Colorado Water

February 2022

COLORADO
WATER CENTER

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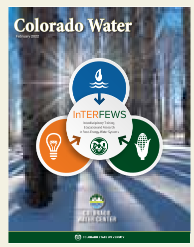

On the cover—InTERFEWS brings together doctoral students to conduct research on key problems in the food-energy-water nexus with a focus on water-scarce, arid regions. Photo © Thorin Wolfheart/stock.adobe.com.

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

Confined feeding operations, commonly known as feedlots, are generally part of the beef production system and are part of the food, water, energy nexus conversation for both water supply and quality factors. Photo by Emmett Jordan.

COLORADO **WATER**

Volume 39, Issue 2

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

Colorado Water. (2022).
Colorado Water Center,
Colorado State University

watercenter.colostate.edu

Published by

COLORADO WATER CENTER
COLORADO STATE UNIVERSITY

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Supported by
This publication is financed in part by the U.S. Department of the Interior Geological Survey, through the Colorado Water Center and CSU's College of Agriculture, Warner College of Natural Resources, Agricultural Experiment Station, and Extension.

Director's LETTER

Jennifer Gimbel, JD

Welcome to the inaugural edition of the InTERFEWS newsletter by the Colorado Water Center (CoWC). InTERFEWS is an Interdisciplinary Training, Education and Research in Food-Energy-Water Systems Program. This program brings together doctoral students from traditionally disparate disciplines to conduct research on key problems in the food-energy-water nexus with a focus on water-scarce, arid regions. In this edition there are four student articles on a wide range of issues. Brandi Grauberger, a Doctoral Student in Mechanical Engineering analyzes the wastewater management practices of meat and dairy processing facilities and proposes a couple of re-use opportunities for the treatment and processing of wastewater. Kimberly Fewless, a Doctoral Student in Civil and Environmental Engineering, analyzes several programmatic and policy concepts for streamlining and incentivizing water sharing through open space programs and land trusts. Azmal Hossan, a Doctoral Student in Sociology, discusses his interaction with the Colorado State University (CSU) Agriculture Experiment Station in the western slope and the ground-breaking (literally and figuratively) work done there through a sociological viewpoint. He features CoWC's very own Dr. Perry Cabot. Joey Blumberg, Doctoral Student in Agriculture and Resource Economics, explains that the impacts of climate change call for localized policy and resource management strategies, noting that every county is different. Finally, Peter Goble a Climatologist at the Colorado Climate Center gives a summary of Colorado's 2021 runoff season and we introduce you to Dr. Sunshine Swetnam, an Assistant Professor and the lead for the Ski Area Management Program within the Human Dimensions of Natural Resources Department at CSU. As you can see by this issue, the InTERFEWS program offers a broad range of experience and analysis. I encourage you to look into the program at the following link: erams.com/interfews/.

Jennifer Gimbel, JD

Interim Director, and Senior Water Policy Scholar, Colorado Water Center

InTERFEWS...brings together doctoral students from traditionally disparate disciplines to conduct research on key problems in the food-energy-water nexus with a focus on water-scarce, arid regions.

InTERFEWS participants toured an Occidental Petroleum well pad near Fort Lupton, Colorado, to learn about the different processes involved in fracking and production. Photo by Telbe Storbeck, Occidental Petroleum.

Holstein cattle photographed near Montrose, Colorado. Up to 36% of the water used by the food processing industry in the U.S. is used to produce beef, pork, poultry, and dairy products (Bustillo-Lecompte & Mehrvar, 2015). Photo © Jon/stock.adobe.com.

A cheese forming machine. Photo © Kadmy/stock.adobe.com.

The Needed Evolution of Animal Product Processing Facility Water Management in the U.S.

Brandi Grauberger, Doctoral Student, Mechanical Engineering, Colorado State University and InTERFEWS Trainee

Wastewater management practices of meat and dairy processing facilities need significant improvements to promote the industry's sustainability. Up to 36% of the water used by the food processing industry in the U.S. is used to produce beef, pork, poultry, and dairy products (Bustillo-Lecompte & Mehrvar, 2015). Not only is this a significant amount of water consumption, but the wastewater production from meat and dairy processing is highly concentrated with constituents including salts, proteins, oils, and nutrients. Current management systems threaten the sustainability of meat and dairy processing industries in terms of water quality maintenance and water resource management. The complexity of wastewaters from meat and dairy processing presents a barrier to developing innovative and sustainable wastewater management practices due to cost.

Over the past year, Dr. Thomas Borch from the Soil and Crop Sciences Department and Dr. Todd Bandhauer from the Mechanical Engineering Department at Colorado State University, along with their graduate and post-doctoral students, have led a collaborative research project in identifying challenges and opportunities for the use of non-traditional water sources in meat and dairy processing industries. This project was initiated through the National Alliance for Water Innovation (NAWI), a Department of Energy (DOE)-funded Energy-Water Desalination Hub project. The collaboration led to content contribution for the NAWI Agricultural Sector Technology Roadmap, published in May 2021 (Borch et al., 2021).

Meat and Dairy Processing Water Use

In the U.S., meat and dairy processing facilities generate approximately 1.8 billion gallons or 6.8 cubic meters of wastewater per day (Li, Ziara, Dvorak, & Subbiah, 2018; Masse & Masse, 2000; Matlock et al., 2011; Mekonnen & Hoekstra, 2012; Northcutt & Jones, 2004; Stanchev et al., 2020; USDA, 2005, 2020), which is equivalent to 0.5% of the total U.S. water withdrawals and 1.5% of the total freshwater withdrawals for irrigation in the U.S. (Li et al., 2018; Masse & Masse, 2000; Matlock et al., 2011; Mekonnen & Hoekstra, 2012; Northcutt & Jones, 2004; Stanchev et al., 2020; USDA, 2005, 2020). Wastewater from these operations is typically treated and either discharged to surface waters or blended with municipal wastewater for further treatment. Water use amounts and qualities vary within the industry based on the product being processed and plant scale. For example, cheese production results in an excess of water, as milk solidifying into cheese leaves a large quantity of whey, a liquid that remains after milk curdling and straining. The addition of whey into wastewater streams results in the dairy processing industry discharging more volume in their wastewater streams than the volume of fresh water they consume. As a result, cheese processors are net water producers. In contrast, wastewater volumes from meat processing facilities are similar to the amount consumed in their operations.

The composition of wastewater from meat and dairy processing is also site-specific and varies based on the processed products. For example, beef processing plants can have a hide brining process, adding a considerable amount of salt into wastewater streams. However, wastewater discharges from all facility types contain organics, solids, and nutrients such as nitrogen and phosphorous (Li et al., 2018; R. Ziara, 2015; R. M. M. Ziara, Li, Subbiah, & Dvorak, 2018). The uniquely high solids load in beef processing wastewater due to the brining processes and the challenges associated with management of those wastewaters were the drivers in focusing efforts on beef processing for this initial research.

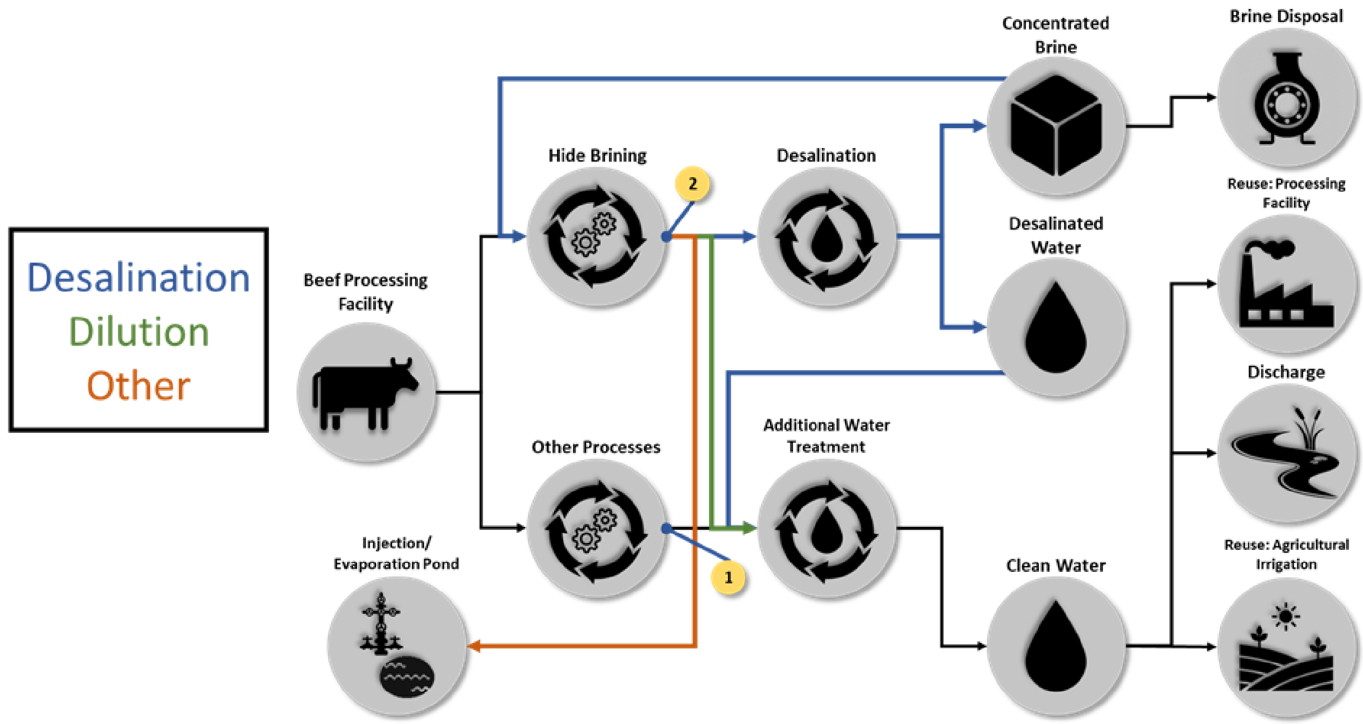


Figure 1: Flows of water through a beef processing facility. Water is used in hide brining and other processes, producing wastewater streams at points 1 and 2. Opportunities for wastewaters from hide brining include dilution for discharge, desalination, or disposal through injection or evaporation ponds. With close management of beef processing wastewaters, there may be opportunities for reuse within the processing facilities or agricultural irrigation. Graphic by Brandi Grauberger.

Beef Processing Wastewater Flows

As shown in Figure 1, the processes within a beef processing facility can be split into two different streams: meat production and hide brining. The meat production processes include all processes within the facility that are not hide brining. The brining process is removed from the rest of the facility for two reasons. First, hide brining does not contribute to the production of meat and, therefore, does not require a food-grade production system. Second, the wastewater from the hide brining process is very highly concentrated with salts. Hide brining requires a 25-40% concentration of salts (i.e., 250,000-400,000 mg/L) (Pajonk, Saurel, & Andrieu, 2003). Most of this salt leaves in the wastewater stream and produces highly saline wastewater to be managed by the processing facility. Although the volume of the stream is low compared to the main wastewater stream from the processing plant (e.g., less than one percent of total wastewater flows are from hide brining processes), the wastewater from hide brining still contributes to 64% of the total salt loads in beef processing plant wastewaters.

Figure 1 also shows the three methods of hide brining wastewater management practiced within the industry. Shown first in green is dilution, where hide brining wastewaters are added to the main wastewater stream of the processing facility in hopes that the salt concentration of the wastewater will be low enough for discharge from the plant. If the concentration is too high, freshwater is added until the required dilution is met. Alternatively, shown in the orange pathway, the brine can be sent to evaporation ponds or injection wells. In evaporation ponds, the wastewater is left to evaporate, and salts are solidified out of the wastewater. Once the water is evaporated from a pond, cleanup of the dried salts can be a hazardous and costly operation. Injection of the wastewater into the ground removes water from current water cycles and can also be expensive. A final option for hide brining wastewater management, shown in blue, is to treat it for reuse, discussed below.

Machine-formed beef patties move on a packaging conveyor in a meat processing facility. Photo © nordroden/adobe.stock.com.

Treated Wastewater Use Opportunities

The treatment of wastewater from processing facilities is currently limited by cost. Surprisingly, costs for treatment of the main wastewater stream in a beef processing plant match those for treatment of the hide brining wastewater flows, even though the volumes being treated are vastly different. Freshwater can be obtained for $0.03 per cubic meter (Borch et al., 2021). For similar volumes, treated wastewater costs are over three times higher when hide brining wastewaters are not considered and over ten times higher when they are included. The technologies capable of treating highly saline wastewaters are very expensive to install and maintain. However, one industry leader uses 17% of their treated wastewater streams for agricultural irrigation (2019 Annual and Sustainability Report, 2020). Reports from cheese production facilities also show that treated wastewater streams are used for multiple purposes throughout their plants before being discharged in surface waters or used for irrigation (*2015* Global Responsibility Report, 2017). These cases are not representative of the entirety of meat and dairy processing facilities but do provide a standard for the rest of the industry to follow in reducing water consumption and in supplying higher quality wastewaters to promote the sustainability of the industry.

There are two potential re-use opportunities provided by the treatment of meat and dairy processing wastewater. First, meat processing wastewater can be re-used within the processing facility after the treatment. This would require the removal of organics, solids, and other harmful constituents that can impact food safety. Other internal reuse options that do not require precision separation include using the wastewater in facility boilers (i.e., no need to remove nutrients) and cattle truck cleaning operations (i.e., no need to remove organics or nutrients). There is support from the U.S. Department of Agriculture (USDA) Food Safety and Inspection Service to implement wastewater reuse within processing facilities (Borch et al., 2021).

The second re-use option is outside the processing facility for agricultural irrigation. This option is attractive in areas of agricultural production and water shortages. Treating the wastewater for irrigation would require the removal of large amounts of salt and other constituents harmful to crops (Borch et al., 2021; Burkhalter & Gates, 2005). The treatment goals may change depending on the crops being irrigated, as some are more tolerant to certain constituents. The removal of nutrients (i.e., nitrogen and phosphorous) would not be required because they can serve as fertilizers for crops and result in less chemical application. There have even been studies that report benefits from using meat processing wastewaters for irrigation (Matheyarasu, Bolan, & Naidu, 2016).

A Natural Resources Conservation Service Area Engineer sets up a laser level to perform a construction inspection on a waste water lagoon for a dairy in Sacramento Valley, California. Photo courtesy of the NRCS.

None of the above opportunities are consistently implemented in current meat processing wastewater management plans due to the high cost of wastewater treatment. However, there are examples of each option being explored within the industry as indicated by the sustainability reports of industry leaders (2015 Global Responsibility Report, 2017; 2019 Annual and Sustainability Report, 2020). Wastewater reuse within the plant has been implemented at Harmony Beef in Alberta, Canada. The Harmony Beef facility has a 90% recovery rate from their wastewater treatment, and the plant shows the potential for wastewater reuse within a facility ("Our Facility - Green Practices," 2021). However, the Harmony Beef facility is not optimized for costs and is operated under gold-standard sustainability guidelines. Customers of Harmony Beef are willing to pay higher prices for products produced under the high sustainability that the facility provides. Implementation of wastewater reuse in large-scale facilities proves more difficult. Barriers to adoption include the regulations surrounding re-use within the U.S., the cost of treatment technologies in a competitive market, and the public perception of using treated wastewaters for the production of food products (Borch et al., 2021).

Continuing Research and Considerations

Implementation of sustainable wastewater management practices in the meat and dairy industry are going to prove technically difficult and financially burdensome in coming years, as the industry is pushed to achieve their promised 2030 and 2050 sustainability goals. In future efforts, this team will consider the technical and economic barriers in place for the industry. Furthermore, considerations of social and regulatory barriers will be implemented into the research. Through these efforts, we hope to assist the meat and dairy industry in meeting their sustainability goals with social and economic considerations providing support to the development of new wastewater management practices within the industry.

Collaboration for Resilience

Colorado Open Space Programs and Water Sharing

Kimberly Fewless, Doctoral Student, Civil and Environmental Engineering, Colorado State University, InTERFEWS Trainee, and Researcher, Colorado Water Conservation Board

Colorado's urban areas need water for growing populations, and they can find it from agricultural producers who hold senior water rights, but this impacts rural communities, Colorado's economy and, potentially, food security.

Along Colorado's Front Range, growth has increased urban demand for water, food, land, and energy. Although conservation, efficiency, and waste reduction reduce demand, urban areas must have a secure food and water supply. Increased demand for water has led to 'buy and dry': the acquisition of agricultural land and associated water rights and subsequent drying up of that land to allocate the water for municipal supply. Crowley County is a prime example of the devastating effects of buy and dry. During the 1970s and 1980s, a large sale of agriculture water rights to the growing Front Range resulted in a 92% decline of irrigated acreage in Crowley County. This devastated the local economy and led to drastic population decline and cascading third-party impacts.

Planning for urban water security without addressing the multitude of factors leading to 'buy and dry' has led to unprecedented loss of irrigated agriculture (working landscapes) throughout Colorado. Yet, working landscapes provide many services in addition to supporting rural economies and communities (and the agricultural heritage of Colorado) and are valued by the public. Working landscapes provide buffers between urban areas, wetland habitat, wildlife corridors, opportunities for local food procurement, and open space. A 2016 Colorado State University Food Systems public attitudes survey (foodsystems.colostate.edu/research-impacts/colorado-blueprint/public-attitudes-survey/) found that the public values working landscapes: 95% feel maintaining land and agricultural water production is important, preservation of open space and wildlife habitat are top priorities, and 83% support the use of public funds to protect working landscapes. Without a necessary transition policy in place, buy and dry impacts rural economies and social resilience. Permanent fallowing (drying up of previously irrigated agriculture) also can potentially impact wetlands and streams limit future local food procurement (potentially through regenerative practices).

Another Way Forward Through Water Sharing

One way to avoid buy and dry is through water sharing, also known as Alternative Transfer Methods (ATMs). ATMs typically pair municipal water departments with

Crowley County Crowley County, Colorado, is an is an example of how buy and dry impacts economies and communities. Photo by Jennifer Goodland.

Through a water-sharing partnership, or Alternative Transfer Method, the Little Thompson Farm, owned by Larimer County, will remain in active production with a water partner sharing some of the water during drought years. The farm is located one mile southwest of Berthoud, just north of the Little Thompson River. Photo courtesy of Larimer County.

agricultural producers in an agreement that provides urban areas water in drought years and compensates farmers for lost or changed production in those years. Alternatively, a ditch company, which provides water to a group of producers along a ditch system, could pair with municipal water providers to accomplish larger scale and added allocation flexibility. A 2020 status report provided an overview of ATMs and many examples of current projects.

The Colorado Water Conservation Board (CWCB), through the comprehensive Colorado Water Plan (cwcb.colorado.gov/colorado-water-plan) and subsequent technical update (cwcb.colorado.gov/colorado-water-plan/technical-update-to-the-plan), set goals for the adoption of water-sharing agreements to abate the buy and dry trend. The slow adoption of those agreements has led to new research endeavors.

Open Space Programs and Land Trusts as Valuable Players in Enabling and Increasing the Benefits of Water Sharing

A recent stakeholder outreach effort, conducted by the CWCB, grew out of the potential for open space programs and land trusts to engage in water sharing agreements more routinely. Open space programs and land trusts are uniquely situated to participate in water-sharing agreements. The Little Thompson ATM (larimer.org/naturalresources/openlands/acquisitions/little-thompson-farm) is an example. Institutional knowledge of the benefits of conservation, including the ecosystem services and public benefits of working landscapes, could improve many aspects of creating and managing agreements. Open space programs and land trusts already engage in conservation easements, have experience with land transactions and asset valuation, and regularly collaborate with others. They have social capital, especially in relationships with private landowners, and an institutional framework for fundraising and outreach.

The outreach effort consisted of interviewing open space programs, land trusts and other decision-makers working along the rapidly urbanizing Front Range of Colorado. Moreover, it included:(1) assessing the knowledge of and interest in water-sharing agreements, (2) investigating the conditions, such as community support for working landscapes or interagency expertise, which enable participation in water-sharing agreements, (3) understanding barriers to water sharing, and (4) developing, through stakeholder input, resources that could streamline or facilitate water sharing. Although the focus was on open space programs (municipal and county) and land trusts, other perspectives were sought after, including producers, municipal water utilities, and local politicians.

The interviews revealed several key themes. Most open space programs valued the ecosystem services, urban buffering, and habitat provided by working landscapes. Community resilience and agricultural heritage were also important. Many agreed with the value of increasing cross-department collaboration and incorporating local food into comprehensive planning.

Concerns and evident tensions speak to the need for improved resources. The increasing value of water rights and transaction costs related to water-sharing contracts are problematic. Farmers may be disinclined to tie up even a portion of their water right with its value rapidly escalating unless motivated by other factors. This is compounded by externalities, the failure of the market to capture the public benefits of working landscapes, and third-party impacts of buy and dry. In addition, differing planning horizons creates tension: municipal water providers need long-term guarantees, whereas producers may be hesitant to commit to long-term contracts. Finally, and importantly, trust and risk were also recurring themes in conversation with stakeholders, especially regarding past urban/rural dynamics and the need for farmers to look out for their financial viability and planning.

Ideas to Streamline and Incentivize Water Sharing

In conversation, several programmatic and policy ideas were suggested for streamlining and incentivizing water sharing. Many interviewees identified matchmaking (finding and/or connecting interested parties), navigation (of the water sharing agreement creation), education, and incentivization (for producers) as beneficial strategies. Many also acknowledged that involving a third party with a positive track record of producer engagement would be beneficial to facilitate communication and water-sharing agreement initiation.

Guided by those needs, three ideas resonated with most interviewees: centralized web resources, an annual or biannual webinar, and educational outreach. A centralized database/web resource could be a passive resource for interested parties to locate ideal partners. It could provide evidence of process and outcomes for existing water-sharing agreements and contact information for knowledge sharing between stakeholders. It could also provide a basic flowchart or checklist. An annual or bi-annual webinar, a sort of “ATMs 101,” could educate interested or curious parties about the water sharing agreement process, identify potential roadblocks and necessary steps to streamline future agreements, and perhaps bring stakeholders together for roundtables.

Many of the interviewees noted the need for additional education and outreach. They generally felt that it would be beneficial if more people, including municipal water departments, landowners/producers, open space programs, land trusts, elected officials, planners, and the public, knew more about water sharing and buy and dry. Finally, policies that increase flexibility in water law for these types of transactions or that incentivize water sharing for producers could be beneficial. Although this process yielded a launching-off point, additional outreach, collaboration, and feedback are needed to create tractable and effective policy ideas.

Imagining Increased Regional Resilience Through Institutional Collaboration

Meerow et al. (2016) define urban resilience as “the ability of an urban system —and all of its constituent socio-ecological and socio-technical networks across temporal and spatial scales—to maintain or rapidly return to desired functions in the face of a disturbance, to adapt to change, and to quickly transform systems that limit current or future adaptive capacity.” Working landscapes, and the cross-department collaboration necessary to facilitate water-sharing agreements, could increase resilience by providing adaptive capacity for local food systems, regional water resources management, synergistic food-energy-water opportunities such as agrivoltaics (see nature.com/articles/s41893-019-0364-5) or nutrient recycling, and social systems (especially rural communities). In contrast, buy and dry decreases adaptive capacity due to a loss in agricultural knowledge, infrastructure network/support for working landscapes, community/heritage, and ecological functions. The resilience-building aspects of water-sharing agreements are additionally benefitted (see coloradoopenlands.org/wp-content/uploads/2018/07/SHARING-WATER-TO-SAVE-THE-FARM-digital.pdf) by the expertise of open space programs and land trusts. In contrast, water sharing strictly guided by producers and municipal water departments may fail to prioritize and realize the public benefits potentially provided by working landscapes.

Looking Forward

The interview process will provide a path forward for the CWCB, open space programs, and land trusts to assist stakeholders in the initiation and execution of water-sharing agreements. This may include webinars, trust-building through messaging and communication of outcomes, dedicated expertise, or involvement of regional or state incentive programs. Although water-sharing agreements are just one piece of a large system, the collaborative nature may shape the future of Colorado’s Front Range by opening dialogue between typically siloed institutions and providing intention for maintaining working landscapes and the public benefits thus provided.

Ordway, Colorado (above), is the county seat of Crowley County. Between the 1950s and 1980s, Crowley farmers sold an estimated 80,000 acre-feet of water rights to the growing cities along the Front Range. As a result, only about 7 percent of the previously farmed land is now irrigated.

Azmal Hossan assists his mentor, Dr. Perry Cabot, place irrigation drip tape underground at CSU's Western Colorado Research Center-Grand Valley. Photo by Cordelia Anderson.

A Tale of Water Conservation Efforts of a CSU Agriculture Experiment Station

Azmal Hossan, Doctoral Student, Sociology, Colorado State University and InTERFEWS Trainee

As a sociology doctoral student concentrating on social dimensions of the food-water nexus, I am aware that agricultural water resource management is fundamentally a complex problem. This complexity is exacerbated due to water scarcity fueled by climate change and increasing water demand from population growth and growing urbanization. Western Colorado Research Center-Grand Valley (WCRC-GV) is one of the three Colorado State University (CSU) agriculture experiment stations on the Western Slope of Colorado, a region that is highly water-stressed. Irrigation-based agricultural production is the region's economic engine that is fully dependent on the Colorado River for both drinking and irrigation water. The 1,450 miles long transboundary river supplies drinking water for nearly 40 million people in seven U.S. western states and some parts of Mexico. The Colorado River also is the source of water for over 5 million acres of irrigated agricultural land. Due to rapid urban expansion and climate change, irrigated agriculture in the Colorado River Basin is confronted with a supply-demand imbalance. In 2021, the federal government declared the first water shortage on the Colorado River amid historic and prolonged drought in the region. With legal rights to 70% - 80% of the Colorado River surface water flows, irrigated farmers and ranchers of the region were asked to conserve water to share their agricultural water rights with other users, mainly with cities and municipalities. But the existence of legal, political, and cultural barriers can hinder them to conserve irrigated water. For example, the Doctrine of Prior Appropriation is the defining characteristic of Colorado water law under which water rights are determined by historical priority. As senior water right holders, agricultural producers are fearful that if they do not fully use their allotted water on time, they will lose their water rights. This fear is propagating water conflict between expanded urban settings and rural agricultural communities.

While participating in the CSU Extension Summer Internship at WCRC-GV, I understood this Agriculture Experimental Station (AES) has full potential to lead local communities in conserving agricultural water. The Center has been transforming its irrigation system from furrow to drip and conducting different irrigation experiments including planting sweet corn, hemp, and watermelon under the drip irrigation system. During my internship, I helped develop and fix a drip irrigation system as well as assisted with the science communication program using social media. In addition, WCRC-GV has been implementing an interdisciplinary project examining how a large irrigation canal system can administer a voluntary, temporary, and compensated conservation program in the Upper Colorado River Basin. The project is supported by the System Conservation Pilot Program of the Colorado Water Conservation

Board. After one year, the project found a positive outcome on water conservation with participation from local agricultural producers. Here I remember three scenarios from my summer internship, denoting the station's significance in water conservation efforts.

Scenario 1: Different Perspective

Azmal: *What are you doing here, Dr. Cabot?*

Dr. Cabot: *I am fixing the leaks in the drip system.*

Azmal: *You are a senior water expert with a Ph.D., right? Are you supposed to do it in such a manner?*

Dr. Cabot: *It is part of my job, Azmal, and I am doing it.*

This was the first conversation I made with my internship supervisor Dr. Perry Cabot. I met him early in the morning on June 2, 2021, the very first day of my internship, in one of the drip irrigation systems installed at the WCRC-GV. Lying in the dirt and muddy ground, he was fixing some leaks in the system installed to supply water to adjacent hemp and sweet corn plots. Dr. Cabot is a Water Resource Specialist with the Colorado Water Center and the Research and Extension Leader for WCRC-GV. He received his doctorate in Agricultural Engineering and Land Resources and received a Bachelors of Science in Civil Engineering. His research interests include innovative irrigation technologies, sustainable water resources management, and crop consumptive use evaluation. It may be normal for someone from the U.S. to see a water engineer with a doctorate fixing a drip irrigation system, but not for me. As an international doctoral student coming from Bangladesh, where 70 % of the population depends on irrigation-based agriculture for their survival, this scenario is quite unusual for me. With this experience, I realized that it does not matter whether an individual has a doctorate or not; rather it matters whether you are sincere and dedicated to your job. It also reminds me of the difference between professionalism in the working environment of two different cultures: the developed and developing world.

Scenario 2: Trust, Not Bugs

Local citizen: *Is there anyone who can help me identify whether these bugs are good or bad?*

Cordelia: *There is no entomologist here. But we can help you after talking to an entomologist.*

Azmal: *This is an Agriculture Experiment Station. Why is he here with the bugs?*

Cordelia: *People trust us so much.*

It was almost noon on June 2, 2021 and it was90⁰F outside. I was working in the field with Cordelia, a research assistant for Dr. Cabot and she was teaching me how to connect the tape with the manifold in a drip irrigation system. Suddenly we heard a voice asking for help to identify some bugs. We both looked back and saw a gentleman standing in front of an SUV in the middle of a plot prepared for sweet corn plantation, who was showing us a ziplock bag and asking whether the bugs were good or bad. I was a little surprised by the situation as we were at an irrigation Experiment Station doing different experiments on agricultural water conservation. When I asked Cordelia why he was there with the bugs, she simply responded that "*local people trust us so much, and they think we can help them in every way.*" Cordelia asked him to keep the bag with the bugs and she would speak with an entomologist. After this instance, I realized how the local communities trust this AES. Through the science communication training that I have been receiving over the last two years as a National Research Trainee of Interdisciplinary Training, Education and Research in Food-Energy-Water Systems (InTERFEWS) at CSU, I know that trust is a crucial component for science communication, especially if we want to highlight water-related science in water-stressed regions.


Azmal Hossan planting hemp in one of the irrigation plots at CSU's Western Colorado Research Center Station Photo by Cordelia Anderson.

Scenario 3: Community Engagement

I worked as a social media manager of the WCRC during my internship, managed the Center's Facebook and Twitter accounts and highlighted up-to-date science on agricultural water conservation with a special focus on the Western Slope of Colorado , different individuals working in the station as employees and stakeholders, collaborations with local, regional, and national agencies and research organizations.. On June 21, 2021, I highlighted Cheryl Whiteman on Facebook and Twitter, acknowledging her voluntary contributions to the Center's various operations for more than 15 years. Whiteman is a CSU alumni who received her undergraduate degree in Occupational Therapy and Biological Science. She oversees a family-owned ranch on the Western Slope of Colorado. Her volunteer work is a great example of community engagement in the Center's ongoing projects that is consistent with CSU's land-grant mission. CSU's Office of Engagement and Extension delivers on its land-grant mission by making the university's educational programs, services and resources accessible to all, enabling individuals to act as agents of change and together build thriving communities.. The post received the highest coverage in the history of the Center's social media presence. From this instance, I realized that stakeholders who follow the Center's social media platforms are more interested in the Center's community engagement programs. As a sociologist, it was also encouraging to see that people are engaged in the stories covering human components.

Acknowledgment of Financial Support:
I received financial support from CSU's College of Liberal Arts, the InTERFEWS program, and the Western Colorado Research Center-Grand Valley to complete my 2021 CSU Extension Summer Internship. I am grateful for all of the support.

Every County Has Unique Climate Risks. What Are Yours?

Joey Blumberg, Doctoral Student, Agricultural and Resource Economics, Colorado State University and InTERFEWS Trainee

Introduction

Earth's average temperature has increased by more than 2°F since the 1880s. 2016 and 2020 are tied as the warmest years on record (NASA, 2021). Seven in ten Americans believe climate change is happening and six in ten believe that the weather in the U.S. has already been impacted (Leiserowitz et al., 2021). There is a consensus among scientists and policymakers on the need for efficient and sustainable resource planning moving forward (IPCC, 2021). Despite the general agreement on the existence of climate change, and the importance of mitigating potential damages, only four in ten Americans believe climate change will harm them personally (Leiserowitz et al., 2021). This is partially due to commonly reported statistics of rising sea levels and global temperature changes by 2050 or 2100, which feel impersonal and distant. In general, the individualized impacts of climate change often seem nebulous.

The extent to which global climate change affects individual regions will depend on geographic location and the ability of human and environmental systems to adapt. Recent incidents of extreme drought, flooding, heat domes, and wildfires in the U.S. highlight the potential damages of current climate trends, but many areas will not experience damages so obviously. A burgeoning literature on the interactions between climate and society suggests impacts across physical, social, and economic systems. Additionally, the effects of different weather disruptions are not uniform across space, and the success of policies aimed at bolstering climate resiliency is dependent on local leaders, resource managers, municipal planners, and individual citizens understanding the climate risks in their communities. The purpose of the present article is to provide an overview of the growing literature examining climate change damages, highlight the heterogeneity of industries and climate trends across the U.S., and briefly introduce an extensive, county-level vulnerability assessment that is currently underway.

Current Research Landscape

Climate change, at the most basic level, describes a shift in the underlying distribution of weather patterns—such as temperature and precipitation—over an extended period of time. Periods of shifting weather patterns have occurred in the past. However, current rates of change are more extreme than any other historical period. Such changes in the natural environment have implications for economic productivity and public health. While the economic impacts of climate change have been of interest since the early 1990s (e.g., Cline et al., 1992), the last decade has brought an increased understanding of more nuanced social impacts. Anderson and Bell (2009) evaluate the impacts of weather on mortality risk, finding sizeable spatial heterogeneity in the effects of both hot and cold temperatures across U.S. counties. Temperature has also been found to have a positive association with criminal activity (Ranson, 2014), and associations with violent crime differ in magnitude depending on county demographics (Berman et al., 2020). There is evidence that climate change may exacerbate the frequency of civil conflicts (Hsiang et al., 2011). In summary, when focusing on public health, the literature indicates that the impacts of climate change will vary greatly across different communities.

Burke et al. (2015) find that global temperature changes influence economic production in all countries, and the magnitude of economic losses will vary between high- and low-income countries.

Contrasting the crime and mortality research, most studies evaluating the economic damages from climate change estimate average impacts at a macro-scale (i.e., sector or country-level), and often neglect the spatial distribution of impacts within countries or regions. Moreover, it is well established that a changing climate can negatively affect agricultural (Schauberger et al., 2017) and energy (Schaeffer et al., 2012) production, however, little attention has been given to identifying specific geographic areas that are most vulnerable. Burke et al. (2015) find that global temperature changes influence economic production in all countries, and the magnitude of economic losses will vary between high- and low-income countries. Similar studies commonly provide broad policy considerations, such as those in the Intergovernmental Panel on Climate Change "Summary for Policymakers" (IPCC, 2021), that may not be suitable for decision-makers operating at local levels. In the U.S., risk management strategies in drought-facing, agriculture-dependent economies in the arid West will look significantly different from flood-facing, tourism-dependent economies along eastern coastlines. Following that reasoning, the information needs of local policymakers will vary greatly between those two areas.

Important Industries and Climate Trends in the U.S.

The advent of rich and spatially disaggregated data sources for both economic and climatic information has brought forth new opportunities for micro-scale analysis in the U.S. government agencies such as the U.S. Census Bureau, Bureau of Labor Statistics, and Bureau of Economic Analysis provide annual data on county-level employment, wages, and gross domestic product. Additionally, a suite of climate models now offers daily meteorological data at a high-spatial resolution, both historical and projected. Currently, there are many options for historical data,

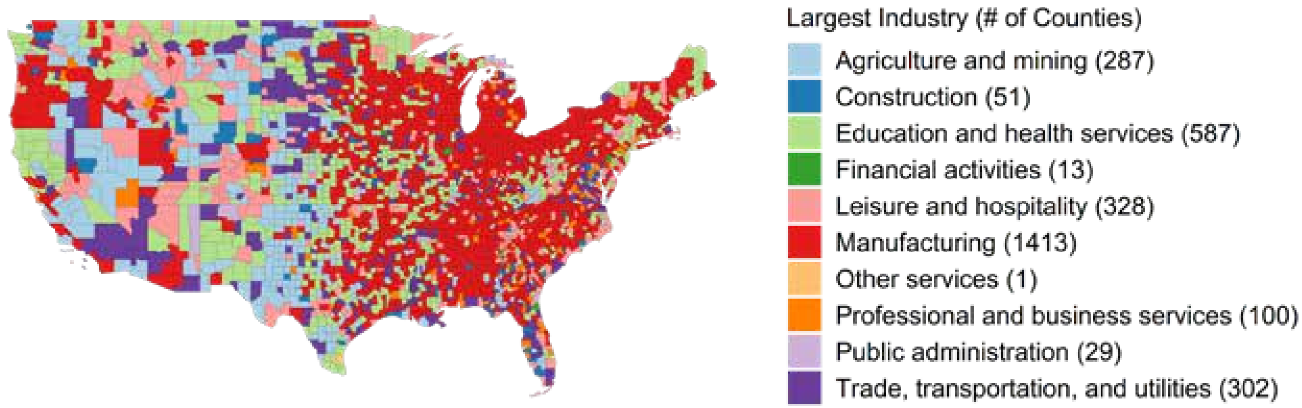


Figure 1. Largest Industries by Total Employees in 2019. Source data: BLS Quarterly Census of Employment and Wages.

such as NASA's Daymet, the PRISM Climate Group out of Oregon State University, or the Climatology Lab. For projected data, about 20 climate-modeling groups worldwide engaged in the World Climate Research Program's Working Group on Coupled Modeling in 2008. Outputs from their models are used by the IPCC and available to the public. Combining these sets of data can provide useful information across decades.

The economies of different counties depend on a wide variety of industries, as exemplified in Figure 1, and some industries will be more sensitive to climate than others. Crop production is sensitive to prolonged heat exposure, drought, and flooding in agriculture. For labor-intensive industries (e.g., agriculture, construction, and manufacturing), hotter working conditions can dampen productivity through employee discomfort, fatigue, and even cognitive impairment. For leisure and hospitality, changes in weather patterns may impact the allure of economically important tourist attractions. By contrast, it is also important to note that some industries may benefit or even become feasible due to a change in a previously suboptimal climate.

When examining the impacts of weather events on economic productivity, damages from hotter temperatures usually result from prolonged heatwaves, whereas damages from changes in precipitation can result either from sustained drought or short and intense events that cause flooding. Most crops are sensitive to temperatures above 90°F, and human health is significantly affected by temperatures above 100°F. Figures 2 and 3 portray how increasing temperatures from climate change will change the number of days in which agricultural production and human health can be impacted in an average year. Climate projections suggest that crop production may be affected in most of the U.S., whereas increases in human health and labor risks are more concentrated in southern counties, excluding mountainous areas. Figure 4 highlights the heterogeneity in changing precipitation patterns, where risks of drought and flooding are more likely in western and eastern counties, respectively. Juxtaposing the industry and climate figures provides a clear indication for which counties face higher risks, if any.

County-Level Vulnerability Assessment

Given the geographic distribution of risk within the U.S., it is important to rigorously identify vulnerable counties. For this research, vulnerability is defined as the state or propensity of an area to be negatively impacted by climate change, which I will evaluate using a common framework of (1) exposure, (2) sensitivity, and (3) adaptive capacity (Cardona et al., 2012). Impacts on a variety of economic industries will be evaluated, both historical and projected, with a particular focus on agricultural sectors in rural economies.

Figure 2. Increase in Days when Temperature Exceeds 90°F. A yearly average was calculated for each 20-year period, and then a baseline average from 1980-1999 was subtracted from each. Source data: Historical: gridMET; Projected: CCSM4 RCP4.5.

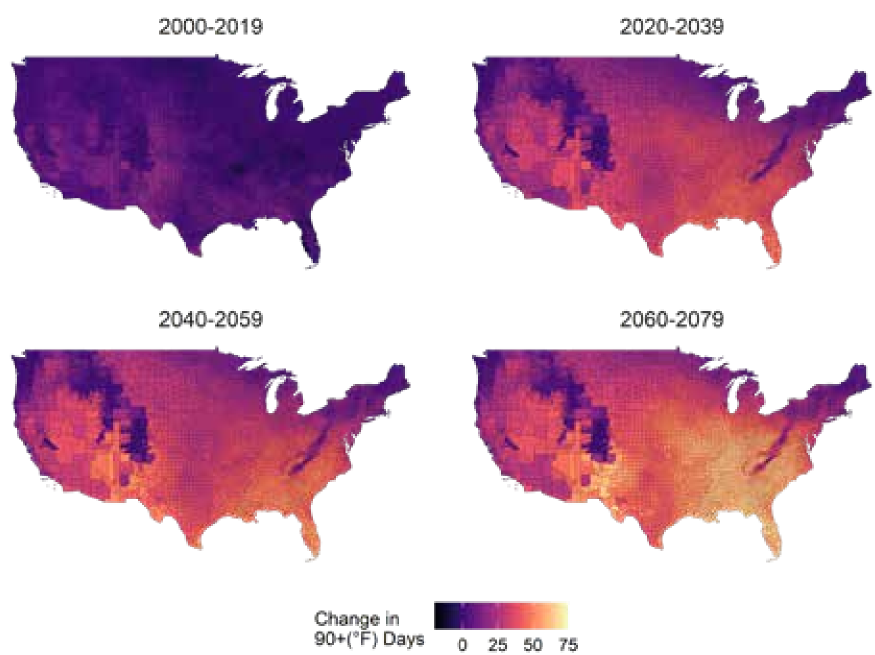


Figure 3. Increase in Days when Temperature Exceeds 100°F. A yearly average was calculated for each 20-year period, and then a baseline average from 1980-1999 was subtracted from each. Source data: Historical: gridMET; Projected: CCSM4 RCP4.5.

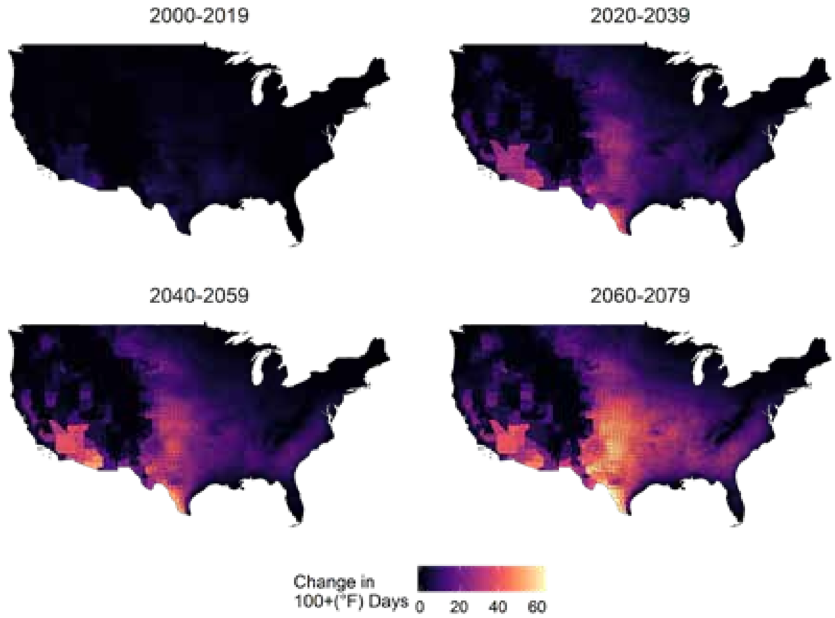
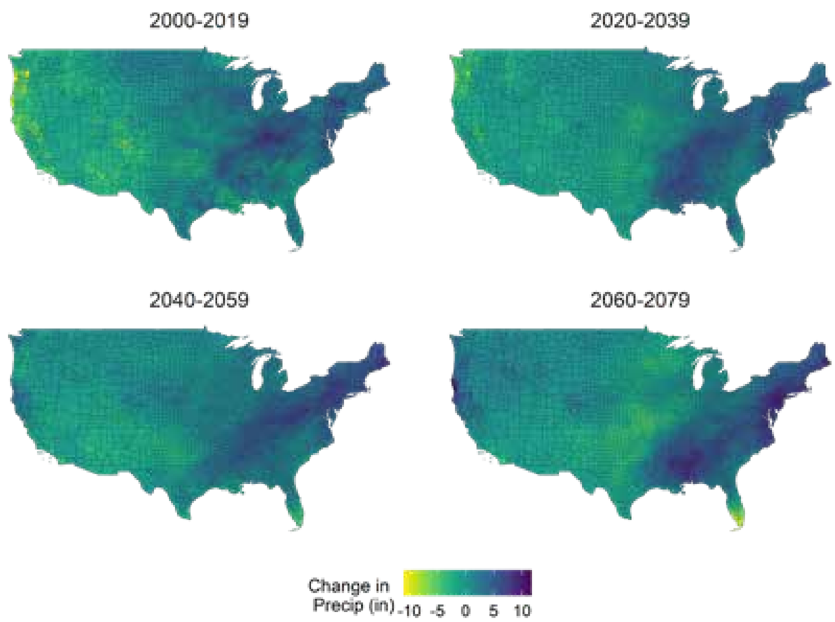


Figure 4. Change in Average Yearly Precipitation. A yearly average was calculated for each 20-year period, and then a baseline average from 1980-1999 was subtracted from each. Source data: Historical: gridMET; Projected: CCSM4 RCP4.5.



Exposure constitutes the presence of economic systems in a county and the past and future climate settings that can affect those systems. For example, counties with large populations and considerable projected climate changes would be considered highly exposed. Sensitivity measures the extent to which local industries are influenced by a changing climate. Data on exposure will be regressed on economic indicators such as wages and employment to estimate historical impacts and identify climate-dependent industries. Climate projections can then be used to predict economic outcomes under a variety of forecast scenarios. Regression and forecasting results will be used to create an index that conveys a county's sensitivity relative to others. Adaptive capacity refers to the ability of a county to mitigate potential damages based on current institutional resources. The availability of local, state, and federal opportunities for subsidies and alternative funding for climate-sensitive industries will be evaluated. All data and results will be reported consistently and uniformly across counties in an interactive map tool.

Research Implications and Conclusions

The heterogeneous impacts of climate change call for localized policy and resource management strategies. Many U.S. counties have already experienced substantial changes in temperature and precipitation compared to 1980-1999 averages, and with more extreme changes predicted to occur soon, it is imperative to meet the growing information needs of local decision-makers. For the proposed research, using the county as the unit of analysis has the benefit of communicating information already conformed to a common organizational unit for existing institutions. For example, the U.S. Department of Agriculture's (USDA) Farm Service Agency, Natural Resource Conservation Service (NRCS), and the Rural Development agency already tailor program characteristics to meet country-specific needs, and USDA Service Centers designed for community access are available in most counties (see offices.sc.egov.usda.gov/locator/app). Results from the proposed research can assist in designing more effective and targeted policies. Overall, understanding the historical economic impacts from climate disruptions across counties is critical for future damage mitigation.

Dale Trowbridge (left), General Manager of New Cache La Poudre Irrigating Company, and Mark Simpson (second from left), Poudre River Commissioner, speak to the group about how water flows through the New Cache ditch and how the Colorado Division of Water Resources administers water availabilty.

2021 InTERFEWS Workshop

InTERFEWS trainees participated in an intensive week-long EMBeRS (Employing Model-Based Reasoning in Socio-Environmental Synthesis; embers.cybershare.utep.edu/index.html) workshop led by Dr. Deana Pennington (University of Texas at El Paso) and Dr. Dave Gosselin (University of Nebraska-Lincoln) in August 2021. The workshop was designed to develop doctoral students' capacity for leading interdisciplinary synthesis efforts around food, energy, and water issues. The workshop consisted of stakeholder engagement field trips to learn about local resource allocation related to water scarcity and the issues surrounding the administration and management of each. The goal of the field trips was to have the InTERFEWS trainees interact with and learn from water experts and stakeholders on local food, energy, and water matters and provide them transdisciplinary experiences. The following are short descriptions of some of the stops along the field trip.

Doug Henderson with the Larimer Alliance for Health, Safety, and Environment discussed the history of Bella Romero Academy, the nearby oil and gas wells, and the efforts taken to bring attention to the situation.

Bella Romero Academy

The group visited the Bella Romero Academy campus in Greeley, Colorado where the school's playground is a mere 1,200 feet from an active oil and gas pad. "A few weeks after the wells first started flowing in October 2019, a state mobile lab stationed at the campus detected an elevated level of benzene (CPR, 2020)."We met at the playground to talk with Doug Henderson of the Larimer Alliance for Health, Safety, and Environment, as well as Therese Gilbert, resident and teacher in Greeley for 28 years (also a well known anti-fracking activist in the area), to discuss the environmental [in]justice issues surrounding Bella Romero Academy, which enrolls mainly minority and economically disadvantaged students.

Dave Eckhardt (center), owner Eckard Farms, provided an overview of farming operations and water rights on his farm.

Eckhardt Farm

We visited the Eckhardt's farm in LaSalle, Colorado to hear from Dave Eckhardt and his son on their operations and water rights. We also visited with Erik Wardle and Christina Welch with CSU's Ag Water Quality Program to discuss the research they are conducting on their test plots located at the farm.

New Cache La Poudre Irrigation Company

We visited with Dale Trowbridge, General Manager of New Cache La Poudre Irrigating Company, Mark Simpson, the Poudre River Commissioner, and Dan Brown, a water law attorney at Fischer, Brown, Bartlett, Larsen & Irby, P.C., who has been New Cache's water attorney for over 20 years. We met at the New Cache diversion/ditch structure in Timnath, Colorado where Mark spoke about the Poudre River system and how water is delivered to the New Cache ditch. Dale spoke about New Cache's operations and how their shareholders receive water, and Dan spoke about Colorado's water rights system and more specifically about New Cache's agricultural water rights.

Joe Elliot, City of Westminster Reclaimed Water Treatment Facility Chief Plant Operator, explains different wastewater treatment processes and the stage at which solids are separated.

City of Westminster Reclaimed Water Treatment Facility

We visited with Joe Elliot, Chief Plant Operator, who provided a tour of the processes and operations involved in reclaiming water at the plant. We also heard from Sarah Borgers, Water Resources & Quality Manager, and Bret Eastberg, Reclaimed System Coordinator, who presented information on the reclaimed distribution system and how reclaimed water fits into the City of Westminster's water resources management plan.

Occidental Petroleum

We visited an Oxy signal pump station near Thornton, Colorado, as well as a completed well pad near Fort Lupton, Colorado. Telbe Storbeck, Advocacy Advisor, and his team discussed their operations, how they acquire land/water rights, and their community outreach efforts surrounding their work.

We also visited with (virtually) Jim Becklenberg, City of Evans City Manager, and Greg Fischer, Manager of Demand Planning at Denver Water, to provide more of the urban water perspective.

Thank you to all our speakers and tour hosts for this learning experience!

InTERFEWS

Interdisciplinary Training, Education & Research in Food-Energy-Water Systems

The NSF-funded InTERFEWS National Research Traineeship (NRT) program was designed to equip students with 21st century career skills, preparing graduates to solve complex FEWS problems. InTERFEWS brings together PhD students from traditionally disparate disciplines to conduct research on key problems in the **Food-Energy-Water (FEW) nexus** with a focus on water-scarce, arid regions.

The program includes four components to achieve this goal:

Curriculum - Two newly developed InTERFEWS courses as well as communication and elective courses that specifically address FEWS issues.

- Understanding the FEW Nexus
- Tools for Analysis of FEWS Issues
- STEM Communication
- Technical, Policy & Economics Electives

Research - Activities are focused on sustainable technological, infrastructural, policy, and institutional FEWS innovations.

Professional Development - InTERFEWS equips students with 21st century professional skills and networks to solve complex FEWS issues in a changing world.

MISSION

Prepare a diverse cohort of graduate students with the transdisciplinary and systems-level thinking skills necessary to make meaningful contributions to the complex and changing interactions in FEWS under water scarcity.

Apprenticeships - InTERFEWS trainees will participate in an apprenticeship during their program of study. We have partnered with several companies, NGOs, and government agencies to host students for apprenticeships in FEWS.

PARTICIPATING COLLEGES of TRAINEES & CORE FACULTY

Agricultural Sciences
- Soil & Crop Sciences
- Agricultural & Resource Economics

College of Health & Human Sciences
- Food Science & Human Nutrition

College of Liberal Arts
- Sociology
- Political Science

College of Natural Sciences
- Psychology
- Chemistry

Colorado School of Public Health
- Global Health & Health Disparities

Walter Scott Jr. College of Engineering
- Atmospheric Science
- Civil & Environmental Engineering
- Chemical & Biological Engineering
- Mechanical Engineering
- Systems Engineering

Warner College of Natural Resources
- Ecosystem Sciences & Sustainability

8 Colleges	25 Departments	9 Core Faculty	35 Partners

InTERFEWS NRT Program
Sybil Sharvelle, Director
Elizabeth Plombon, Coordinator

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https://erams.com/interfews

COLORADO STATE UNIVERSITY

Colorado's 2021 Runoff Season

Peter Goble, Climatologist, Research Associate, Colorado Climate Center

Introduction

Spring in Colorado. The days get longer. Our mountain snow melts. The rivers rise. It's a story that has been playing itself on repeat for centuries. The people of our state rely on this seasonal runoff for drinking water, food, power, and recreation. Winter snowfall has always been variable across Colorado's high country, so it's a well-known fact that our water resources will fluctuate from year-to-year. Uncertain as our water resources may be, we are fortunate to be able to predict our water supplies ahead of time. Our peak snowpack is historically very well correlated with water supply through the spring and summer, but that relationship may be changing. In 2021 we observed well below normal runoff despite a near-normal snowpack. In this article, we look at our 2021 runoff season in more detail, discuss how a warming climate changes seasonal runoff and some of the methods being used to improve upon snowpack-only runoff predictions.

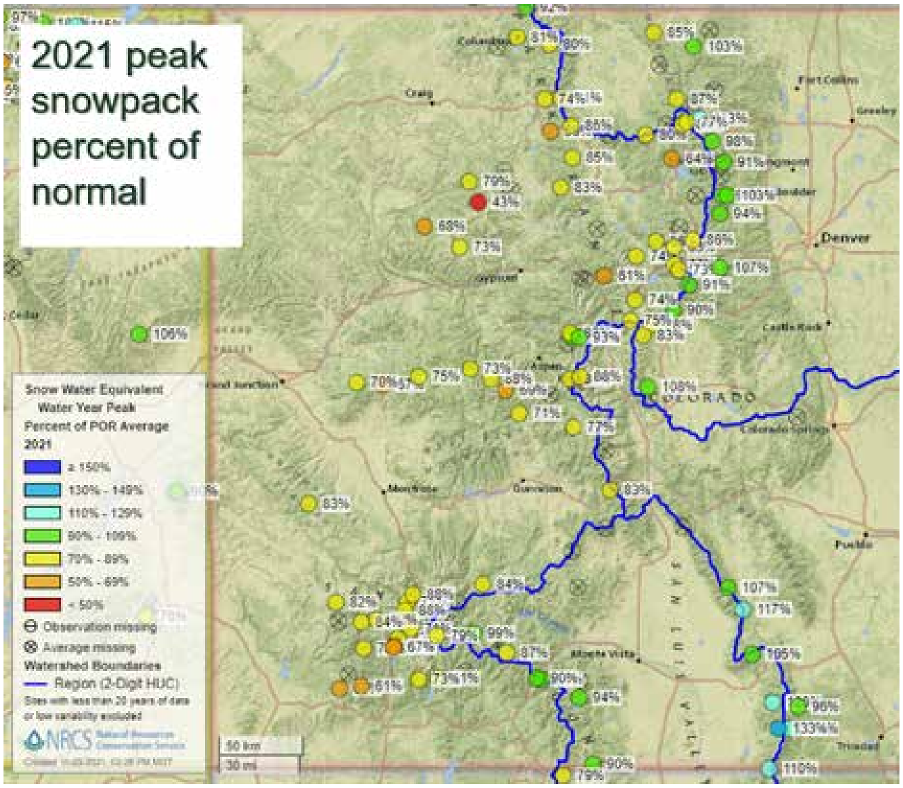

Figure 1: 2021 percent of the period of record average peak snowpack. Data from National Resource Conservation Services.

2021 Runoff

The 2021 season was not a banner year for Colorado snowpack, but it was far from disastrous. Basins on the Western Slope averaged about 90% of the normal April 1st snowpack, much better than other recent drought years like 2012 and 2018. Other major basins, such as the Upper Rio Grande and Arkansas River Basin fared well, netting over 110% of the normal peak snowpack.

Spring and summer runoff totals were far less encouraging. Major West Slope river basins recorded 34-58% of normal spring and summer runoff. This led to the third call for water usage curtailments on the Yampa River in four years, a watershed that did not see curtailments in any year prior to 2018. The Upper Rio Grande Basin, which notched above normal peak season snowpack, recorded only 75% of normal runoff.

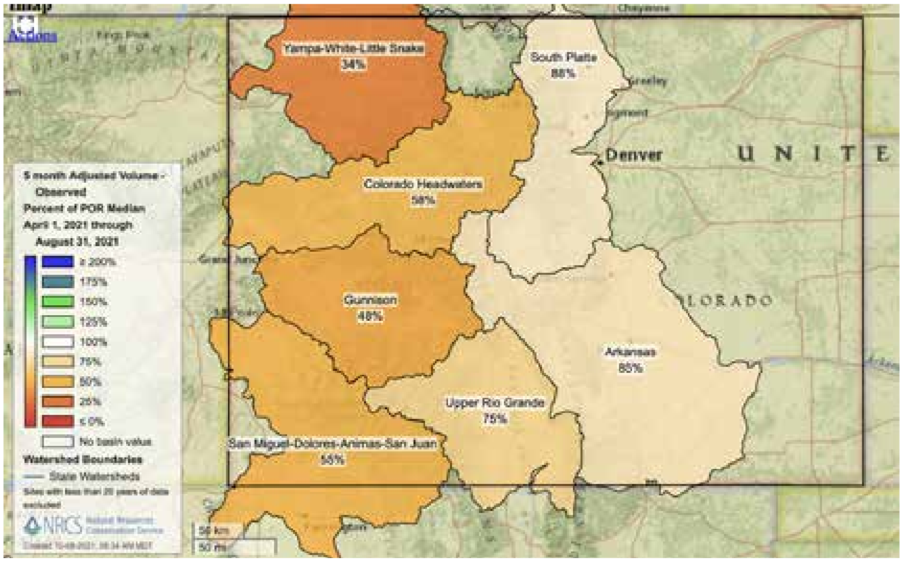

Figure 2: April 1st – August 31st, 2021, percent of the period of record median runoff for major Colorado River Basins. Data from National Resource Conservation Services.

Even a savvy snowpack-only prediction of runoff would not suggest 90% of the normal snowpack will produce 90% of normal runoff. The relationship between peak snowpack and runoff is not 1:1. To understand why we can think of total water supplies like a budget and runoff like spending money. In a low snowpack year, a higher percentage of the snowpack will go directly into recharging soil moisture and groundwater supplies. Similarly, in a leaner financial year, we still have to pay the bills. Spending money (runoff) will be disproportionately impacted. While our example is oversimplified, we can understand why 90% of the normal snowpack will yield less than 90% of normal runoff. Even so, peak snowpack percentiles were higher than peak seasonal runoff percentiles across the state, so a snowpack only forecast would have erred high.

Changing Runoff Dynamics

Colorado is warming (NOAA 2021). Changes in temperature through the 20th and 21st centuries have been greater in Colorado than the global average, with parts of western Colorado observing as much as 2 Celsius of warming (Eilperin 2020). Western Colorado has experienced particularly warm summers recently, with all five of the hottest summers on record occurring since 2000 and three of the top six hottest summers occurring in 2018, 2020, and 2021. Warmer temperatures impact how much snowfall we receive and how much snowpack is actually converted to runoff. 2000-2014 was found to be the lowest 15-year period of streamflow on the Colorado River at the Colorado/Utah state line despite not being the lowest 15-year period of precipitation on record (Udall and Overpeck 2017). Since then, we have observed additional low runoff years in 2018, 2020, and 2021.

Warmer temperatures in winter mean a higher fraction of cold-season precipitation falls as rain and less consistent snow cover at middle elevations. This leads to smaller, episodic runoff events and less runoff from the big melt at the end of the snow season. Warmer temperatures in summer mean more of the rainfall we receive evaporates before reaching our lakes, streams, and reservoirs. The net impact is smaller and less predictable runoff volumes (Livneh and Badger 2020). Warmer summers also dry our soils more rapidly. Lower soil moisture entering winter means lower runoff is to be expected the following spring. To understand why think back to the budget example above. Soil moisture and groundwater recharge are likened to paying the bills, and runoff is likened to spending money. Higher bills (dry soils) mean less spending money (runoff) is to be expected even if income (snowpack) is normal. In recent years like 2020 and 2021, runoff has been lower than expected from snowpack alone, in part due to the effect of low soil moisture and groundwater entering the cold season.

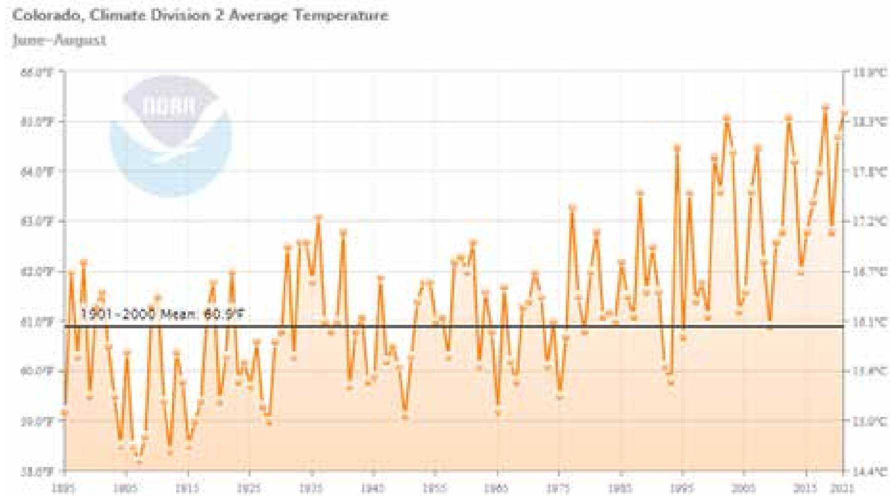

Figure 3: Colorado Climate Division 2 (western Colorado) summer temperatures 1895-2021. Data from National Centers for Environmental Information.

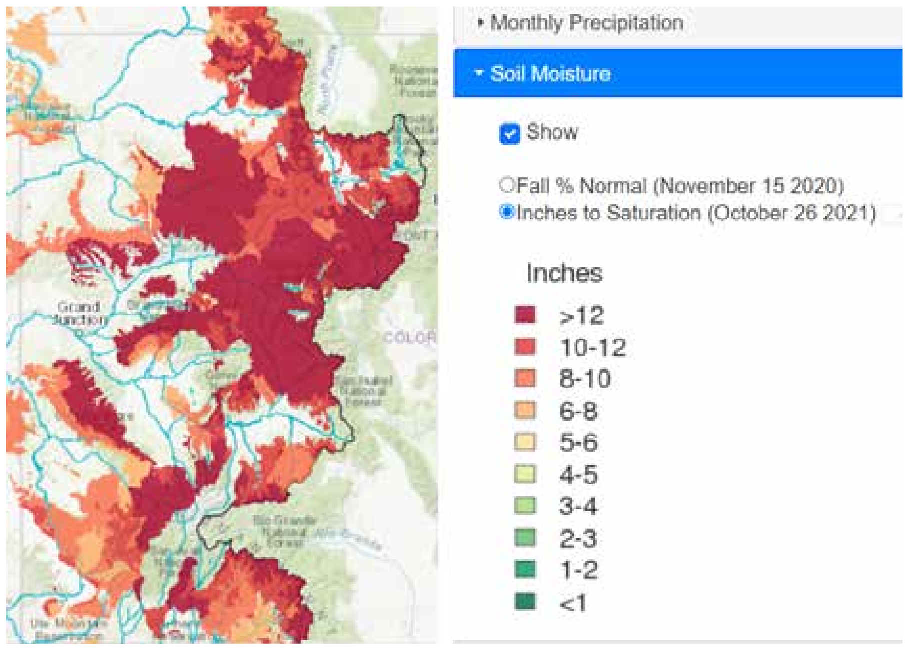

Figure 4: Representation of soil moisture (measured in inches to saturation) from Colorado Basin River Forecast Center.

Current Prediction Methods

Current runoff prediction methods are more evolved. The two largest operational runoff forecasting presences in Colorado are the Natural Resource Conservation Services (NRCS) and the Colorado Basin River Forecast Center (CBRFC). Of course, both entities do use peak snowpack data in their forecasts, but with added complexities. The CBRFC uses a computer model to simulate runoff based on observed snowpack and precipitation, soil moisture, and forecasted precipitation (Moser et al., 2021). The NRCS applies a machine learning approach to generate a statistical forecast based on snowpack, precipitation, and antecedent streamflows, or baseflows, entering the winter season (Flemming and Goodbody 2019). Both organizations did forecast lower streamflow values in 2021 than one would forecast based on snowpack only, so the low flows of 2021 were reasonably well warned. A sample forecast from the CBRFC is included in figure 5. This forecast is for the Cameo gauge, which is on the Colorado River near Grand Junction, CO. We can see that early in the snow season, the CBRFC was already 90% confident that seasonal runoff would be below the historical average. This is in part due to low soil moisture. Regardless of the

The Colorado Climate Center is partnering with the National Integrated Drought Information System (NIDIS) to see which available gridded soil moisture datasets add the most skill to a runoff prediction.

forecasting method, a warming climate makes prediction more difficult; it's harder to hit a moving target.

Experiments at the Colorado Climate Center

There is an increasing number of soil moisture datasets available, which may be leveraged for improved streamflow prediction. The Colorado Climate Center is partnering with the National Integrated Drought Information System (NIDIS) to see which available gridded soil moisture datasets add the most skill to a runoff prediction. This work is not yet complete, but a sample is discussed here:

We used peak snowpack data from 1992-2020 for all snowpack telemetry stations in the Colorado River headwaters and the Gunnison River Basin to derive a statistical relationship between peak snowpack and observed April-July streamflow. We used the USGS streamgage on the Colorado River at the Colorado-Utah state line to record streamflow. We then added a number of other potential predictors to the analysis to see which one(s) explained the most additional variance in runoff: antecedent streamflow (Nov 15th of the previous year) at the CO-UT state line, antecedent soil moisture volumes from the North American Land Data Assimilation Systems NOAH soil moisture model, annual change in major reservoir storage (Lake Granby and Blue Mesa), April-July precipitation in the basin, and all factors above.

As expected, the peak snowpack was strongly correlated with subsequent April-July runoff. Peak snowpack explains 81% of the variance in seasonal

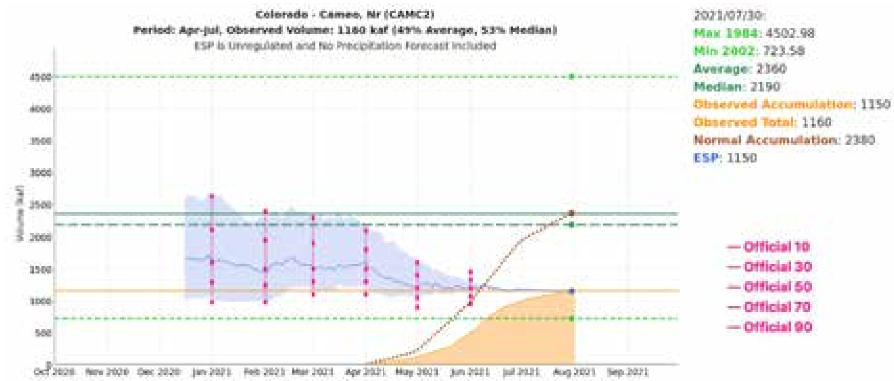

Figure 5: Colorado Basin River Forecast Center Official April-July streamflow forecast for Cameo stream gauge from January-July 2021 in thousands of acre-feet. Historical average (solid green), historical median (dashed green), historical maximum and minimum (dashed green above and below), observed cumulative runoff (shaded brown), historical average accumulation (dashed brown), forecast 10-90% confidence intervals by month (pink bars).

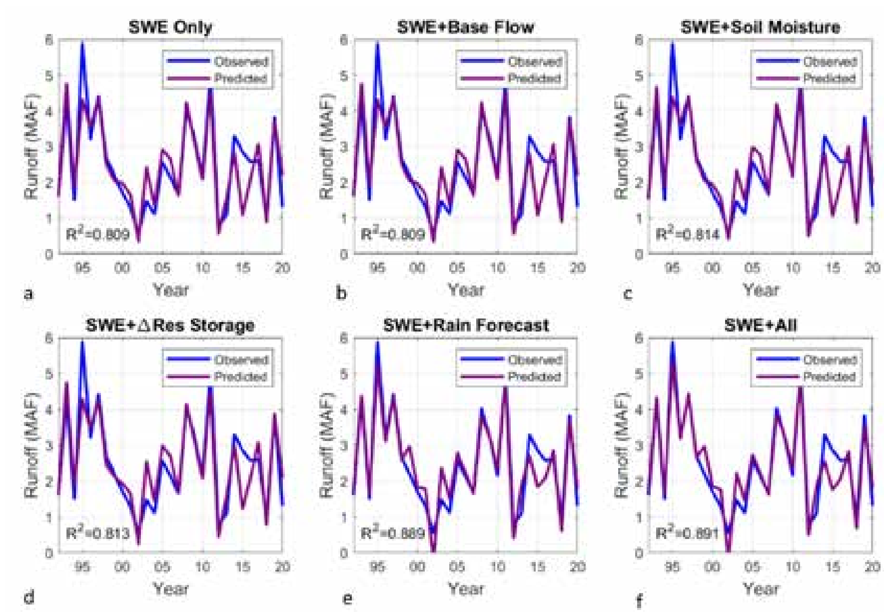

Figure 6: Observed (blue) and predicted (purple) runoff April 1st–July 31st cumulative streamflow (runoff) at the Colorado-Utah state line (millions of acre-feet). Runoff prediction based on six regressions: a. SWE (snow water equivalent) only, b. SWE + Base Flow (Nov 15th streamflow in the previous year), c. SWE + Soil Moisture (November 15th soil moisture from the prior year), d. SWE + change in Blue Mesa and Lake Granby change in reservoir storage in the previous year, e. SWE + precipitation in following four-month period, and f. SWE + all factors in b-e.

runoff; the relationship is significantly different than 0 at 99.99% confidence. In this example, antecedent streamflow, NLDAS soil moisture, and change in reservoir storage did not explain much of the remaining variance in seasonal runoff. Some of the snowpack-only forecast's largest, most conspicuous misses came during wet springs like 1995 and 2015 (Figure 6), which could be largely corrected by adding April-July precipitation. Of course, a spring and summer precipitation forecast is not known to be accurate at the time of peak snowpack. A reliable seasonal precipitation forecast could certainly add value to a snowpack-based runoff forecast. Soil moisture still may indeed be important, but the analysis presented here may not use the right dataset or be a large enough sample of years to showcase its importance.

Conclusions

Colorado is a headwaters state that has long relied upon the seasonal runoff from its major rivers for drinking water, irrigation, power, and recreation. A warming climate is lowering peak season runoff volumes and making them more difficult to predict. While prediction tools continue to be improved, the Colorado Climate Center's work underscores the importance of a good seasonal spring precipitation forecast when forecasting runoff.

Dr. Sunshine Swetnam

Dr. Sunshine Swetnam

Dr. Sunshine Swetnam is an Assistant Professor and the lead for the Ski Area Management Program within the Human Dimensions of Natural Resources Department at Colorado State University (CSU). Swetnam's educational background includes a Doctorate of Philosophy in Human Dimensions of Natural Resources and a Masters of Adult Education from Colorado State University. Moreover, she attended Northern Arizona University's Parks and Recreation Management Program and emphasized in Outdoor Leadership.

In regard to courses, Swetnam teaches Natural Resource Ecology and Measurements at CSU's Mountain Campus located in Pingree Park, Colorado. She teaches the suite of courses within the Ski Management Program including Ski Management Perspectives, Sustainability, Operations and Human Resources, Strategic Marketing and Management, Ski Area Finance and Investment, as well as Ski Area Planning and Development. Additionally, Swetnam also teaches the Leading the Adventure Tourism Experience course at CSU. Currently, she is working with an undergraduate honor's student at CSU to assess and analyze the intersection of the ski industry and climate change adaptations. She was recently featured on Marketplace National Public Radio (NPR).

Swetnam is a native Coloradan and lifelong skier with a deep appreciation for the wilderness. She views ski areas as the gateway experience to the wilderness. During her first career path, Swetnam was a ski instructor for a decade, a backpacking concessioner in Grand Canyon National Park, led sea kayaking in Haines, Alaska, guided teens throughout the Pacific Northwest and Northern California, and taught wilderness medicine. She also has over 25 years' experience white river rafting. Furthermore, Swetnam is learner-centered, with the philosophy of stewardship at her core. She hopes to educate more people about the environment, the earth, and sustainability with the intent that they fall in love enough to want to take care of the land and one another.

Dr. Sunshine Swetnam
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Colorado's Quandary Peak and the Breckenridge ski area photographed at dawn. Colorado State University's Ski Area Management program (SKAMP) provides students with the skills and knowledge to differentiate themselves from others and advance their career as a successful ski area manager. © Gary/stock.adobe.com.

2022 American Geophysical Union **Hydrology Days**

April 25-27, 2022 | Fort Collins, Colorado State University

Save the date for the upcoming 2022 American Geophysical Union (AGU) Hydrology Days event at the Lory Student Center, Colorado State University. This event will highlight multiple keynote speakers and aims to bring together water scientists, researchers, and students to discuss the current state of the science and latest water-related research.

Each year at the AGU Hydrology Days meeting the Hydrology Days Award is presented in recognition of outstanding and significant contributions to hydrologic science. Two Borland lectures are also honored, one in hydrology and the other in hydraulics. In partnership with Colorado Water Center, the Dr. Norm Evans Lecture and Reception will also take place during the event. The following Hydrology Days keynote speakers for 2022 are:

- **Hydrology Days Award Recipient:** Dr. Soroosh Sorooshian, Distinguished Professor—Departments of Civil and Environmental Engineering and Earth System Science, University of California, Irvine
- **Borland Hydraulics Award Recipient:** Dr. Ellen Wohl, Distinguished Professor—Geology and Geosciences, Colorado State University
- **Borland Hydrology Award Recipient:** Dr. Ana Barros, Distinguished Professor—Edmund T. Pratt, Jr. School of Civil and Environmental Engineering, Duke University
- **Dr. Norm Evans Lecture:** Dr. Jery Stedinger—Dwight C. Baum Professor of Engineering, Department of Civil and Environmental Engineering, Cornell University

To learn more about these outstanding keynote speakers scheduled for 2022, please visit: hydrologydays.colostate.edu/keynote-speakers/

For additional information about the event follow hydrologydays.colostate.edu/

Dr. Soroosh Sorooshian

Dr. Ellen Wohl

Dr. Ana Barros

Dr. Jery Stedinger

The white band at Lake Mead, as seen from Hoover Dam, marks the high-water storage level. Lake Meade, located in Nevada and Arizona on the Colorado River, is the largest reservoir in the U.S. in terms of water capacity. Photo ©iStock.com.

Colorado River Special Project Now Available

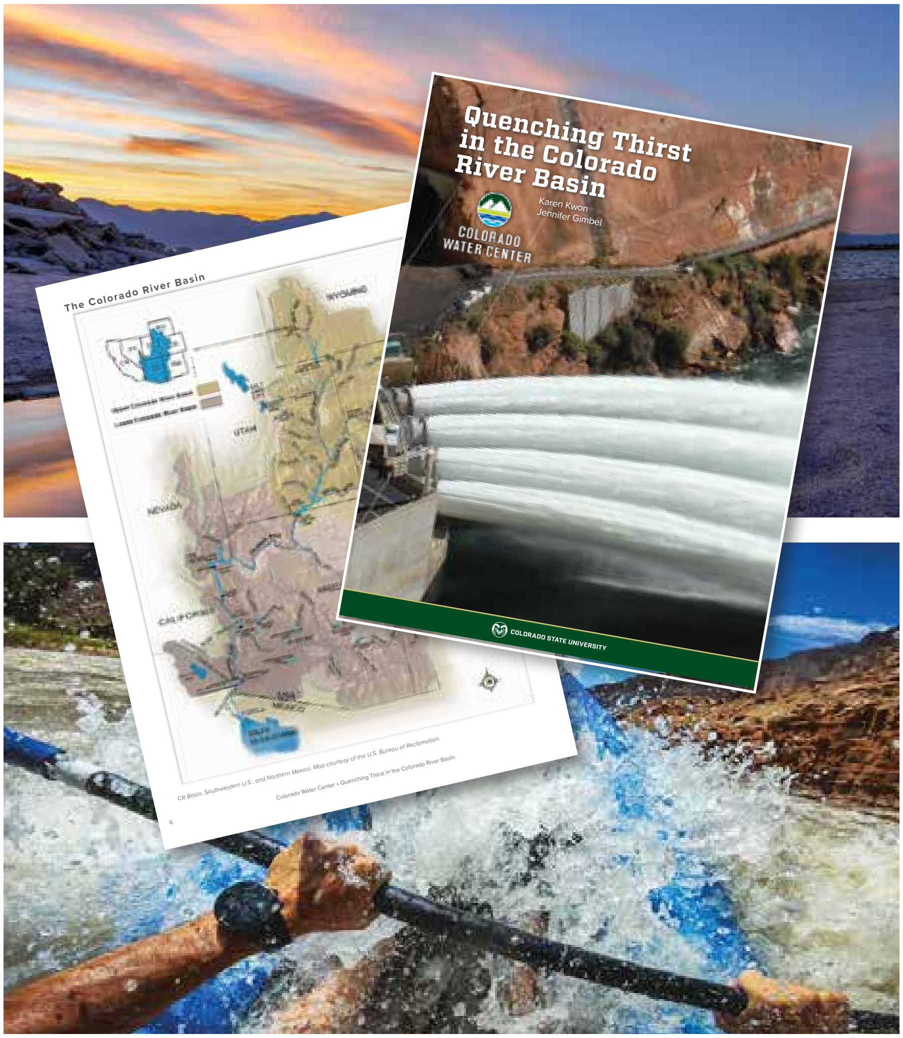
There is little dispute that the Colorado River Basin is thirsty. In an attempt to learn from that condition, a new series, published by the Colorado Water Center and co-authored by Karen Kwon and Jennifer Gimbel, is intended to provide an understanding of issues and relationships that have shaped the Basin so that the historical doctrines can bend to the needs of the present and future without eroding a foundation upon which we all stand. The Basin has been enduring a prolonged drought since 2000 with no apparent relief in sight. The 2021 water year was one of the driest in the CR Basin's recorded history. The science presents a cautionary tale that the abundance of 20th Century water supplies may be a thing of the past.

On-the-ground experience and various models demonstrate a regularly hotter, drier future for the CR system going forward. In other words, it may not be just a persistent drought but a more pronounced drying of the system. At the same time, there remains a strong need to support and maintain the agricultural spirit that has defined much of the West's heritage for well over 100 years. There is also a significant pull to sustain urban cities that rely on Colorado River water to help supply their growing populations. Not to be overlooked, there is an ever-growing recognition that various Native American Tribes hold legitimate claims to the river to support their cultures, reservations, and homelands throughout the desert southwest. Finally, there is the added pressure to provide for all of these and other demands without deteriorating the aesthetic and ecological values of the CR Basin.

Past experience teaches us that neither protracted litigation in courts nor political maneuvering through Congress will guarantee successful outcomes in response to the Basin's complex challenges. Instead, collaboration and cooperation are also necessary ingredients for thriving in the 21st Century. For the Colorado River Basin, this requires a commitment to and focus on cooperation and beneficial arrangements among varying interests to help mitigate and adapt to changing conditions throughout the region.

This series encourages such commitments by providing background and context regarding the forces that have compelled the development and operation of the Colorado River from the 1920s to today. Find a more in-depth examination than may otherwise be identified in news stories and articles of four primary forces that influence decision making: (i) History, Law, and Policy; (ii) Indian Reserved Water Rights in the Colorado River Basin; (iii) Environmental Perspectives in the Colorado River Basin; and (iv) Sharing the River Between the U.S. and Mexico. Insight into how the Basin has arrived at where it is today will hopefully help inform how best to direct where it needs to be tomorrow.

Find the full series and learn more about the Colorado Water Center at watercenter.colostate.edu.



Excerpted images and pages from "Quenching Thirst in the Colorado River Basin."

WATER22
It All Starts Here

WATER22.ORG

Water ’22 is a year-long celebration of Colorado’s water, dedicated to the idea that “It all starts here.”

It’s about Coloradans from all corners of the state, and all walks of life, recognizing the value of water, and growing in understanding of how water connects all people, upstream and downstream, past, present and future. It’s about coming together as a statewide community to collectively act, in the face of drought and climate change, in order to make sure our water can meet all of the needs of today and for future generations.

2022 is a milestone year for water in Colorado.

It is the 100th anniversary of the Colorado River Compact; the 50th anniversary of the Clean Water Act; the 20th anniversary of Water Education Colorado; and the year when the 2015 Colorado Water Plan will be updated to continue our long history of ensuring high quality water to support our state’s wide range of water uses and values.

Water ’22 invites you to learn more about your water, where it comes from, and ways to protect it for future generations. It’s everybody’s job to take care of this shared resource and **Colorado needs YOU in 2022!**

Take the Water ‘22 pledge to engage in “22 Ways to Care for Colorado Water in 2022” at Water22.org then share a story or post of yourself taking one of the actions with the hashtag #Water22. Each month, five Coloradans who share their commitment will be randomly selected to win incredible prizes!

Engage in events and activities throughout 2022 including a statewide book club and author talks, volunteer days, film screenings, a student water awareness week in schools, a watershed beer competition, on-the-ground tours, and much more!

#Water22

Water22.org

Water ’22 is a campaign spearheaded by WATER EDUCATION COLORADO

For more information about the campaign, visit **Water22.org**

Artist's rendition of the deployed TEMPEST-D nanosatellite. TEMPEST-D is a CubeSat project of Colorado State University, Fort Collins, CO, with the objective to demonstrate the ability to monitor the atmosphere with small satellites. The mission, led by Principal Investigator (PI), Prof. Steven C. Reising of Colorado State University in partnership with JPL and Blue Canyon Technologies (BCT), reduces the risk, cost, and development duration for a future TEMPEST mission, which would provide the first ever temporal observations of cloud and precipitation processes on a global scale. Image courtesy of BCT, CSU.

Arabi, Mazdak, Texas A and M University, Bureau of Land Management-National Operations Center, Enhancement of APEX Model for Simulating Soil Erosion and Salt Transport in the Colorado River Basin, $200,000

Bailey, Ryan T., Civil and Environmental Engineering, Bureau of Land Management-National Operatiosn Center, Enhancement of APEX Model for Simulating Soil Erosion and Salt Transport in the Colorado River Basin, $38,000

Henry, Charles S., Department of Defense, Army, Army Research Office, Paper-Based Colorimetric Water Quality Sensors, $66,602

Keys, Patrick W., National Aeronautics and Space Administration, Research Proposal Type A – Cross-Scale Impacts of SDG15-Achievement: Household Decisions, Ecosystem Change, and Atmospheric Water Recycling, $99,169

Kummerow, Christian D., National Aeronautics and Space Administration, Untangling Changes in the West Pacific Water Cycle, $279,318

Nelson, Peter August, Coalition for the Poudre River Watershed, Hydrologic, Geomorphic, and Biogeochemical Impacts of Post-Fire Mulching, $35,000

Osborn, Blake Justin, Colorado Department of Agriculture, Expand Capacity of the Watershed Assessment and Vulnerability Evaluations Program (WAVE), $25,000

Reising, Steven C., California Institute of Technology/Jet Propulsion Lab, Retrieval of Water Vapor Profiles, Cloud Ice Water Path and Precipitation from the TEMPEST-D2 Sensor on the International Space Station, $100,000

Ross, Matthew Richard Voss, Department of the Interior, U.S. Geological Survey, Process-Guided Deep Learning for Informing Selection of Monitoring Locations in Priority Watersheds, $199253

Russell, Kathleen, Oregon State University, Hemp Irrigation Project-2021, $20,000

Venayagamoorthy, Subhas K., Department of Defense, Navy, Office of Naval Research, Dynamics and Modeling of Small-Scale Nonlinear and Nonhydrostatic Phenomena in Oceanic Flows, $63,027

USGS Recent Publications

Data Releases

Analysis of escherichia coli, total recoverable iron, and dissolved selenium concentrations and loads for selected 303 (d) listed segments in the Grand Valley of western Colorado, 1980-2018 (version 3.0); 2021, U.S. Geological Survey data release; R.G. Gidley, L.D., Miller, N.K. Day
doi.org/10.5066/P9P6WI44

https://Assessment of a conservative mixing model for the evaluation of constituent behavior below river confluences, Elqui River Basin, Chile; 2021, River Research and Applications (37)7, 967-978; C. Rossi, J. Oyarzún, P. Pastén, R.L. Runkel, J. Núñez, D. Duhalde, H. Maturana, E. Rojas, J.L. Arumí, D. Castillo, and R. Oyarzún
onlinelibrary.wiley.com/doi/10.1002/rra.3823_

Continuous water-quality data for selected streams in Rocky Mountain National Park, Colorado, water years 2011-19; 2021, U.S. Geological Survey data release; D.W. Clow, S.L. Qi, and G.A. Akie
sciencebase.gov/catalog/item/5ebb130582ce25b51361818c

Datasets for estimating invertebrate response to changes in total nitrogen, total phosphorus, and specific conductance at sites where invertebrate data are unavailable; 2021, U.S. Geological Survey data release; R.E. Zuellig and D.M. Carlisle
doi.org/10.5066/P9SMFACO

https://Estimated use of water by subbasin (HUC8) in the Upper Rio Grande Basin, 1985-2015; 2021, U.S. Geological Survey data, T.I. Ivahnenko and A.E. Galanter
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sciencebase.gov/catalog/item/5e289643e4b0d3f93b0560a0_

Journal Articles

Assessing specific-capacity data and short-term aquifer testing to estimate hydraulic properties in alluvial aquifers of the Rocky Mountains, Colorado, USA; 2021, Journal of Hydrology: Regional Studies (38), C.P. Newman, Z.D. Kisfalusi, and M.J. Holmberg
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Snow depth retrieval with an autonomous uav-mounted software-defined radar; 2021, IEEE Transactions on Geoscience and Remote Sensing, S. Prager, G. Sexstone, D. McGrath, J. Fulton, and M. Moghaddam
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Spatiotemporal dynamics of CO_2 exchange from headwater streams in mountain ecosystems; 2021, Journal of Geophysical Research: Biogeoscience (126)9, D.W. Clow, R.G. Striegl, and M.M. Dornblaser
doi.org/10.1029/2021JG006509

Uncertainty in remote sensing of streams using noncontact radars, (In Press-Journal Pre-Proof), Journal of Hydrology, M. Rahman Khan, J.J. Gourley, J.A. Duarte, H. Vergara, D. Wasielewski, P.A. Ayral, and J.W. Fulton
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Using an unmanned aerial vehicle water sampler to gather data in a pit-lake mining environment to assess closure and monitoring: Environmental Monitoring and Assessment; 2021, Environmental Monitoring and Assessment (193), B.J. Straight, D.N. Castendyk, D.M. McKnight, C.P. Newman, P. Filiatreault, and A. Pino
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Water–rock interaction and the concentrations of major, trace, and rare earth elements in hydrocarbon-associated produced waters of the United States; 2021, Environmental Science: Processes & Impact (23), 1198-1219; C.R. Bern, J.E. Birdwell, and A.M. Jubb
pubs.rsc.org/en/content/articlelanding/2021/em/d1em00080b

USGS Scientific Investigations Reports and Maps

Analysis of Escherichia coli, total recoverable iron, and dissolved selenium concentrations, loading, and identifying data gaps for selected 303(d) listed streams, Grand Valley, western Colorado, 1980–2018; 2021, U.S. Geological Survey Scientific Investigations Report 2021-5053, 37; L.D. Miller, R.G. Gidley, N.K. Day, and J.C. Thomas
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Assessment of diel cycling in nutrients and trace elements in the Eagle River Basin, 2017–18; 2021, U.S. Geological Survey Scientific Investigations Report 2021–5066, 36; R.J. Richards and M.F. Henneberg
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Assessment of streamflow and water quality in the Upper Yampa River Basin, Colorado, 1992–2018; 2021, U.S. Geological Survey Scientific Investigations Report 2021–5016, 45; N.K. Day
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Estimates of public-supply, domestic, and irrigation water withdrawal, use, and trends in the Upper Rio Grande Basin, 1985 to 2015; 2021, U.S. Geological Survey Scientific Investigations Report 2021–5036, 31; T.I Ivahnenko, A.K. Flickinger, A.E. Galanter, K.R. Douglas-Mankin, D.E. Pedraza, and G.B. Senay
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Water Calendar

The Indian Peaks Wilderness photogrpahed near Winter Park, Colorado. Photo © ipivorje/stock.adobe.com

February 2022

23-25 **RiversEdge West 20th Annual Riparian Restoration Conference**
Grand Junction & Virtual
Connect with other professionals managing and studying riparian lands and stream environments.
riversedgewest.org/events/2022-conference

March 2022

22-24 **International Conference on Water Resources Management and Sustainability: Solutions for Arid Regions**
Dubai, United Arab Emirates
This conference provides the opportunity to learn about innovative technologies that can transform water management and sustainability in arid and semi-arid regions around the world. It will also address current challenges and priorities in water management.
conferences.uaeu.ac.ae/expo2020_wms/en/about-conference.shtml

April 2022

25-27 **American Geophysical Union (AGU) Hydrology Days**
Fort Collins, CO
This event will showcase multiple keynote speakers and aims to bring together water scientists, researchers, and students to discuss the current state of the science and latest water-related research.
hydrologydays.colostate.edu/

View additional water events at watercenter.colostate.edu/events/

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This publication is financed in part by the U.S. Department of the Interior Geological Survey, through the Colorado Water Center and CSU's College of Agriculture, Warner College of Natural Resources, Agricultural Experiment Station, and Extension.

Three oil drilling rigs as seen in Weld County, Colorado, later required supplies of water for hydraulic fracturing and also produce waste water. Doctoral students participating in the InTERFEWS program are conducting research on key problems in the food-energy-water nexus with a focus on water-scarce, arid regions. Photo by Emmett Jordan.