildren: Kristina, Alexandra, Nicolas, and Eleni, and many friends and colleagues.

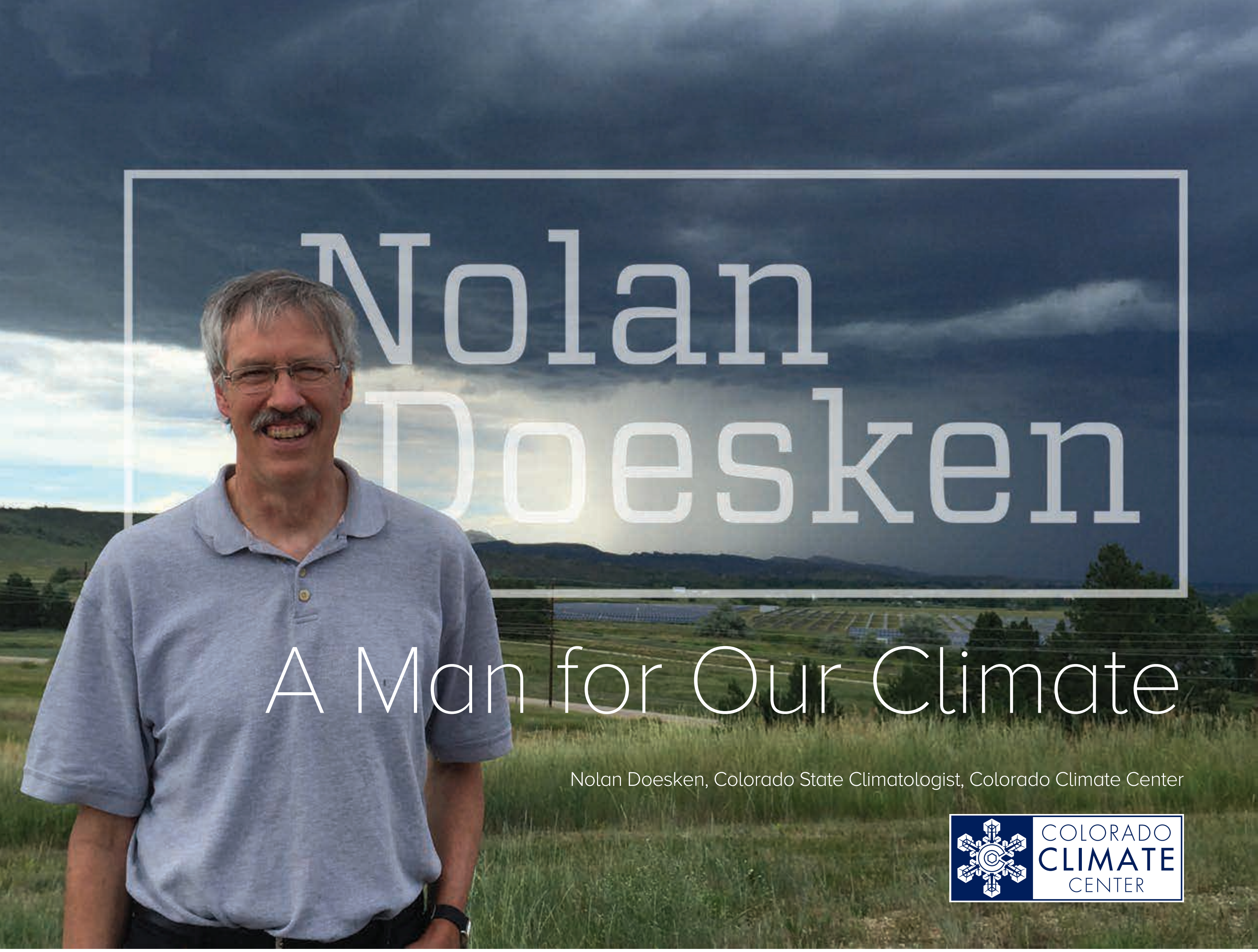
Dr. Vlachos was born on November 15, 1935, in Piraeus, Greece. Upon the completion of a Bachelor of Laws from the University of Athens and subsequent military service in the Greek cavalry, he received a Fulbright Scholarship in 1960, which led him to pursue his graduate studies in the U.S. In 1962, he received a M.A. in Sociology, and in 1964, he obtained his Ph.D. in Sociology, as well as a Certificate of Russian Studies, all from Indiana University. Moreover, he was a polyglot having mastered English, French, Russian, and German, with some Italian along with his native language Greek. Dr. Vlachos was a true scholar, pursuing continuous learning to various topics and a bibliophile with a personal library exceeding 30,000 volumes.

After his graduation and for the next two academic years, Dr. Vlachos taught sociology at the American College of Greece, in Athens as an Assistant Professor. In 1966, he returned to the U.S., and accepted a faculty position from the University of Colorado at Boulder. Dr. Vlachos joined the Department of Sociology at CSU in 1967. Early on, Dr. Vlachos progressed his career from general sociology to interdisciplinary studies, particularly in integrated water resources planning and management, environmental studies, urban planning, technology assessment, futurism, and social forecasting. He was a Principal Investigator, Co-principal Investigator and a key scientific member of extramural research projects funded by several federal and state agencies, along with the European Commission. Dr. Vlachos has been invited as a prominent expert by the United Nations and European Union agencies, NATO, foreign governmental units, professional organizations, as well as an foreign universities

Dr. Vlachos had held key administrative positions such as: Director of the Environmental Resources Center, Associate Director of the International School for Water Resources, Chairman of the Environmental Advisory Board (USACE), and Chairman of the Advisory Panel on Environmental and Earth S&T (NATO). He was the driving force behind CSU's role as a founding member of the International Center for Integrated Water Resources Management (ICIWaRM), a UNESCO category II center. During his academic career, he has produced ten books, 63 articles/chapters in books, 20 book reviews and essays, 42 monographs and technical reports, and over 130 papers for professional meetings. Even after his official retirement in 2008, he continued with the same eagerness and enthusiasm to be active in research, advising, and consulting.

Dr. Vlachos has been the recipient of several awards including the U.S. Army's Corps of Engineers Medal of Outstanding Civilian Service Award, the American Water Resources Association's Icko Iben Award, the CSU Oliver Pennock Distinguished Service Award, the Outstanding APA Colorado Planning Award, and the CSU Office of International Programs Distinguished Service Award. In 2011, as a result of his life-long significant scientific contributions, he received an Honorary Doctorate in Civil Engineering from Aristotle University of Thessaloniki, Greece. The European Water Resources Association (EWRA) honored Dr. Vlachos as a distinguished member of EWRA for his outstanding contributions in the field of water resources management.

A notable part of Dr. Vlachos's life was devoted to educating the future generations of sociologists and engineers, giving emphasis on the importance of interdisciplinary work. He was an encouraging, empowering, and an altruistic mentor, putting first the academic success and the wellbeing of his students. Dr. Evan Vlachos considered the biggest gift of his career to be the shared memories and long-lasting friendships with numerous colleagues, from all over the world, who he collaborated with throughout the years. He will continue to be a part of the hearts and minds of the people who had the privilege to cross his path, and will stand as the epitome of an exemplary scholar and a wonderful man.



Nolan Doesken

A Man for Our Climate

Nolan Doesken, Colorado State Climatologist, Colorado Climate Center

I had visited Colorado twice before coming to Fort Collins to interview for the position of "Assistant State Climatologist" in the fall of 1977. When I was 7 years old, our family took an amazing two-week camping trip to Rocky Mountain National Park (RMNP)–towing a home-made camper trailer that my dad had designed and built. A few years later when I was 18, just before I headed off to college to study meteorology at the University of Michigan, we made a return trip – this time driving a Volkswagen pop-up camper that could maybe hold a top speed of 35 mph (on a good day) climbing Colorado's mountain passes. Those summer camping trips to the Rockies left thrilling memories of sudden summer hail storms turning the ground white and morning ice on the water bucket resting the camp stove. I knew I was far from my home in rural (and very flat) central Illinois. I never dreamed I would be back to work here.

Weather changes and storms were both thrilling and fascinating as long as I can remember. As a little boy, I was already watching the clouds every day and was totally entranced by lightning dancing on the horizon during many summer evenings. Watching snowflakes in the yard light outside the kitchen window was equally mesmerizing. I loved listening to the local farmers talking outside the post office or at the grain elevator about the weather and their crops. Many then still relied on folklore passed down through the generations, to provide clues about upcoming weather changes. As best I can remember, we talked about the weather every day and always looked forward to what Mr. Roberts had to say on his weather report each evening at precisely 6:15 PM on WCIA Channel 3 (the only station we could get on our TV). As a young teenager delivering the afternoon newspaper to almost every house in our little town

Photo by Henry Reges

(about 60 as I recall), I could already read the clouds and interpret changing wind patterns. On Palm Sunday in 1965 I road my bike faster than I had ever ridden before – propelled northward by a 40 mph tail wind towards a billowing storm cloud ahead. Despite my speed, the storm moved away even faster. Then a subtle change in wind direction and humidity told me our threat for storms had passed. I was disappointed at first, but when we heard the news of a massive tornado outbreak not that far from us over in Indiana, my attitude changed. Yes, we were missed but we were also spared.

Every writing assignment I had in my high school English classes, I would work in some interesting content about the weather. That was the only way I could stay motivated. During my junior year of high school, my English teacher gave me a little card with a hand-written note saying "Nolan, you should be a weather writer". While there was no such job, I did find that hopeful. I also was encouraged when I picked up the local paper (which I did each day as I loaded the papers in my bicycle baskets before heading out to deliver them) seeing articles written by the "State Climatologist" describing agricultural impacts from recent storms and how the past month's temperature, precipitation, and snowfall compared to long term averages. That seemed like a really cool job.

> "Every writing assignment I had in my high school English classes, I would work in some interesting content about the weather. That was the only way I could stay motivated."

The statistics of weather fascinated me – even more than the statistics of my favorite baseball players. Here is where my dad helped out. He kept a journal much of his life where, among other things, he recorded temperatures, precipitation, snow accumulation, and cloud cover. My dad always let me look at his journals from past years and share them with my friends. While it may seem odd, my friends and I really enjoyed pouring through those journals, remembering what we were doing on those previous days and years, and then tabulating averages, ranges, and extremes from his weather reports. How often does it rain on the 4th of July? How often have we had snow on Christmas? What's the most rain we've ever had in one day? When it was too hot or cold outside to play our favorite sports, we played "climatologist" and had a blast. What did our parents think? They must have been amused.

When it was time for choosing a college, I still was not sure you could make a living as a meteorologist, but that was really the only subject that was interesting to me. There were no colleges nearby then that had a meteorology program, so with some trepidation and financial fear, I applied out of state and ended up being accepted at the University of Michigan's College of Engineering where they had a meteorology and oceanography program. I am getting way too long-winded here, but there was a memorable moment in my life there where my academic advisor, I am sure with my best interest in mind, told me firmly and sincerely, "Do not go into climatology. It is a dead field". He went on to describe the growing opportunities in computer modelling, numerical weather prediction, industrial and air pollution meteorology, satellite and radar (remember, Colorado's first operational weather radar was installed out in Limon in 1970 – right when I was starting college. He broke my heart, but I knew he was probably right. There were scarcely any jobs in the 1970s for climatologists. More than half of my classmates quickly got jobs as weather forecasters with the National Weather Service (NWS) right after they graduated. Others chose TV – a rapidly growing field then, too. For some reason, I chose grad school instead and headed back to Illinois to be closer to home – and closer to "climatology".

On to Colorado – Just Barely

I finished my Master's degree in Atmospheric Science during 1976 and turned down PhD research opportunities. I was burned out from school and I hoped a climatology job would appear in Illinois. It did, but I was not selected. After over a year looking for work and finding nothing, I was discouraged and considering a career change – to food service. There were always jobs in food service, and there would be plenty of opportunity to talk about the weather. But then that magical day came – a new job posting in Colorado "Assistant State Climatologist" Wow, what could be more perfect. While I never heard of Colorado State University (CSU), I had heard of Fort Collins. I had toyed with short wave radio and had built one in 8th grade. WWV – was the all-important transmitter of the official "National Bureau of Standards" time and pure radio frequencies. I imagined "Fort Collins" as a military base, high in a secure portion of the Rocky Mountains. I imagined wrong.

To earn an interview, I had to submit a short essay with my application about drought and communicating drought information to the public. I do not know what I wrote, but I eventually did get an interview. The late Bill Gray (CSU Hurricane expert) asked some easy questions, Tom McKee, the State Climatologist showed me around and took me to his favorite Mexican restaurant, and the late Lew Grant – both farmer and atmospheric scientist – grilled me with tough questions about climate, water, and irrigation. I thought I was sunk as I knew so little about irrigated agriculture. In Illinois, 30" of rain might be a drought. Here 30" surpasses the wettest ever for much of the state. It was so different, but somehow I was selected and within weeks I was moving to Colorado – young, single, driving a Volkswagen camper, leaving all my "Big Ten" friends behind – but very excited to get to work with a great deal to learn.

40 Years Later

It has been a marvelous ride. From the first week on the job learning the geography of the state point by point (literally – hand tabulating monthly precipitation totals for about 220 weather stations and then plotting them on a map) to my last week working full time in August 2017 wrapping up and cleaning my office, every week has been a pleasure. I have learned something new almost every week, and I have had so many chances to share what I have learned with those of you whose lives and livelihoods are directly affected by the varieties of weather that make up our climate. When I started, slide rules were still acceptable and mainframes and punch cards were the high tech of the day. Whatever we imagined the future might be like 40 years from 1977, I do not think we would have imagined everyone walking around with powerful computers in their hands in near-constant communication with far away friends, family, and colleagues – while often ignoring face-to-face contact. And these "smart phones" put a lot of weather and climate information at our fingertips. The Colorado Climate Center's office phone used to ring many times each day with callers seeking climate information. Now very few individuals think to call – thinking if it is not online it must not be available.

The amount of weather data available has vastly increased–vastly. Instead of a few weather stations reporting once an hour from a handful of airports, now it seems like almost every neighborhood has a weather station reporting almost constantly. But (and this comes as a surprise to many) the amount of weather data well suited for climate analysis remains small. Why do I say that? The most valuable weather stations for climatological analysis have long-term observations taken accurately and consistently over many decades from "representative" locations. Weather stations reporting automatically from the rooftops of neighborhood schools, backyard balconies, or airport taxiways can be very useful for tracking current weather conditions and patterns. But to assess how this year's temperatures or precipitation compare to the last year, ten, or even 100 years ago requires much more rigor.

The Rhythm of Our Annual Climate Cycles

So much about being a climatologist in a place like Colorado is being in tune with the seasons. While my job has been less tied to the academic calendar than most employees at a university, it has been totally tied to

> "Every year I have had the honor of tracking and reporting the conditions and the results—like the scorekeeper in the biggest game of the year. What could be more fun than that?"

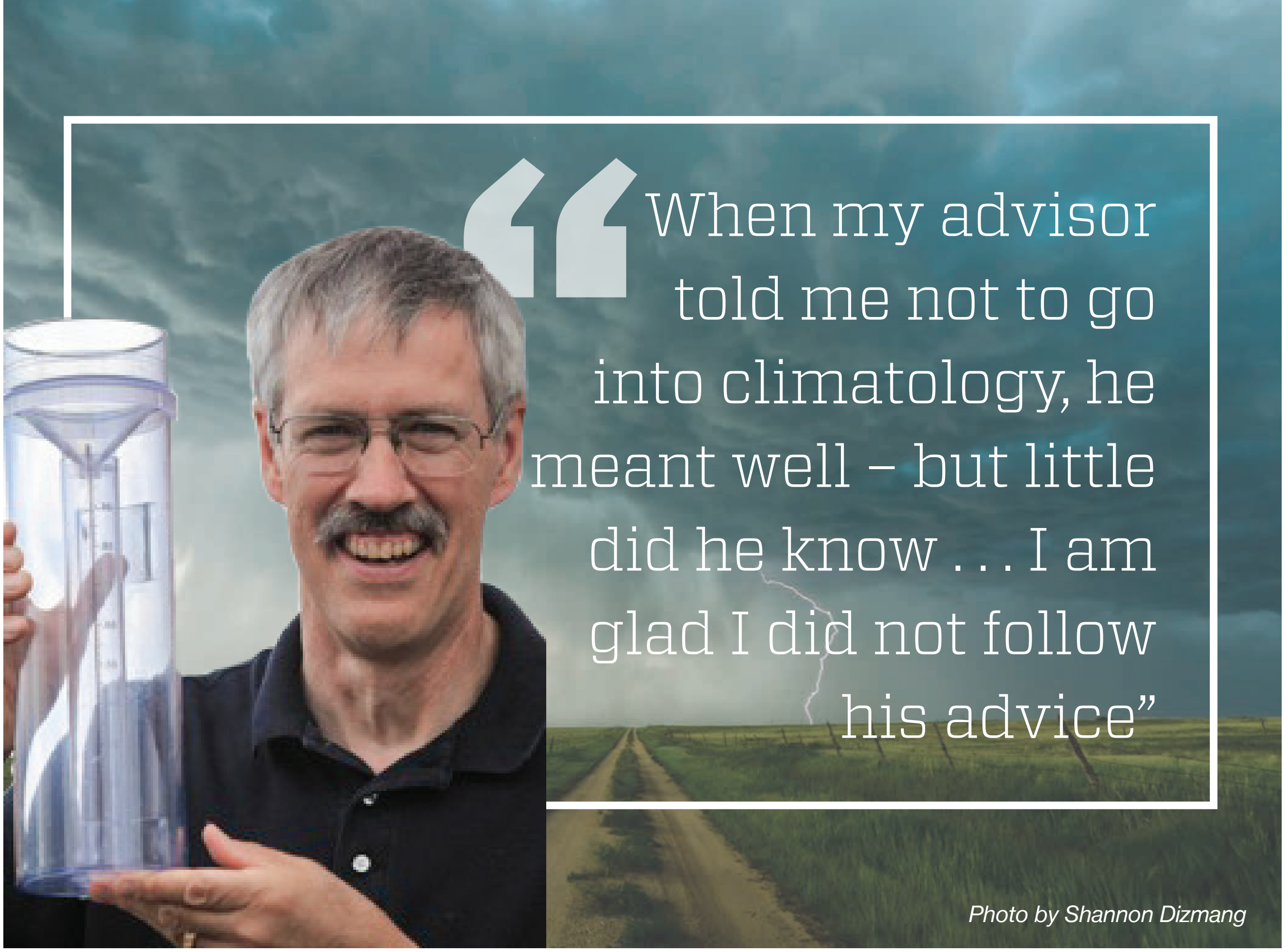


Photo by Shannon Dizmang

Henry Reges

the rhythm of the seasons – particularly the water year calendar (October 1 – September 30). That was new to me when I first came to Colorado but quickly became a part of my calendar and life. Beginning in October, most years at least, snow would begin to accumulate in the high mountains. All winter with a certain level of excitement and anticipation, we follow the accumulation of snowpack. We track it carefully comparing it closely with previous years we were familiar with. Why? Because it is our immediate water supply for the next year. The culmination each year would come in the spring and early summer when in just a few weeks, the snow would melt and hurry down the rivers. Watching this each year quickly gave me an appreciation for why our agricultural ancestors worked so hard to build dams and diversion to bring that water to the land and spread that water from the few weeks of the runoff season and share it among the duration of the growing season. It converted a resource into livelihoods for many generations and we continue to benefit from their efforts long ago.

Each year the general cycle is the same – driven by the calendar and the position of the sun. But the details are always different – the dry years, the early snowmelts, the wet years, the big spring surprises. And every year I have had the honor of tracking and reporting the conditions and the results—like the scorekeeper in the biggest game of the year. What could be more fun than that?

Floods, Droughts, and Some Really Big Storms

As I get older (and this is probably true for all of us and not just climatologists) I remember most clearly the big events – the floods, droughts, and the really big storms. The more average years blend into the background while the extreme events stand out. For example, I will never forget the remarkable May snowstorm in Fort Collins during my first spring in Colorado (1978) or the giant hail storm the following summer. The winter drought of 1981 on the heels of the 1976-77 drought changed the way Colorado’s ski industry did business. Likewise, the back-to-back huge snowmelts of 1983 and 1984 impacted water management for decades to come.

Floods and big storms leave indelible marks on lives and landscapes, but it is drought that troubles us climatologists most. I will never forget the drive to Denver in 2002 to our spring “Water Availability Task Force” meeting – a task force that I have served on since it was created back in 1981. It was hot, windy, and painfully dry for what is normally our spring wet season and snowmelt runoff time. Smoke was already billowing from an early season wildfire southwest of Denver. Pulling into the parking lot of the Colorado Office of Emergency Management (then at Camp George West in Golden), the parking lot was jammed with emergency vehicles and TV camera crews. Rather than the normal friendly meeting with 10-15 water experts from a variety of local, state, and federal agencies, the meeting had to be moved to a large building packed with commissioners, agency leaders, and emergency responders. What had been "dry weather" had exploded into a drought emergency and we had let it slip up on us. Of all the situations, we deal with, drought is the least satisfying, the most nagging, depressing, and probably the most important. Every year that Colorado escapes drought is a good year indeed, but drought lurks right around the next turn.

Coming to Grips with Climate Change

People have always talked about climate change. The variable nature of climate makes it seem like things are always changing – at least in some ways. We found a comprehensive climate report written here at the Colorado Agricultural College (CSU's original name) 100 years ago addressing the question of climate change. Following on the western expansionist theory that "rain follows the plow", many Colorado farmers and economic developers had come to believe and promote that expanded agricultural irrigation was further changing the climate – making it wetter and even more favorable. But data collected here on campus at our long-term weather station, plus other similar weather and water supply observations in Colorado and beyond indicated differently. Indeed, there are wetter periods and drier periods, but overall the report states that contrary to popular beliefs, the climate here was not changing.

Fast forward 100 years. It is quite remarkable what has taken place over my career. When I took my first college course on general climatology over 45 years ago, I was taught that we may be headed towards the next ice age. There was a growing sense that our 6,000 years of relative climate comfort and stability may be nearing an end. We had a homework assignment on "geoengineering" to come up with theories on how to save the globe and civilization from glaciation. We talked about how we could spread carbon black in polar areas to hasten snowmelt and, perhaps try to increase the consumption of fossil fuels to emit more greenhouse gases into the atmosphere. Funny huh? Meanwhile at that same time other scientists were tracking the first 15 years of data collection on the carbon dioxide content of the free atmosphere over Hawaii and were concluding that was already taking place.

When I first started working at CSU, I think many if not most of our faculty were skeptical about the potential for humans influencing the climate on a global scale. With our National Oceanic and Atmospheric Administration (NOAA) and National Center for Atmospheric Research (NCAR) colleagues in Boulder closely tracking greenhouse gas concentrations, there was no doubt what was happening. And year-by-year it became more obvious that the source was our global emissions from burning fossil fuels. Still, many of us believed that our atmosphere, land, and oceans would somehow rally on our behalf to compensate for the increases in greenhouse gases we were observing – perhaps by reflecting more of the sun's incoming energy from more and brighter clouds or perhaps by absorption in the deep ocean.

We climatologists, intimately familiar with the strengths and weaknesses of the data from our networks of weather stations, also questioned our own data. When temperatures appeared to be rising a little bit, we found that some of our own favorite weather stations (like our precious historic station on the CSU campus dating back to the 1870s) were affected by urbanization, and showed warming trends that were not necessarily representative of rural areas. Automation of weather measurements and changes in instrumentation added more uncertainty. We saw warming trends emerging in our datasets, but we doubted our own data.

It is true that the climate varies a lot for several reasons and that variability continues. When there is large year-to-year variability like there is in our precipitation totals, it is hard to notice change. But after 40 years here in Colorado and another century of data before that, the observational evidence for climate change is great. The theoretical evidence for greenhouse warming is even greater. Spending time as a child in the Great Lakes area, we used to honestly believe the lakes were so large they would dilute the effluent from our industrial cities and would remain pristinely clean. By the 1960s we were learning we were wrong and acted. The same thought process has gone on with the atmosphere and oceans. They are so large they will offset anything we as humans can do. Again – a poor assumption. I was slow to grasp the seriousness of "global warming" but I am on board now.

I will always remember our first invited talk about climate change. It was 1988 or thereabouts. The Colorado Young Farmers organization from northeastern Colorado invited the State Climatologist, Tom McKee, out to Akron, Colorado. I got to tag along. There was no politics or cynicism involved. The farmers were sincerely interested in getting a scientific assessment specific to Colorado on what increases in greenhouse gases might mean. Tom prepared an excellent talk making a case for why increases in greenhouse gases could increase temperatures and affect other parts of our climate. One of the farmers followed up with an earnest comment. "It looks like the climate may be changing. But look at agriculture and how our practices have changed over the past 60 years. We are adaptable and we can and will change as the climate changes. But what we can't handle is the darn year-to-year variability." -- words of wisdom, I am sure.

When my advisor told me not to go into climatology, he meant well – but little did he know . . . I am glad I did not follow his advice.

The Most Fun of All – Getting Folks Involved in CoCoRaHS

When we had the historic 1997 flash flood in Fort Collins, it was a terrible time – deaths, damage, trauma, and despair. But it launched CoCoRaHS – the Community Collaborative Rain, Hail, and Snow network. Yes, we were just a bunch of volunteer enthusiasts watching the weather and sharing our rain gauge reports online and seeing how amazing our weather world is—the big sprinkling can in the sky soaking some, missing others, the coming back later to catch the places that were missed. Volunteers, equipped with plastic rain gauges and helpful spirits continue to collect a plethora of valuable scientific data. But CoCoRaHS has becomes so much more than just a source of precipitation data. It has also helped build friendships, collaborations, and even government agency partnerships beyond our wildest dreams. And the fact that the White House continues as an active participant – icing on the cake!!! CoCoRaHS is my favorite "lowest common denominator". Carrying a rain gauge with me everywhere I go these past 20 years in hopes of stirring up more volunteers has been fun, and I will not stop just because I am retiring.

Climate is not a specialist's science. It is our science – a public science--something we can all share. CoCoRaHS has made that easier.

The Next Generation

As I exit my role as State Climatologist, I am happy to report that we have very competent and energized younger staff who have the same interest and passion as I did when I started, plus a lot more technical skills. The Colorado Climate Center and the state of Colorado will be in very good hands. And with any amount of luck I may stay around part time helping in the background – organizing our climate library, preparing some of our information for the CSU Water Resources Archive, finishing some research projects, and telling stories about the "good ole days" when climatologists plotted and drew the monthly precipitation maps by hand. ☺

Check out our website at:
http://climate.colostate.edu/

Twin Lakes, Colorado by Mark Byzewski

A Changing "Climate" at the Colorado Climate Center

Saying Goodbye to Familiar Faces, Hello to What's New

Becky Bolinger, Climatologist/Drought Specialist, Colorado Climate Center

Introduction

Let me introduce you to the Colorado Climate Center (CCC). Some of you may know us, some may not. But we have been here, within Colorado State University's (CSU) Department of Atmospheric Science since the mid-1970s. Many of you are already acquainted with our leader, Nolan Doesken, who has been with the Climate Center since 1976 and has been State Climatologist since 2006. Some of you may not know that he is retiring. As of my writing this, he is still in the office, wrapping up what has been a remarkable career. But as you are reading this, our Climate Center is changing management, and Colorado will see a new State Climatologist at the helm.

We could not have asked for a better State Climatologist than Mr. Doesken. His passion for observing the climate is evident. His easy-going, salt-of-the-earth personality has garnered him many friendships, not only amongst climate experts, but also throughout all sectors of Colorado and beyond. He loves talking to people, and people love hearing about the climate of Colorado from him. He has been highly regarded, across the entire spectrum: from scientists and researchers, to state government and decision makers, to farmers and ranchers and teachers. And while it is always hard to say goodbye, I want to take this opportunity to share with you why the Colorado Climate Center is still going strong and is better than ever!

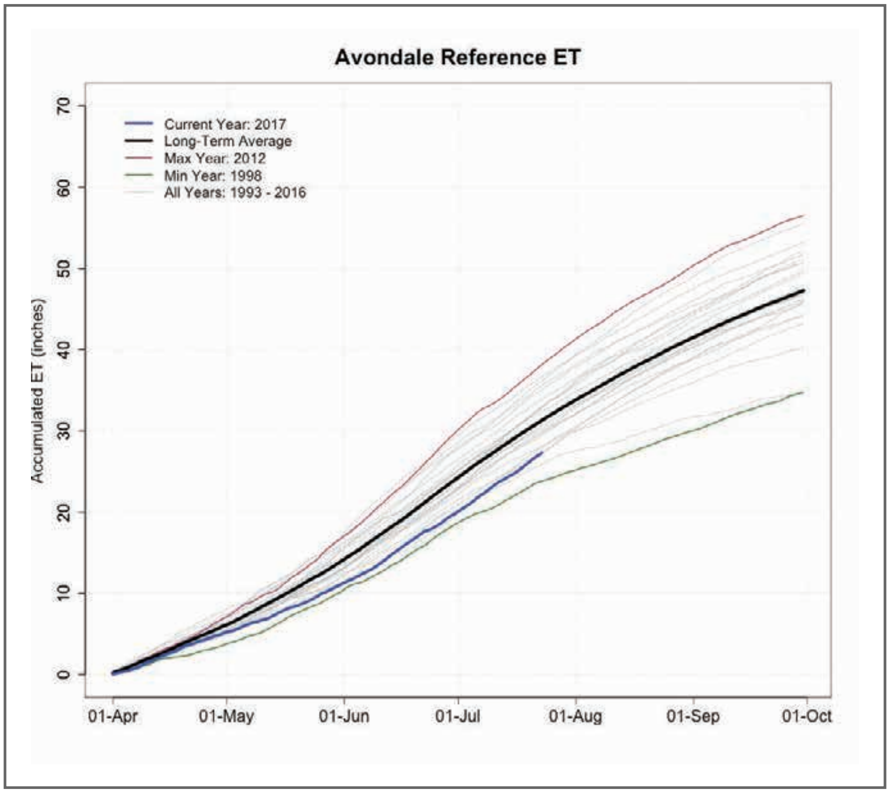


Figure 1. Accumulation of daily evapotranspiration calculated at Avondale from CoAgMET data, starting from April 1 through October 1. Farmers rely on CoAgMET's ET data for irrigation scheduling. These maps also help with drought monitoring (higher ET means more water lost from the system).

Main Functions of the CCC

Monitoring Climate of Colorado

Like a doctor, assessing the condition of their patients, the CCC takes the pulse of the state's climate, diagnoses the "health" of the current climate conditions, and identifies the causes of anomalies. The primary mission of the CCC is to monitor Colorado's climate, achieved through three activities: 1) observing and measuring the climate, 2) identifying trends and variability, and 3) placing events into historical context.

The CCC not only collects and provides data, it also operates and maintains several datasets. The Colorado Agricultural Meteorological Network (CoAgMET, also known as Colorado's mesonet) is comprised of 75 stations, mostly located in rural, irrigated agriculture areas. While there are, many uses of the data for agriculture, natural resources and environmental protection, a main motivation for this network has been to estimate evapotranspiration needed for irrigation scheduling and more effective water use (Figure 1). The CCC also operates the Community Collaborative Rain Hail and Snow network (CoCoRaHS). CoCoRaHS began in Colorado in 1998, to better capture the spatial details of local extreme flooding events (Reges et al., 2016). Since its inception, it has expanded to cover all 50 states, Canada, and the Bahamas – and still maintained by CCC staff to this day.

The CCC provides comprehensive data collection and climate monitoring on its own historical station on the Colorado State University Campus. 2016 marked the 128th year of complete and consistent uninterrupted data collection for this station. Daily data are available back to 1893, and 5-minute data can be accessed back to 1996. Not only does the CCC provide the raw data and graphics online, it also publishes a monthly report of conditions at the station.

Using the aforementioned data, and a multitude of other resources currently available, CCC researchers assess temperature and precipitation for long-term trends and variability. While researchers have identified warming trends across most regions of Colorado, little to no trends have been detected in precipitation. And, although observed trends can be useful for making assumptions about the future climate of the state, the CCC has found that the majority of its users are more interested in preparing for variability that will occur in the next season to two years. For that purpose, CCC researchers focus much effort on understanding the variability of temperature and precipitation (e.g., Bolinger et al., 2014).

One of Colorado's predominant responses to climate variability is drought. Staff at the CCC dedicate extensive resources and time to monitoring drought conditions through data and reported impacts. The CCC works closely with the sectors that are most vulnerable to drought (i.e. water and agriculture) and collaborates with scientists and experts, both locally and nationally, to better prepare for drought and mitigate its impacts.

Climate variability research also includes identifying the relationship between large-scale and local variability

> "Like a doctor, assessing the condition of their patients, the CCC takes the pulse of the state's climate, diagnoses the "health" of the current climate conditions, and identifies the causes of anomalies."

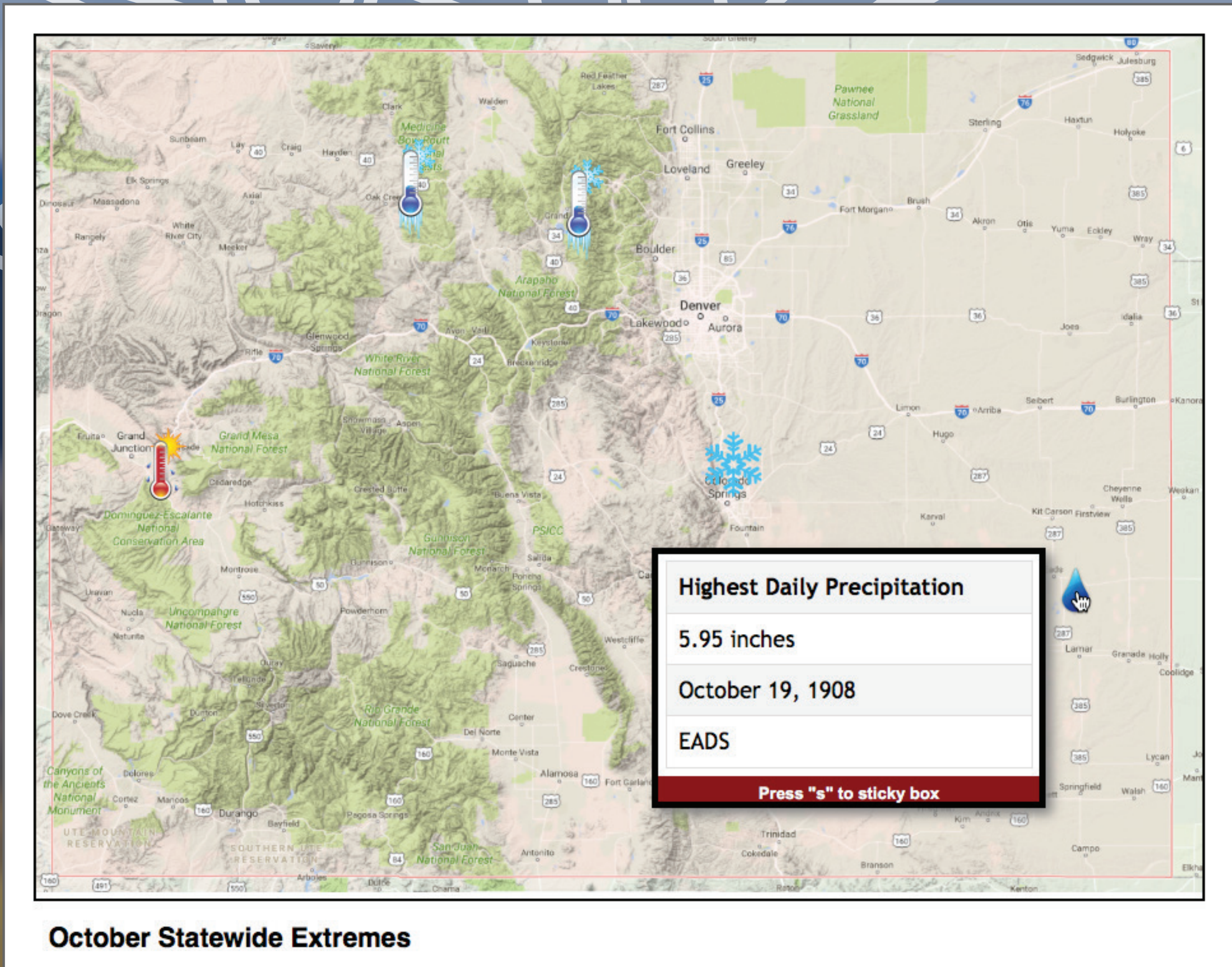


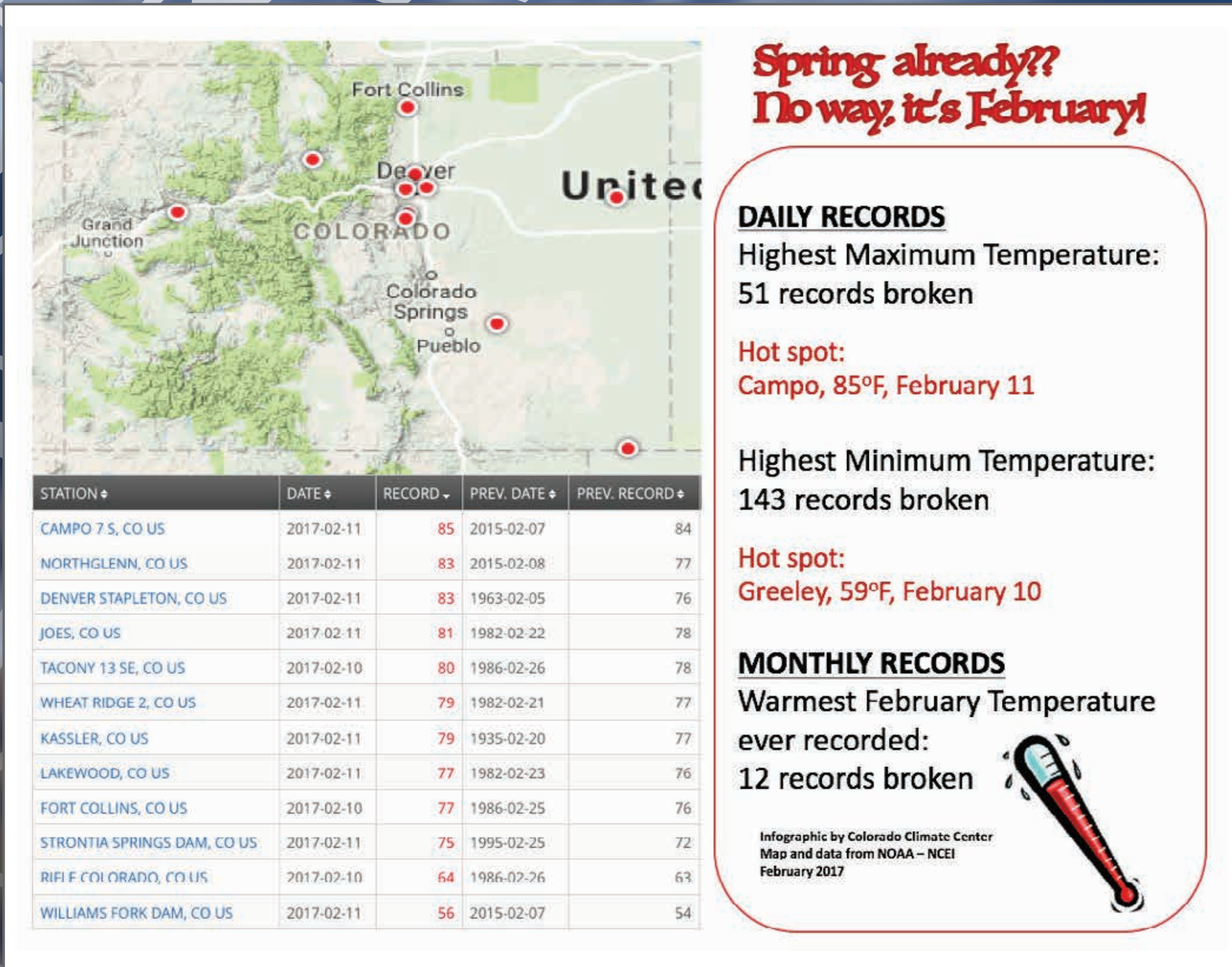
Figure 2. Map of statewide extremes for October. Mouseover an extreme location to see details, such as date of extreme, value of extreme, and station name. Taken from ***http://climate.colostate.edu/extremes.html****.*

(such as El Niño – Southern Oscillation and the Pacific Decadal Oscillation) and testing applications in seasonal forecasting (Bolinger et al., 2017).

Investigating climate variability as it relates to the long-term climatology (what may be referred to as climate "normals") allows CCC staff to communicate what is expected at any given time or location. But when an extreme event occurs, it is – by definition – rare and unexpected, far from average and sometimes outside the range of variability. The CCC works diligently (through internal research or in collaboration with others) to place these extreme events into historical context. CCC has written, or contributed to documentation, on extreme events related to flooding ("The Great Colorado Flood of September 2013" by Gochis et al., 2013 and "An Analysis of Rainfall for the July 28, 1997 Flood in Fort Collins, Colorado" by Doesken and McKee, 1998), precipitation ("Precipitation Frequency: Defining the 100-year Storm" by Doesken and Ryan, 2014), drought ("Drought of 2012 in Colorado" by Ryan and Doesken, 2013), and temperature ("July 2005 Denver heat wave: How unusual was it?" by Pielke et al., 2005). These types of analyses help the CCC better communicate how extreme these events are, and how likely they are to occur again.

Service Providers

While the CCC could conduct research and analysis (as detailed above) and simply publish within the research community, the knowledge and expertise gained is much more useful when broadly disseminated. Providing services begins with information gathering as part of the main objectives described in the previous section. It ends with how CCC communicates that information to its users. Communication can occur with



STATION	DATE	RECORD	PREV. DATE	PREV. RECORD
CAMPO 7 S, CO US	2017-02-11	85	2015-02-07	84
NORTHGLENN, CO US	2017-02-11	83	2015-02-08	77
DENVER STAPLETON, CO US	2017-02-11	83	1963-02-05	76
JOES, CO US	2017-02-11	81	1982-02-22	78
TACONY 13 SE, CO US	2017-02-10	80	1986-02-26	78
WHEAT RIDGE 2, CO US	2017-02-11	79	1982-02-21	77
KASSLER, CO US	2017-02-11	79	1935-02-20	77
LAKEWOOD, CO US	2017-02-11	77	1982-02-23	76
FORT COLLINS, CO US	2017-02-10	77	1986-02-25	76
STRONTIA SPRINGS DAM, CO US	2017-02-11	75	1995-02-25	72
RIFLE COLORADO, CO US	2017-02-10	64	1986-02-26	63
WILLIAMS FORK DAM, CO US	2017-02-11	56	2015-02-07	54

Figure 3. Infographic posted to CCC's Facebook page in response to the statewide extreme heat that had been occurring during the first half of the month. Infographic designed by Becky Bolinger on February 13, 2017.

media inquiries, outreach and education efforts, presentations to the public or special interest groups, or as specific products delivered to stakeholders and decision makers.

New Web Services

One of the most efficient ways to disseminate climate services and information is via the internet. The CCC has provided web services since the late 1990s (http://climate.colostate.edu). At that time, the website was at the cutting edge of technology, delivering climate data – raw data and graphics – that were not available anywhere else. Until recently, CCC's website has seen little change, while great leaps in technological advances and data storage have meant what could once only be accessed on CCC's website was now easily accessible in many places.

To adjust to the needs of users, the website has undergone a major "face lift" within the last nine months. Since users can access data at a variety of websites, it became pertinent to shift the direction of the site toward something more unique, while still providing information pertaining to the climate of Colorado.

One major addition to the website is the "Normals and Extremes" page (http://climate.colostate.edu/normals_extremes.html). Interactive maps display long-term average precipitation and temperature across the state. Extremes maps show the locations of temperature and precipitation extremes for every month of the year (Figure 2). Additional normals and extremes data for individual long-term stations are easily accessible. The page also includes a database "scrapbook" of historic events and interesting climatological facts for several holidays.

In addition to its main website, the CCC also hosts and updates the CoAgMET website (http://coagmet.colostate.edu) and a drought website (http://climate.colostate.edu/~drought). The CoAgMET website has recently introduced a new mapping system that allows users to view the latest updated CoAgMET data across the state and easily display graphs of a station's data over a specified time. The drought website (with support from the National Integrated Drought Information System, NIDIS) has been in operation since 2010 and is updated weekly with the latest climate, drought, and water conditions for the Intermountain West (which covers Colorado, Wyoming, Utah, Arizona, and New Mexico).

The combination of the three websites (the main, CoAgMET, and drought websites) highlights the achievements of the CCC within its three main objectives.

What the Future Holds

As we near the end of the second decade of the 21st century, it is becoming apparent that the needs of users are rapidly evolving. People do not want to take time to read lengthy publications of research. They are not interested in waiting for results. They do not want to take as much time searching for answers. They want information provided in a rapid manner and customized to their personal interest. It is essential for the CCC to be at the forefront of the ever-changing dissemination efforts. The next generation of communication is focused on social media platforms. It is found in infographics and flashy press releases (Figure 3). The CCC is currently working toward reaching that broad user-base through Facebook and Twitter.

Also, instead of simply sharing results from research, the CCC is focusing on product and tool development that will allow users to interpret climate information in meaningful ways specific to their needs. Tools will continually be added to the website to address the most popular requests.

Rest assured, that while we undergo our latest personnel change, the core mission of the CCC still stands. And we strive to provide the best climate services possible to the state of Colorado.

References

Bolinger, R. A., A. D. Gronewold, K. Kompoltowicz, and L. M. Fry, 2017: Application of the NMME in the Development of a New Regional Seasonal Climate Forecast Tool. Bull. Amer. Meteor. Soc. doi:10.1175/BAMS-D-15-00107.1

Bolinger, Rebecca A., Christian D. Kummerow, and Nolan J. Doesken, 2014. Attribution and Characteristics of Wet and Dry Seasons in the Upper Colorado River Basin. Journal of Climate, Vol. 27, pp. 8661-8673.

Doesken, N., and Wendy Ryan, 2014. Precipitation Frequency: Defining the 100-year Storm. Colorado Water, News letter of the Water Center of Colorado State University, vol. 31, 2 (Mar/Apr), pp. 20-23.

Doesken, Nolan J. and Thomas B. McKee, 1998: An Analysis of Rainfall for the July 28, 1997 Flood in Fort Collins, Colorado. Climatology Report 98-1, Dept. of Atmos. Sci., CSU, Fort Collins, CO, February, 55 pp.

Gochis, D. and Coauthors, 2015: The Great Colorado Flood of September 2013. Bull. Amer. Meteor. Soc., 96, 1461-1487.

R.A. Pielke, K. Wolter, O. Bliss, N. Doesken, and B. McNoldy, 2007: July 2005 Denver heat wave: How unusual was it? National Weather Digest, Vol. 31, #1, 24-35.

Reges, H., N. Doesken, J. Turner, N. Newman, A. Bergantino, and Z. Schwalbe, 2016: CoCoRaHS: The evolution and accomplishments of a volunteer rain gauge network. Bull. Amer. Meteor. Soc. doi:10.1175/BAMS-D-14-00213.1.

Ryan, W., and Nolan Doesken, 2013. Drought of 2012 in Colorado. Climatology Report 13-01. Dept. of Atmos. Sci., CSU, Fort Collins, CO. June, 2013.

"while we undergo our latest personnel change, the core mission of the CCC still stands"

Optimistically Innovating

Ideas Arise at the Western Water Symposium and Barbecue

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

Innovation has been constant within the Colorado water community, ebbing and flowing over time. Louann DeCoursey describes the present time as an incubation period, where ample ideas exist but lack an ecosystem supportive of innovation.

DeCoursey, CEO of the Open Water Foundation, opened the July 24 2017, Western Water Symposium and Barbecue's closing panel "The Future of Water Innovation" by describing the state of innovation. Some factors limiting achievement are the presence of subject silos, the aversion to risk and failure, and determining the "why" of innovation. As another panelist, Stewart Environmental Consulting Group CEO David Stewart, described, innovators have major obstacles to overcome, including resistance and the big one, funding.

Panelists furthered the idea of an innovation ecosystem, which would be an environment where testing could be supported and failure accepted. Facing the risk of failure is not easy for water managers, especially those who must deliver water reliably daily. To help mitigate that, Denver Water, in partnership with Colorado State University (CSU), is establishing a water lab at the redeveloped National Western Center in Denver. Greg Fisher, Manager of Demand Planning at Denver Water, discussed it as a place where scientists and engineers can try out their ideas as well as invite the public and students in to discuss and learn from what is going on.

Others on the panel moderated by Colorado Water Institute (CWI) Director Reagan Waskom included three of the symposium's four speakers. The first speaker of the day, retired Colorado Supreme Court Justice Greg Hobbs set the stage in the morning by discussing "The Poudre River's Heritage: Turn Back or Move Forward?" Many early pioneers in the area brought optimism and innovation, which mixed with inevitable conflict to produce new water laws, doctrines, and institutions. In particular, prior appropriation evolved "out of the ground, not top down" by administrators or legislators.

John Stulp, Special Policy Advisor to the Governor for Water and Director of the Interbasin Compact Committee, discussed "Water's Innovative Future," focusing on "gadgets and guts," or technological advances and the political will to imple-

(Above) Attendees enjoyed getting to know each other over the barbecue lunch in the Morgan Library courtyard.

All photos courtesy of CSU Libraries

(From top)
Emcee Jennifer Gimbel welcomed the audience to the Western Water Symposium and Barbecue.

Justice Greg Hobbs began the day by donating additional objects, including a medal from the Wright Paleohydrological Institute, to archivist Patty Rettig for his collection in the Water Resources Archive.

The panel on the future of water innovation shared their thinking in discussions with the audience. (L to R, Hobbs, Stewart, Stulp, Waskom, O'Toole, DeCoursey, and Fisher)

Jennifer Pitt highlighted innovative water management decisions on the Colorado River during her talk.

ment them. Many new gadgets exist in the various arenas of conservation, land use, agricultural practices, and the "future is here" in some cases. However, the Colorado needs to work on having the guts to achieve bigger, better outcomes, whether through simply building on previous successes, improving education and outreach about innovations, or encouraging innovation in water administration and administrators.

Following the barbecue lunch, the National Audubon Society's Colorado River Program Director Jennifer Pitt shared her experiences surrounding innovative management approaches for the Colorado River in "We're All in It Together: Crafting Colorado River Management for the 21st Century." She emphasized that while the numbers in terms of population growth and lower water supplies are not optimistic, the reasons to have hope for the basin include unprecedented opportunities for innovation, as well as existing examples of shortages breeding practical solutions, especially where population growth and water use have been decoupled. Additionally, with conservation groups now regularly invited to the table for discussions, conversations about future solutions are improving.

Patrick O'Toole, President of the Family Farm Alliance, spoke about water innovation in relation to agriculture. His talk, titled "What's Old is New, What's New is Old," emphasized finding balance in the necessary use of water for agriculture but also sustaining the environment. He stated that "the American farmer will surprise you with innovation" and they just need to be given the opportunity.

The day-long event, held by CSU's Water Resources Archive at Morgan Library in Fort Collins, began with emcee Jennifer Gimbel discussing the theme of "Water Optimism and Innovation." Gimbel, now Senior Water Policy Scholar at the Colorado Water Institute, was formerly Colorado Water Conservation Board's Director and was the Principal Deputy Assistant Secretary for Water and Science at the United States Department of the Interior.

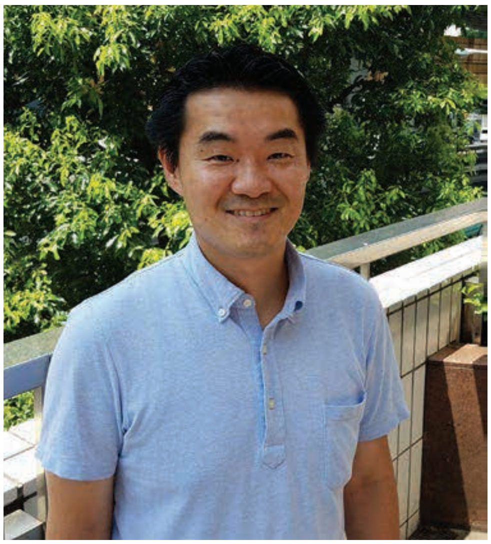
From start to finish, the day made clear that optimism drives innovation, and innovation gives a reason to be optimistic. The cycle continues in order to solve problems and improve life. Going forward, water leaders in all sectors should avoid crisis planning, engage in conversations and collaborations, nurture the right people, and remove obstacles to achievements.

Coloradans have been part of this cycle of innovation since Native Americans captured scare rainwater, Hispanics built acequia systems, and more modern settlers invented measurement devices, legal systems, and management institutions. The Water Resources Archive documents much of this history and makes it available for all to use.

The symposium concluded with displays at and tours of the archive, along with a networking reception. For more information about the Water Resources Archive and its activities, see the website (https://lib2.colostate.edu/water/) or contact the author (970-491-1939; Patricia.Rettig@ColoState.edu) at any time.

Yoichiro Kanno

Yoichiro Kanno, Fish, Wildlife, and Conservation Biology, Colorado State University



Shiho Kanno

I am a stream fish ecologist with a broad interest in conservation and management of aquatic biota and ecosystems in our increasingly human-dominated landscape. This is my first semester at Colorado State University (CSU) and I came from Clemson University in South Carolina, where I similarly held a faculty position. Throughout my career, I have studied patterns of aquatic biodiversity and processes to sustain them, which are often impacted by human activities. In fact, aquatic organisms such as freshwater fish and mussels are proportionately more imperiled than terrestrial organisms such as mammals and birds. Understanding and quantifying the linkage between aquatic ecosystems and humans is a rewarding, but a challenging task. In my pursuit of answers for sustainability, I have studied streams with a focus on fishes, ranging in topics from genetics, behavior, population dynamics to 'riverscape' ecology and have been fortunate to cover many taxa including trout, bass, minnow, sculpin and sucker.

Why do humans have to work so hard to save aquatic species and ecosystems? This is a difficult question, potentially with a wide range of answers. But I can better explain why I study stream fish ecology and conservation. I have always been fascinated by aquatic organisms and ecosystems ever since my childhood thanks to fishing and ornamental fish tanks. I grew up in the heart of Tokyo, Japan, where streams were channelized or buried underground. In some sense, urban life shaped my thinking as I wondered how streams in Tokyo would have been like hundreds of years ago, and feel on a daily basis what it would take to feed the burgeoning human population. Prior to my current endeavor as a scientist, I studied law and worked in the diplomatic service of Japan as I was primarily interested in international environmental policy. So, it may be a natural progression that I currently study how streams are affected by habitat loss and fragmentation, non-native species, climate change and angling, and relate science to conservation practices.

As I transition to Colorado, I expect to work on similar conservation ecology themes in a wide range of areas from the Rocky Mountains to the Great Plains streams. Given the arid climate and demand for water resources, I am particularly interested in how water management in the state affects stream biota and ecosystems. Needless to say, stream fish and ecosystems cannot sustain themselves without water in the stream channels and human activities inadvertently affect water quality and quantity. Water is certainly a challenging societal issue in the western U.S., but I am excited to join the CSU water community and find solutions as a member of interdisciplinary teams. In addition, my transition to Colorado will broaden opportunities to study environmental change at the continental and global scales, based on synthesis and analysis of data from other regions of the world that I am familiar with (e.g., eastern U.S. and Japan).

Every fall, I teach an undergraduate course in fish conservation (FW 400: Conservation of Fish in Aquatic Ecosystems) at the Department of Fish, Wildlife, and Conservation Biology. This course examines major threats to fish conservation and management actions to protect and restore ecological processes by drawing examples from many regions of the world. I look forward to teaching and interacting with the future steward of aquatic resources.

Yoichiro Kanno

Assistant Professor

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Water Calendar

October 2017

24-27 United States Committee on Irrigation and Drainage International Conference on Irrigation and Drainage; Sacramento, CA
This conference will provide tools and case studies for water districts to address a wide spectrum of issues while also identifying funding sources that districts can use to assist with their operations.
uscid.org/17caconf.html

25-26 South Platte Forum; Loveland, CO
The South Platte Forum provides an opportunity for multi-disciplinary exchange of information and ideas important to resource management in the South Platte River Basin.
southplatteforum.org/

30-31 21st Century Energy Transition Symposium; Fort Collins, CO
The Energy Institute and School of Global Environmental Sustainability at Colorado State University is hosting the 7th annual 21st Century Energy Transition Symposium. The 2017 theme is "Tackling, Solving & Addressing Grand Challenges"
energytransition.colostate.edu/

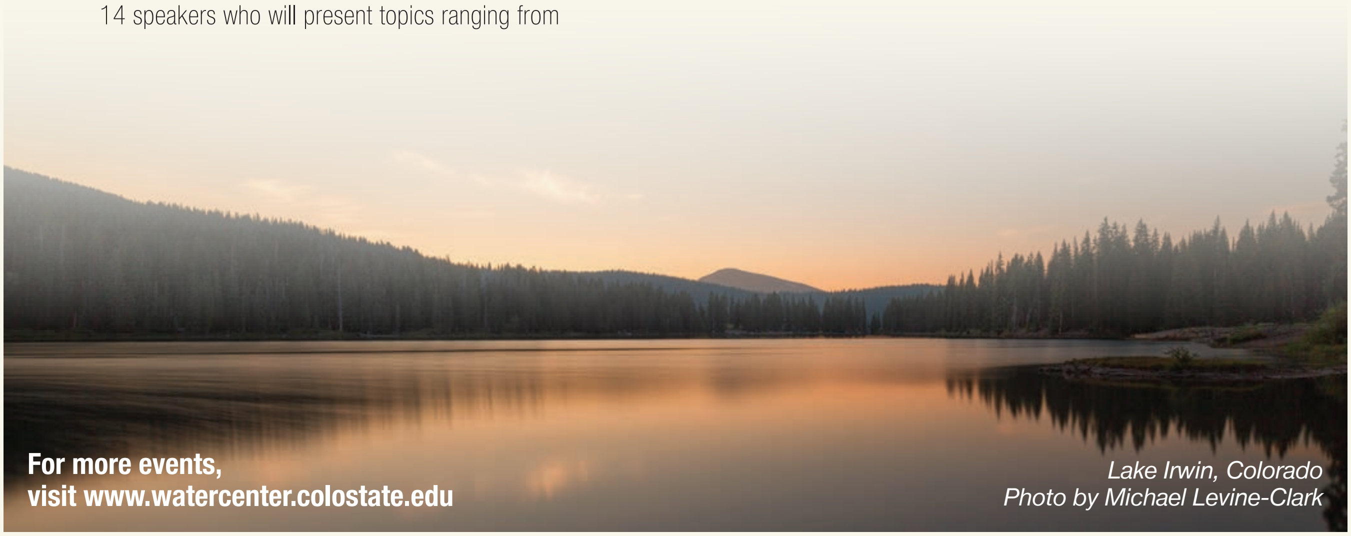
November 2017

1 2017 Big Thompson Watershed Conference – Sustaining the Health of a Working River; Loveland, CO
Join the Big Thompson Watershed Forum for its 15th biennial watershed conference. The conference will include 14 speakers who will present topics ranging from abandoned mines in the Big Thompson Watershed to status updates on Highway 34 construction.
eventbrite.com/e/big-thompson-watershed-forum-conference-tickets-32132123045

1-2 Upper Colorado River Basin Water Forum – Colorado Mesa University; Grand Junction, CO
The 2017 Forum will showcase stories that illuminate the challenges and complexities involved in trying to under stand Upper Colorado River Basin issues and manage water in new ways.
coloradomesa.edu/water-center/forum/

5-7 American Water Resource Association Annual Water Resources Conference; Portland, OR
This annual conference will highlight emerging issues related to technology, flowing water, future risk, and public policy, and management of water resources.
awra.org/meetings/Portland2017/

6-9 Operation and Maintenance of Stormwater Control Measures Conference; Denver, CO
The focus of this conference is on advances in operation and maintenance of gray and green stormwater control infrastructure, including design for maintenance, O&M training programs, new maintenance approaches, advances in municipal program management and implementation, and life cycle cost analysis.
omswconference.org/



Lake Irwin, Colorado
Photo by Michael Levine-Clark

Water Research Awards 2/10/17 — 7/1/17

Bailey, Ryan T., Colorado Water Conservation Board, Constructing and Testing a Refined Groundwater Flow Model for the LaSalle/Gilcrest Area, $48,515

Baker, Daniel W., Department of the Interior, National Park Service, Answering Ecological Management Questions for Aquatic Resources in National Parks using GIS and Remote Sensing Tools, $97,852.62

Clements, William H., Colorado Division of Parks and Wildlife, Post-Restoration Assessment of Macroinvertebrates and Terrestrial Subsidies to Brown Trout Populations in the Arkansas River, Colorado, $164,812

Cooper, David Jonathan, Department of the Interior, National Park Service, Grand Ditch Restoration Adaptive Management Monitoring, $42,466

Covino, Timothy P., National Science Foundation, Collaborative Research: How Do Interactions of Transport and Stoichiometry Maximize Stream Nutrient Retention?, $126,634

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Forsythe, John M., Department of Commerce, National Oceanic and Atmospheric Administration, Comparison of Model Versus Observationally—Driven Water Vapor Profiles for Forecasting Heavy Precipitation Events, $133,844

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The Niobrara Formation as a challenge to water quality in the Arkansas River, Colorado, USA; 2017, Journal of Hydrology: Regional Studies, (12) 181-195; C.R. Bern, R.W. Stogner, Sr.

The U.S. Geological Survey Monthly Water Balance Model Futures Portal; 2017, U.S. Geological Survey Open-File Report 2016–1212; A.R. Bock, L.E. Hay, S.L. Markstorm, C. Emmerich, Talbert, M.

Synoptic sampling and principal components analysis to identify sources of water and metals to an acid mine drainage stream; 2017, Environmental Science and Pollution Research, 1-21; P. Byrne, R.L., Runkel, K. Walton-Day

Hydrogeologic characteristics and geospatial analysis of water-table changes in the alluvium of the lower Arkansas River Valley, southeastern Colorado, 2002, 2008, and 2015; 2017, U.S. Geological Survey Scientific Investigations Map 3378, pamphlet 9 p., 3 sheets, scale 1: 130,000 and 575,000; M.J. Holmberg

Estimation of salt loads for the Dolores River in the Paradox Valley, Colorado,1980–2015; 2017, U.S. Geological Survey Scientific Investigations Report 2017–5059; M.A. Mast

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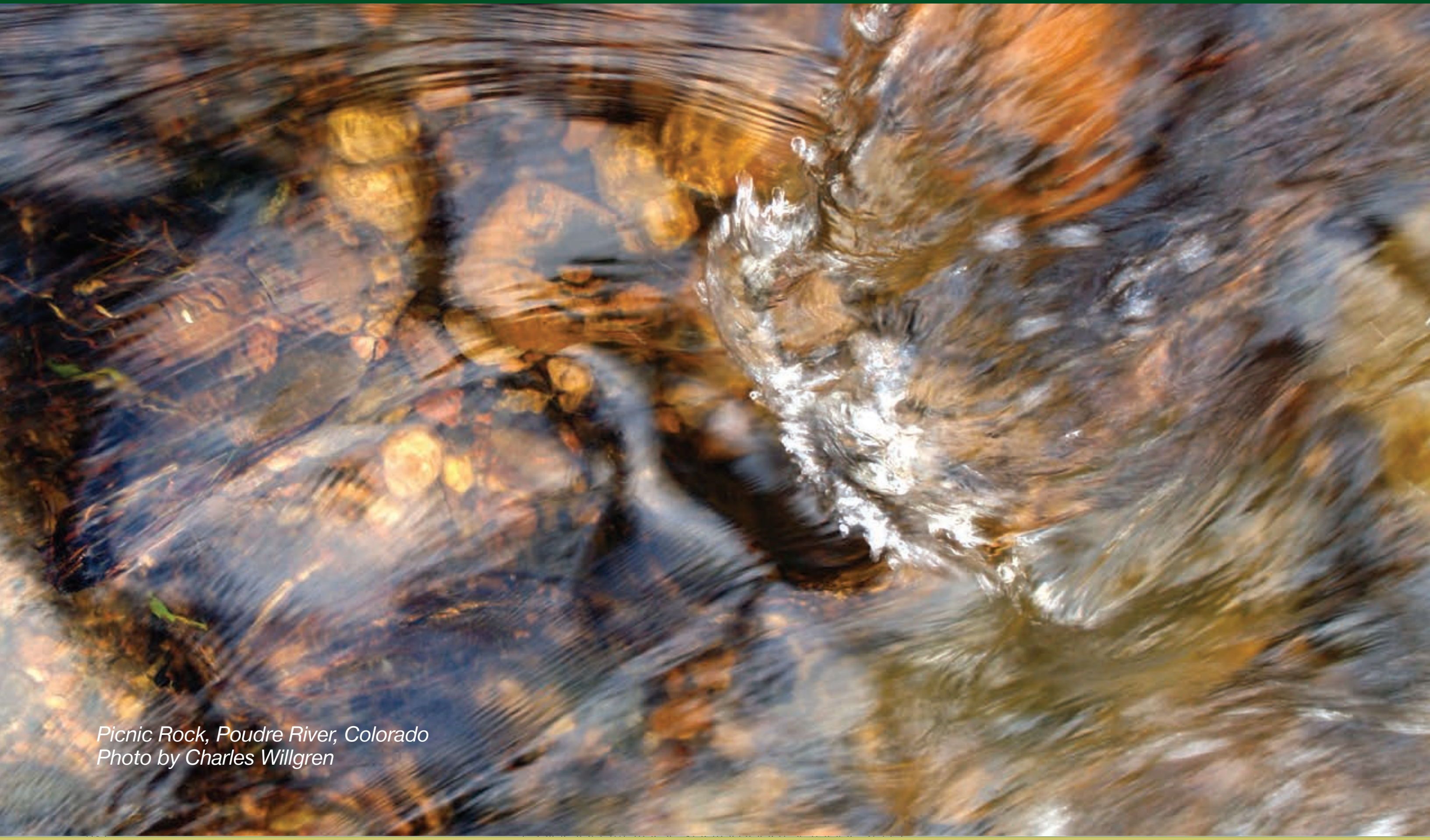

Picnic Rock, Poudre River, Colorado
Photo by Charles Willgren