

# Colorado Water

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## Agricultural Water **CONSERVATION**

Tools, Technology, and Collaboration



The newly released Colorado Water Plan projects water supply shortfalls that could total more than 500,000 AF statewide by 2050. Other western states envision similar supply gap futures and the Bureau of Reclamation's Basin Study on the Colorado River calls for 1 million AF of agricultural water conservation to help meet the projected 2030 gap on the Colorado River. The math is simple: most western water is used in irrigated agriculture – over 70% of consumptive water use is for food production. Since most of Colorado's water supply has been fully developed, the economic realities are such that without planned interventions, future water

gaps will largely be met by voluntary transactions from irrigated agriculture.

If you have not yet looked at the new Colorado Water Plan, it is worth a read at: <https://www.colorado.gov/pacific/cowaterplan/colorados-water-plan-final-2015>.

Urban water conservation is a major component of the solutions proposed in the Water Plan as it calls for 400,000 AF of additional municipal conservation to help cover the projected future supply gap. Given the magnitude of water used for crop irrigation, it is interesting that agricultural water conservation gets relatively little play in the Colorado Water Plan. There are of course some good reasons for this and it was not simply overlooked. In our river basins, water saved by one agricultural user tends to move downstream to the next senior diverter with little benefit accruing to the conserver. Additionally, in a water right change case, historical return flows must be preserved to avoid injury to downstream users. Thus, the water that can be transferred is limited to the proven historical consumptive use. True conservation is water saved that was previously consumed by crops. Unfortunately, the calls for increased agricultural water productivity often conflate irrigation efficiency, conservation and productivity into notions of more crop per drop leading to transferable saved water. In many cases, it will be fewer drops and fewer crops, but let's get the science and the terminology clear. Conserving crop consumptive use comes at a cost in terms of lost yield and revenue.

Does that mean that agricultural water conservation is a lost cause? Not at all. Drought, declining groundwater levels, climate change, the need to enhance environmental flows, and to deal with a water-short future all present scenarios that call for conservation and efficiency to increase agricultural water security. Groundwater declines in some basins will force agricultural conservation and irrigation efficiency both to sustain the resource and to enable individual producer economic survival. But increasing irrigation efficiency will not result in transferable water in Colorado. The Colorado Water Plan focuses on so-called "alternative transfer methods" (aka ATMs) that facilitate easier temporary movement of water between agriculture, municipalities and perhaps the environment, hoping to eventually provide 50,000 AF of municipal supply through these mechanisms. Right now it is more straightforward in some cases to buy irrigation water and go through the water court process than to enter into one of these alternative transfer methods. Water banks, interruptible supply agreements, forbearance arrangements, regulated deficit irrigation, split-season irrigation, temporary fallowing are all tools that could be used to save irrigation water and transfer to other uses if incentives and institutional mechanisms are in place.

Both urban and agricultural water conservation are part of our water future, but it must be recognized they come with costs and tradeoffs. This issue of Colorado Water newsletter looks at current work to better understand and quantify the tradeoffs associated with agricultural water conservation and irrigation efficiency. It takes a lot of water to grow our food. Securing agricultural productivity in a water scarce future is going to take scientific breakthroughs, new technologies, creative institutional arrangements, and political will.

*Reagan Waskom*

Director, Colorado Water Institute

# COLORADO WATER

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Agronomist David Nielsen (right) uses a neutron probe as technician Martin Walker uses time domain reflectometry to assess soil water used by winter wheat in an alternative crop rotation study. Courtesy Stephen R. Ausmus USDA-ARS

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About the cover: UAVs are one of the tools used for remote ET sensing, see page 15. Photo © iStock.com

Susan Schulten (right) explains historic maps in relation to the settlement of the West at the Western Water Symposium and Barbecue. Courtesy of the Colorado State University Libraries

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# Considering Agricultural Water Conservation and Efficiency

*John Eckhardt, Civil and Environmental Engineering, Colorado State University*

## What is Agricultural (Ag) Water Conservation?

There are several definitions of conservation, but one used frequently is *the controlled use and systematic protection of natural resources*. For water, conservation is more commonly defined as *improved management to use less water for a particular need*. There are two components of water use that must be considered—the consumed portion, or the consumptive use (CU), and the non-consumed portion, or the loss. What does it mean to USE less water? In the municipal domain, water conservation is focused on using less water in the home and delivery system loss reduction. In agriculture, there has been encouragement to reduce the crop CU rather than reducing losses as part of water conservation. Crops consuming less water are certainly using less water, but reducing crop yields results in economic as well as food security issues. We should therefore concentrate on using less water in agriculture while maintaining crop yields. The result of Ag water conservation will then be that crop CU remains the same, but the non-consumptive amount of water use is reduced.

Decreasing Ag water losses is commonly referred to as Ag water efficiency conservation. Agricultural efficiency conservation is therefore

### SYNOPSIS

Efforts should focus on reducing agricultural water loss—that is, water that is not consumed by crops—to reduce agricultural use and potentially benefit waterways.

growing the same crops with the same yields using less water. For example, a farmer diverts 100 acre-feet of water to irrigate his crop of tomatoes, but 60 of that 100 acre-feet returns to the river and aquifer and 40 is consumed by the tomatoes. If the irrigation performance is improved so that only 80 acre feet is diverted to maintain the 40 acre feet of crop consumption, 20 acre feet is “conserved” at the diversion. From the river perspective, no water was created because at the return flow point the amount of water in the river is essentially the same. The result of the conservation is a stretch of river between the diversion point and the return flow point experiences 20 acre feet more water. The river rate of flow has improved—i.e., the hydrograph is changed—and if managed properly, the river and possibly other water users are benefited.

## Understanding Farm Irrigation Operations

After many years and in some cases generations, farm irrigation operations have been perfected to meet the available labor needs and adjusted to each field’s soils and slopes, and reasonable irrigation technology has been adopted to grow crops economically to make a living. This is a complex system that varies not only by crop, field, and ditch delivery infrastructure but also river operations. To improve an on-farm irrigation system in most cases requires major changes that can be very costly, and usually, a positive return on investment is not achieved for the farmer.

Water efficiency, and particularly



John Eckhardt

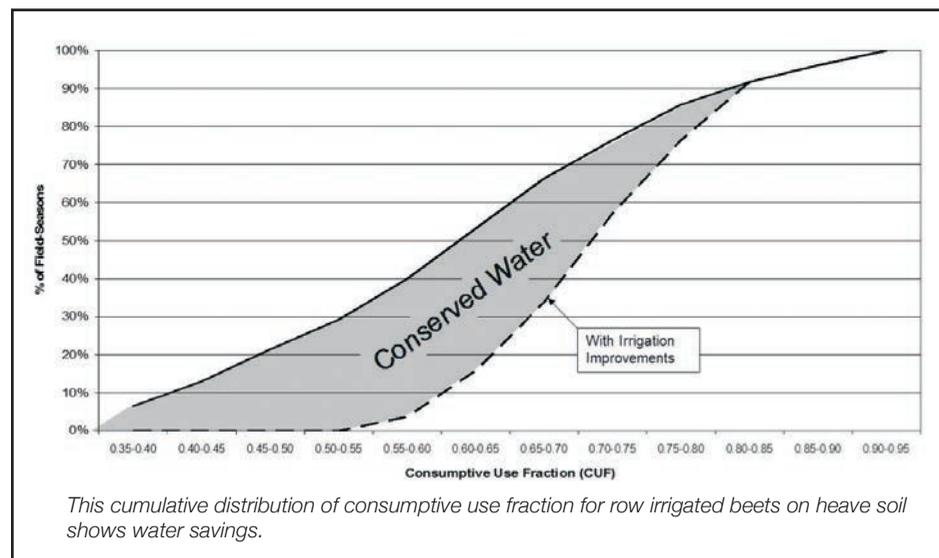
*Agricultural water research in the Colorado River Basin has involved collaboration on conservation projects.*

Ag irrigation efficiency, is a term that is misunderstood. It is generally defined as the amount of water put to beneficial use divided by the amount of water diverted. The question, however, surrounds the term beneficial use, or reasonable beneficial use. Is water used for germination a beneficial use? What about water for softening the soil for harvest or for cooling crops in hot weather? A more exact method to measure Ag irrigation water use and changes in that use is the Consumptive Use Fraction (CUF), defined as water consumed by the crop divided by water diverted and applied to the crop. It is impossible for an irrigation system to be 100 percent efficient, but commonly, this is what is expected by those wanting Ag water to be efficient. The use of the CUF term avoids the 100 percent efficiency opinion, making it a better universal measurement for Ag irrigation performance and improvement.

If you analyze an irrigation district with many farmers and fields, you will find a small percentage have a low CUF, a small percentage have a high CUF, and the bulk of fields falls between these extremes. Experience at improving on-farm irrigation operations has shown that not all farmers and their fields can be moved to a high CUF for many reasons—soil types, field grades, delivery systems, crop requirements, and economics are among these. Thus, an Ag efficiency conservation program must concentrate on improving all field CUFs without expecting them to improve to a specific high level. As shown in Figure 1, nearly all on-farm field CUFs for sugar beets are improved within the limits of each field and farmer operation. The overall irrigation system has improved as measured by the average CUF change from 60 percent to 70 percent, but not all fields have been able to achieve the same level of performance.

The challenge in irrigating crops is to make water available to the plant to meet the CU requirements of the crop. This means wetting the soil profile for the crop root system and ensuring the root zone is not depleted. This is a challenge based on field and soil characteristics, labor, on-farm irrigation technology, and to-the-farm delivery infrastructure. Better on-farm water delivery infrastructure and more labor may increase the amount of water available for the crop root zone, but more flexibility and consistency from the river-to-farm infrastructure needs to be improved as well. The farmer must weigh the costs of these improvements compared to an increase in crop yield. In most cases, the improvements do not prove economical from the farm business perspective. Unfortunately many studies have shown that most crops are under-irrigated, or deficit irrigated. As a result, an improvement in the irrigation process could actually increase the CU of the crop while generally increasing the crop yield. Nonetheless, irrigation improvements can still improve the CUF and reduce the amount diverted from the river.

Return flows enforce the idea that an individual diverter does not have to be efficient, since his return flows are used by someone else.



### River System and Basin-Wide River Operations

Agriculture water use in Colorado from a basin-wide perspective is very efficient. The amount of water diverted by water users compared to the available supply is significant. Water is diverted and reused many times because of return flows, storage, and recharged aquifers. Return flows enforce the idea that an individual diverter does not have to be efficient, since his return flows are used by someone else. The “use it or lose it” concept of the prior appropriation system provides little incentive to be efficient. If there is enough water for all uses, the water supply problem is timing and location. But if there is not enough water for CU needs, something has to give. River administrators must curtail junior water rights when there is not enough water to meet the water rights requirements of the most senior diverters. Generally, since municipal and domestic water rights are the junior rights, they are curtailed for the senior agricultural water rights. The prior appropriation system has some flexibility to relieve this situation, but to date, water rights holders have not

wanted to use this flexibility or share the river systems and infrastructure for improved river operations. And with the lack of sustainable Ag economic and food security legislation as a primary state and federal objective, municipal/domestic and industry can use their economic resources to shift water from Ag.

### Additional Water Conservation Considerations

Measurement is one of the major problems related to on-farm efficiency conservation. Ideally, a measurement is needed to determine the water conserved and where this conserved water is used. If not for contracting the use of the water from efficiency improvements, measurement is needed for maintaining the value of the water right if efficiency improvements are made. How to measure the efficiency savings has been the big challenge. What do you measure against, or what is the baseline? A field of sugar beets is going to have a much different water use pattern than a field of corn. If you could go back in time and measure the amount of water diverted each time a field grew corn and could determine the



CU of that corn for that year, you would have something to measure against. Regrettably, those historical records by field are generally not available.

When water conservation is undertaken on a broader scale, there is a possibility the local economy could be impacted, especially if CU and crop yields are reduced. The best example is dry-up of a field or even yield reduction. The farmer's income is reduced and has the effect of him buying less goods from the local economy. This impacts local businesses, farm labor, and the community economics as a whole.

Irrigation improvements reduce return flows from a field and can in some cases impact habitats such as wetlands using that return flow. Although flows in the river may increase in certain stretches for endangered fish, other species may be impacted by the change in the return flow regime. This can be a mitigation challenge.

### Ag Efficiency Conservation is the Solution

When you ask a farmer to use less water through CU reduction, you are asking him to reduce his income by lowering his crop yields. CU reduction is not the answer. Efficiency conservation requires spending money to improve on-farm irrigation systems and maybe a water rate increase from the ditch company for improvements which in most cases are not economic to farmer. But experience has shown that if you look at the comprehensive perspective of socio-economics and the environment, on-farm efficiency must be focused on the non-consumptive

part of the irrigation systems, perhaps with financial assistance from those wanting the farmer to divert less water.

Generally, delivery system flexibility is one of the most cost-effective ways to

only answer to larger improvements in irrigation performance.

So what is the answer for Ag water efficiency conservation? Perhaps a change in the water rights system or

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**Return flows enforce the idea that an individual diverter does not have to be efficient, since his return flows are used by someone else. The “use it or lose it” concept of the prior appropriation system provides little incentive to be efficient.**

**There are many workable conservation alternatives to improving water use efficiency rather than forcing farmers to farm less.**

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improve irrigation system performance, and more importantly, on-farm irrigation performance. If a farmer could turn on and turn off his water when required, rather than the 24 hour cycle required by ditch delivery systems, return flows would be reduced and irrigation performance improved both on-farm and on the delivery system. Unfortunately, ditch systems were designed to run steady state and thus, one change per 24 hours is normally the least cost ditch operations. Consequently, increased ditch company labor, more reregulating storage, and system-wide automation improvements have developed that do improve delivery and on-farm irrigation performance, but at a cost. In some cases that cost requires energy, such as drip and sprinkler systems, which may not be available. Field leveling and other field sizing and soil modifications have shown to be quite cost effective in some cases, but not the

more importantly, a change in river operations and management, could allow more river operational flexibility. Efficiency savings is generally not a legal issue. The possibility of quantifying a water right to include a certain level of efficiency may be the answer. But what makes the most sense is to fund improved Ag irrigation performance and enhance river flows by improved river and reservoir operations and management. There is no reason why we should be operating our river systems by water rights accounting and policing as if we were still in the 1800s. We have many new technologies that can assist in river basin operations, and we should be adjusting our organizations and tools with those new technologies to meet the water needs of today and the future. There are many workable conservation alternatives to improving water use efficiency rather than forcing farmers to farm less. 

## Moving Forward on Agricultural Water Conservation in the Colorado River Basin

**T**he term “agricultural water conservation” may be among the most misunderstood in western water today. It seems everyone’s definition is a bit different. At one end of the spectrum is the premise that there is no water to be conserved in agriculture because one farmer’s excess provides for the next farmer’s water right. At the other end of the spectrum is that all that’s needed to conserve a lot of water for urban use is for all farmers to start using drip irrigation. Neither exaggeration serves us well as we face the challenge of meeting projected future demands with limited water supplies.

Halfway through a project funded by the U.S. Department of Agriculture, the Colorado Water Institute is trying to reduce misunderstanding by fine-tuning definitions, highlighting where agricultural producers and their water managers are successfully using agricultural water differently to meet multiple objectives, and carefully examining and documenting legal, economic, and social obstacles that have to be overcome if we are to take full advantage of what potential exists for “agricultural water conservation” in the Colorado River Basin.

This compilation of articles describes some of the activities underway.



Rennett Stowe

*The Colorado River*

## Testing a “Why/What/How Agricultural Water Management Decision Tool”

MaryLou Smith, Policy and Collaboration Specialist, Colorado Water Institute

The term “agricultural water conservation” is increasingly being reserved to denote the conservation of crop consumptive use, or the water consumed by the crop. Most agree that such conservation can only be achieved by methods such as fallowing, crop changes, or deficit irrigation. Increasing the efficiency with which water is applied to crops, such as switching from flood irrigation to drip or sprinkler irrigation, is often not seen as agricultural water conservation in Colorado because the crop itself does not consume less water. Terminology is tripping us up, when perhaps the focus should be on how agricultural producers and their water managers could improve their water management to meet any number of important objectives.

The tool we developed and are currently testing with agricultural producers entails first identifying exactly why a farmer might want to manage her or his water differently. Some of the reasons include:

- » Increase yield
- » Reduce labor and other input costs
- » Stretch groundwater supplies

- » Be a good steward
- » Develop a new profit center by leasing some water for urban use
- » Increase water in the stream to support fish habitat
- » Respond to perceived pressure from outside agriculture for agriculture to use its water more efficiently

The methods chosen will differ depending on the goal. And incentives/disincentives for making the change will differ as well. For example, a farmer may want to upgrade to drip irrigation because the increased distribution uniformity will deliver a higher yield—a monetary motivation. However, if his reason for upgrading to drip is to divert closer to crop need/consumptive use so as to leave more in the stream for fish, he may face a disincentive—a belief that diverting less than his fully decreed amount will reduce the value of his water right. We believe the decision tool we are piloting will help farmers and their irrigation companies sort through the various options and barriers in order to not only make better decisions for themselves, but also help them clarify for policy makers the disincentives that make “agricultural water conservation” so complex. 

## Demonstrating Benefits of Improved Irrigation Efficiency

Perry Cabot, Research Scientist and Extension Water Specialist, CSU Extension

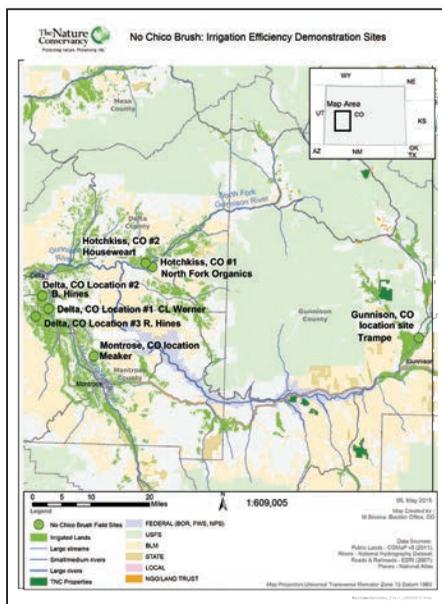


Figure 1. The No Chico Brush work group, which tests and demonstrates improved methods of irrigation technology, has demonstration sites in the Uncompahgre Valley, Rogers Mesa, and Upper Gunnison, Colorado.

The No Chico Brush (NCB) focus group defines itself as a “proactive farmer-led group promoting improved stewardship of agricultural water to secure the future of farming in the Gunnison Basin.” The name of the group originates symbolically from the “chico brush,” also known as grease wood (*Sarcobatus vermiculatus*), that would flourish and likely dominate the arid foothills and plateaus of the Lower Gunnison Basin were it not for irrigation and farming. In 2014, NCB received two grants from the Colorado Water Conservation Board (CWCB) through the Alternative Agricultural Water Transfer Methods (ATM) and Water Supply Reserve Account (WSRA) programs supported by the Colorado River District, The Nature Conservancy, Trout Unlimited, and the Gunnison Basin Roundtable. The purpose of both grants was to demonstrate the feasibility of different methods for efficient irrigation of crops in the Gun-

nison Basin, under the concept that such demonstration of improved irrigation technology and educating water users and regulators is an important step in the adoption of these tools as a viable ATM. The NCB group has elected to focus on irrigation efficiency strategies that are intended to use water more optimally at the field, farm, and district scale. Inclusion of irrigation efficiency is regarded as critical to the portfolio of ATMs. The NCB group is working to contribute knowledge on the diversions that may be foregone as irrigation efficiency improves, while at the same time increasing yields or at the very least maximizing water availability to farmers.

The NCB projects are concentrated in the region of the Uncompahgre Valley Water Users Association (UVWUA), with additional sites in the Rogers Mesa and Upper Gunnison areas (Figure 1). The project is completing the second season of what is expected to be a four-year study, evaluating



Figure 2. The Sensmit® telemetry and software program delivers real-time values of soil moisture so farmers can access their soil conditions from their smart phones.

and documenting the impacts of improved irrigation systems on crop yields, field enterprise budgets, water balances, and irrigation efficiency. The project is conducting water balances of traditional flood-furrow irrigation, contrasted with improved systems using overhead-pivot sprinkler, big-gun sprinkler, and surface drip tape. The water balances calculated for a field focus heavily on monitoring soil moisture throughout the season. Through a partnership with Irrrometer (Riverside, CA), the NCB group has facilitated one of the first deployments of the company's SensMit® telemetry and software program for delivering real-time values of soil moisture so that farmers can access their soil conditions via the Internet or smart phone (Figure 2).

Crop evaluations include alfalfa, corn, grass hay, and onion, which are common to the area. From the previous season in

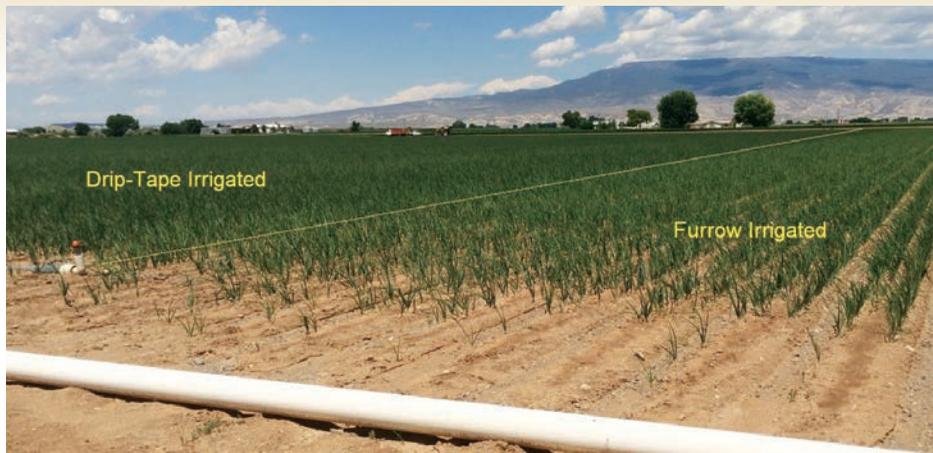


Figure 3. Onion field beds were planted at four rows per bed, and watered using furrow irrigation (right) and drip irrigation (left) for comparison.

2014, for instance, irrigation efficiencies increased on corn and onion fields while also fostering increases in the yield per-acre of irrigated land. In 2015, comparisons of the onion fields show noticeable differences in plant height, density, and color (Figure 3).

Although the tools for improving irrigation efficiencies are widely known and utilized in other parts of the country, Western Colorado has exhibited a slower pace of adoption. The work of NCB is intended to document the value of these tools in one of the most heavily irrigated parts of Western Colorado. Farmers who have adopted these tools express their reasons for doing so as a method to protect themselves from water shortages (many of which have been

induced by drought), labor savings, and economics. Therefore, the tools are certainly available in the region, and farmers are increasingly paying attention to these modern approaches. The primary question that remains is how wider adoption of these tools may result in more foregone diversions that could potentially increase the availability of water for other lands.

The field research cited here is funded separately from the USDA grant "Moving Forward on Agricultural Water Conservation in the Colorado River Basin." However, the work is tied to that grant by virtue of the NCB group having agreed to serve as one of the testers for the Why/What/How Agricultural Water Management Decision Tool described above. 

## Uncovering Barriers and Disincentives, as well as Opportunities for Effective Conservation Collaboration

*Peter Leigh Taylor, Sociology, Colorado State University*

*Kelsea MacIlroy, Doctoral Candidate, Sociology, Colorado State University*

Although much public attention is focused today on agricultural water and conservation as a potential means for dealing with growing water stress in the Colorado River Basin, a better understanding is needed of what the public is really asking of agriculture when it asks farmers to conserve water. As part of the Moving Forward with Agricultural Water project, CSU sociologists Pete Taylor and Kelsea MacIlroy are studying the barriers and disincentives to agricultural water conservation, as well as possible opportunities for effective collaboration for conservation. Legal disincentives may include potential loss of marketable water rights if conservation reduces diversions or historical consumptive use or if water is

leased to other users, third-party injury considerations related to reduced return flows, high costs and risks of adjudication of water use changes, Upper-Lower Basin Compact issues, and others. Economic disincentives include the high cost of conservation-related capital investments and the fact that few economic benefits return back to farmers who invest in conservation and efficiency improvements; real and perceived negative impacts on yields and economic returns; the lack of viable cropping alternatives in many contexts; crop characteristic-related obstacles, and others. Socio-cultural obstacles include the fact that conservation and efficiency are conceptualized and pursued in multiple ways, often leading to people talking past one another; farmers' wariness of potential

risks of new practices; real and potential negative impacts on local farming communities; distrust of non-farm water interests; cultural resistance to fallowing and other practices that may reduce yields and acreage; and others.

Our study recognizes several key dimensions of this complex problem. First, the problem of conservation varies greatly by local context; one-size-fits-all strategies are unlikely to be successful, yet much can still be learned from diverse experiences across the basin. Second, agricultural water conservation is not just the agricultural sector's problem, but involves important stakeholders (and potential supporters) among municipal suppliers, environmentalists, state and federal agencies, and others. Third, we need to better understand key differences in how stakeholder groups conceptualize and pursue agricultural water conservation and efficiency, depending on their relationships to the resource and their objectives. This includes unpacking how "conservation" and "efficiency" terms may be used interchangeably, despite the fact that in practice the two concepts may lead to very different outcomes. Fourth and crucially, efforts are already underway across the Colorado River Basin to tackle the legal, economic, socio-cultural and other barriers to agricultural water conservation. Many of these efforts are collaborative initiatives that try to achieve agricultural water conservation that can benefit farmers and help sustain agricultural security while responding to growing water stress in the region.

We are developing six in-depth case studies in Upper and Lower Colorado River Basin states in which irrigators are collaborating with federal and state agencies, municipal suppliers,



Alex Proimos

*In Arizona, Taylor and MacIlroy are studying the Yuma Mesa Irrigation and Drainage District-Central Arizona Groundwater Replenishment District pilot fallowing program, a collaborative conservation effort that aims to put saved water into Lake Mead (above).*

agricultural water conservation, how they have surmounted or are working to surmount conservation's formidable obstacles, and what lessons may be drawn from their experiences that might be useful elsewhere in the basin.

In Colorado, cases studies include: the Grand Valley Water Users' Association's collaboration with federal agencies and other stakeholders for conservation and efficiency benefiting endangered fish species; efforts to develop a "Super Ditch" in the state's southwestern region involving carefully managed temporary leasing of agricultural water for municipal use, inspired in part by the experience of California's Palo Verde Irrigation District; and the Colorado Water Trust's McKinley Ditch project to generate water from split season irrigation agreements and delivery efficiency improvements for instream flows without injury to downstream irrigators. In Arizona, we are studying the Yuma Mesa Irrigation and Drainage District-Central Arizona Groundwater Replenishment District pilot fallowing program, a collaborative conservation effort that aims to put saved water into Lake Mead. A second Arizona case study is the Diamond S Ditch, where The Nature Conservancy is working with local farmers on delivery efficiency improvements for environmental flows, while maintaining security for downstream agricultural users. A planned sixth case study in California is the Palo Verde Irrigation District, where farmers participating in voluntary paid rotational fallowing make possible non permanent water transfers to Metropolitan Water District; a Mitigation Plan and Community Improvement Board work to address agricultural job losses.

With these six in-depth case studies, we aim to harness already existing on-the-ground experience with collaboration for agricultural water conservation. Under the right circumstances and with effective partnerships with irrigators, agricultural water conservation may benefit farmers and help develop effective broad-based responses to an increasingly uncertain water future in the Colorado River Basin. 



Donna Boley

*In Colorado, Taylor and MacIlroy are studying the Grand Valley Water Users' Association's collaboration with federal agencies and other stakeholders for conservation and efficiency benefiting endangered fish species. The Colorado River, above, makes its way through Palisade.*

and environmental organizations to conserve agricultural water. Participants employ a range of fallowing, market leasing, shared infrastructure investment, and other mechanisms to conserve agricultural water that can be used for multiple uses while generating benefits for irrigators. Through interviews and field visits, we are learning what brought these diverse groups together around

## Reaching Out about Agricultural Water Conservation through Dynamic Websites

Beth Plombon, Master's Candidate, Sociology, Colorado State University

In response to the growing need for resources and tools that provide increased knowledge, understanding, and adoption of agricultural water conservation practices, the Colorado Water Institute (CWI) at CSU has developed two innovative Web-based clearinghouses: the Agricultural Water Conservation Clearinghouse (AWCC) ([agwaterconservation.colostate.edu](http://agwaterconservation.colostate.edu)) and the Colorado River Basin Agricultural Water Conservation Clearinghouse (CRB AWCC) ([crbawcc.colostate.edu](http://crbawcc.colostate.edu)). The AWCC website was originally created by CWI through the Northern Plains and Mountains Regional Water Program, but was later adopted into the outreach and education initiative of their Moving Forward on Agricultural Water Conservation in the Colorado River Basin project in order to preserve the site as an educational resource. While the AWCC addresses agricultural water conservation globally, CWI felt the public could greatly benefit from an additional clearinghouse focused specifically on agricultural water conservation in the Colorado River Basin (CRB AWCC).

Merely understanding the concept of agricultural water conservation and its assortment of impacting factors and considerations is far from easy. The clearinghouses are innovative Web-based projects that seek to bring together science-based, objective information, educational resources, and tools, while at the same time joining together communities of practice to collaboratively address the complex issues of agricultural water use and conservation. In an effort to connect industry with related research, educators to scientists, and technical experts to resource materials, both websites provide information on agricultural water conservation in the form of:

- » State and regional weather stations and ET networks
- » Fact sheets, manuals, and guides
- » Links to online courses and education
- » Schedulers, calculators, atlases, and assessment tools

- » Publications and presentations
- » Links to resources by state, including agricultural experiment stations, Land Grant University resources, USGS water science centers, and other research organizations

The Clearinghouses also stand as platforms for disseminating what is learned and produced from the other Moving Forward project initiatives. Tools developed within the project that will be displayed on the CRB AWCC (and AWCC, when appropriate) will include:

- » A database of conservation practices, costs, and engineering tradeoffs for the CRB
- » A database of legal, institutional and socioeconomic aspects of agricultural water conservation implementation in the CRB
- » A database of facilitation methods and case studies used for local engagement in conservation decisions
- » A decision matrix that leads irrigation districts through a learning and discovery process to local decisions about implementing conservation programs

Already available is a set of almost 80 case studies for those considering agricultural water conservation in the Colorado River Basin. Each case study includes maps and links to original source information.

While the CRB AWCC is focused specifically on the Colorado River Basin, the overarching goal of both clearinghouses is to research, compile, and assemble current and accurate information regarding agricultural water conservation. By increasing access to this information, the clearinghouses help build collaborative relationships between and among agencies, provide technical expertise regarding agricultural water conservation, and offer detailed information on the management, policies, and laws surrounding

agricultural water conservation. Furthermore, through the tools and resources provided, better decisions about future water supply and demand can be made.

### Project Websites



Agricultural Water Conservation Clearinghouse project website: [agwaterconservation.colostate.edu](http://agwaterconservation.colostate.edu)



Colorado River Basin Agricultural Water Conservation Clearinghouse project website: <http://crbawcc.colostate.edu>



Moving Forward on Agricultural Water Conservation in the Colorado River Basin project website: <http://crbagwater.colostate.edu/>

To learn more about specific project activities and outcomes, go to <http://crbagwater.colostate.edu/> or contact the project manager, MaryLou Smith at [MaryLou.Smith@colostate.edu](mailto:MaryLou.Smith@colostate.edu).

# Monitoring Crop Water Use and Stress to Inform Irrigation

José L. Chávez, Civil and Environmental Engineering, Colorado State University

## Introduction

There is an imperative need to improve water management to sustain agriculture and satisfy the increasing demand to grow more food, save water, and preserve the environment. In Colorado, the competition for water in urban, industrial, recreation, and other uses places an increasing pressure on irrigated agriculture to come up with alternatives to make water available for transfers to other uses. Some of these alternatives have included fallowing the land, otherwise known as buy and dry through leasing or sale of water rights; irrigating only a portion of the land; rotating crops with different water requirements; and also a much less desirable deficit irrigation option. This latter option entails reducing the application of water to the crop by a certain percentage of the crop water needs throughout the crop season (e.g., reducing by 20 or 30 percent), at certain growth stages, or only at non-critical (non-sensitive) growth stages such as vegetative or rapid growth stage.

Farmers are generally reluctant to deficit irrigate because of the risk of over-stressing the crop and thus reducing yields to non-profitable levels.

In this regard, a mechanism available to monitor the level of crop water use and stress, among other approaches, is the Crop Water Stress Index, or CWSI. This index is computed based on a difference between the crop canopy temperature and the temperature of the air ( $dT$ ) above the crop

## SYNOPSIS

It can be difficult to know when deficit irrigation can save water without creating crop water stress. This 2014-2015 study looked into methods of monitoring crop water use and stress, and outreach was conducted to share monitoring and irrigation methods.



Figure 1. A field day was held at the USDA ARS Limited Irrigation Research Farm near Greeley, Colorado to show the different irrigation treatments, the instrumentation, methods, and preliminary results; 120 people participated. Courtesy of José Chávez

and variable thresholds for maximum and minimum  $dT$  values. The data needed to compute the stress index can be obtained with an infrared thermometer and weather station measurements of air temperature (with a thermocouple or a thermistor) and relative humidity (with a capacitive sensor).

In order to learn how the CWSI performs in northern Colorado, a demonstrational study was devised as part of an evaluation of several vegetation water stress detection algorithms. This study has been funded by the Colorado Water Conservation Board (CWCB) Alternative Agricultural Water Transfer Models (ATM) program for two years (2014 and 2015).

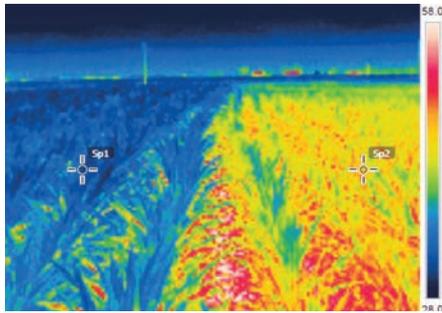
## Outreach

During the summer season of 2014, a field day was held at the U.S. Department of Agriculture (USDA) Agricultural Research Service (ARS) Limited Irrigation Research Farm (LIRF) near Greeley, Colorado, to show the different irrigation treatments, the instrumentation, methods, and preliminary results. One hundred twenty people participated in the field day, including one group shown in Figure 1. This year, the field day will be repeated on August 21 at the same facility. In conjunction with the ARS, the field day will cover the following topics:

- » Measurements and monitoring to manage and document consumptive use savings and support ATMs (including remote sensing)
- » Yield and productivity with reduced irrigation
- » Measurement of plant water stress
- » Scheduling of regulated deficit irrigation
- » Demonstration of irrigation scheduling tool
- » Estimating consumptive use (evapotranspiration) with deficit irrigation

The ARS is a collaborator in this study along with Central Colorado Water Conservancy District (CCWCD), West Greeley Conservancy District (WGCD), and Northern Water.

Furthermore, a workshop will be held in November of 2015 at Colorado State University. At the workshop, participants will be explained the principles of the different crop water stress and use methods studied and will be trained in the use of spreadsheets to process field data to estimate crop water status and thus assist in the decision making of when and how much irrigation is needed.



Canopy air temperature image (above) on stressed and non-stressed (below) corn plots. Courtesy of José Chávez



### Water Stress and Use Studies

Study plots were planted to corn near Greeley, Colorado (ATM field) which included one fully irrigated plot and two deficit irrigation plots (Figure 2). All three plots were instrumented with infrared thermometers looking at the corn rows in an oblique fashion (45 degrees from a hypothetical horizontal line) and North East and North West (two infrared thermometer, or IRT, units per plot). Using the CWSI approach, crop water stress and use (or transpiration) were computed and were compared to evapotranspiration values derived from a soil water balance and an energy balance applied at the land/vegetation surface. Results indicate that the CWSI method is a viable way of monitoring corn water stress and use. The method is more accurate when only temperature from leaves is recorded after local noon time from sunlit leaves. However, some constraints exist that need to be considered.

For instance, regarding the ancillary data required to compute the maximum and minimum dT limits, in situ data collection is preferred to data from a weather station that is not on the farm.

From data collected at LIRF (Kullberg, 2015): “Comparing in situ (field) weather

data in August for 2012 and 2013 to the off-field or agricultural weather station data at 11 am, when CWSI was applied for this study, showed that for all irrigation levels, using nearby weather station introduced error. Full irrigation (FI) had the highest vapor pressure deficit (VPD) error both years, with RMSE (root mean square error) values of 0.31 kPa (14%) and 0.36 kPa (19%) for 2012 and 2013, respectively. Data from 2013 showed that for this year of the study there was consistent underestimation of VPD from weather station data, ranging from -0.07 kPa (-4%) to -0.23 kPa (-11%) for FI and HFDI (high frequency deficit irrigation), respectively. Comparison of weather station to in situ VPD supports the idea that in field conditions may diverge from those of a nearby weather station and introduce error into CWSI calculations.”

To investigate the effect of VPD error on CWSI calculations using a nearby weather station instead of in field readings, CWSI was calculated for the nearby field assuming a canopy-air temperature differential of 2.5 degrees Celsius and using the same baselines (dT limits) as were used in the study using LIRF data. Considering both years, using weather station data collected at two different times of the year also produced different accuracies on estimated CWSI and derived ET values. The CWSI was applied to data collected at 11 a.m. and at 2 p.m. (MST) following Idso et al. (1981) guidelines. Results indicated that the average RMSE of VPD for the 2 p.m. data was 12.0 percent as compared to 15.1 percent for 11 a.m. data, indicating that in situ weather data in this case varied from the weather station more at 11 a.m. than at 2 p.m. This is in accordance with the method guidelines to use data collected from around 1 to 3 p.m. (local standard time) when crops develop and show maximum water stress.

### Applications—How Accurate are Handheld Infrared Sensors?

The discussion so far refers to crop canopy data collected with a research grade IRT (e.g., Apogee) mounted in an oblique fashion and capturing mostly canopy/leaf temperature. However, many users (e.g., farmers and consultants) won't have access to this type of research equipment

and may resort to using less expensive and commercially available handheld IRT guns. The question, then, is how accurate these sensors are. As part of the CWSI study, IRT guns were used to record canopy temperatures, and these were compared to temperatures collected with the research grade sensor. In general, handheld IRT gun sensors cannot be used directly in agricultural fields since they were developed for indoor use, and when used outdoors for extended periods of time they heat up and yield erroneous temperature readings. One handheld IRT gun from Ryobi, in particular, tended to be more accurate under certain conditions but underestimated the true canopy temperature and presented a relatively large standard deviation, which is most probably attributed to lack of correction for sensor body temperature, inclusion of target thermal emissivity values (which changes with the health of the plant and type of surface—sensors should allow for emissivity settings), and corrections for background temperature effects (e.g., air temperature, sky, soil background temperatures). The resulting slope and constant (bias) from the linear regression equation between the IRT gun and the reference sensors were 0.7 and 9.4 degrees Celsius, respectively. Through a calibration effort it was possible to decrease the discrepancy (canopy temperature error) by considering the following variables in a multiple linear regression equation: solar radiation (short-wave incident), air temperature, VPD, and wind speed. The incorporation of a solar zenith angle did not contribute further in the improvement of the calibration equation. The new slope and bias from the evaluation regression line were 0.9 and 3.1 degrees Celsius, respectively. Even though it was possible to reduce the error in canopy temperature error for the data collected with the IRT gun, there is room for further improvement, since the bias needs to be less than one degree Celsius for acceptable accuracy.

Further studies will need to incorporate procedures to collect data a certain distance from and angle to the crop (leaves only) and to record the sensor internal temperature if accurate readings are to be used. ☞

Contact [cwi@colostate.edu](mailto:cwi@colostate.edu) for references.

# A Common Sense Approach to Ensure the Future of Our Built Landscapes

*Zachary Johnson, Horticulture and Landscape Architecture, Colorado State University*

**A**s a landscape architect, I have designed projects of most scales and complexities and for as many varied clients as you can imagine. Some of these were easy and others challenging, but at the conclusion of all of these projects, I can honestly say the most rewarding aspect is working with client personalities and ensuring that their expectations are satisfied.

Growing up in the arid San Luis Valley of Southern Colorado, I was well aware of the importance of water and the power it played in the many decisions regarding its use. While more and more people are understanding water and its value, thanks in large part to the unfortunate and difficult drought situation in California and other western states, too many still don't give much regard to its use. This in my opinion is especially true of water consumption for landscapes. If the grass is green, most everybody is happy. However, depending on exactly where you live in the West, it has been found that as much a 60 percent of all domestic water is consumed by landscapes. While it is true that the population of Colorado is expected to grow by roughly five million in 40 years, we have a good number of tools available to conserve immense amounts of water used for our built landscapes. This is where those in my

profession have an opportunity and responsibility to step up and become smart water use leaders.

Some of these tools are based on technology. Smart irrigation controllers are a great starting point. Smart controllers can gather an enormous amount of site data and then determine when and how much to irrigate. In addition to collecting real-time on-site weather conditions such as wind speed, temperature, precipitation, and humidity, they can also calculate the actual water requirements of the landscape plants. While these controllers are designed to shut down during wet periods or windy days, water managers can directly communicate with many of these controllers simply with a smart phone. Flow meters can also be connected to these devices, sending out alerts to the homeowner, contractor, or water manager, limiting running an irrigation system which has suffered a pipe break or has possibly been vandalized. It is estimated that these types of controllers can provide a water savings of upwards of 50 percent over traditional irrigation controllers.

Another tool is proper plant selection for the site. The use of water-wise plants is a big piece of the solving the outdoor water conservation puzzle. The availability of beautiful xeric plants has never been greater. These can offer year-round appeal as varying colors, textures, and forms appear in different months. I'm able to convince many of my clients to use these types of plants once they understand that a xeric landscape doesn't necessarily mean yucca and rock. One of the most controversial components of a landscape are lawns. While it may not always be the case, at this point in time, it is fair to say that well thought out lawns

can be part of a Colorado landscape, although with certain caveats. One of my teaching colleagues assigns a project in his Turf Management class called Stupid Turf Areas. This assignment challenges students to find a turf area that does nothing other than consume resources and provides a very limited benefit. Most of his students identify grass areas which can't be efficiently irrigated, are too small to use for recreation, or in general are just not good places for lawns. I often notice turf areas which are never really used—that is, they are for visual enjoyment only. In my opinion, if a lawn is only irrigated, mowed, and fertilized and not enjoyed either as recreation or pleasure, it is time to reconsider the space.

The most important piece of education we can provide for our clients is to modify their expectations. In working with landscape design and contracting students for over a decade, I can tell you that their favorite color to render landscape plans is green—not sage green or olive green, but grass green. This is in large part because of client expectations. It is much easier to sell a plan which is covered in grass green rather than areas of golden yellow, maize, desert tan, or other colors often associated with xeric landscapes. The days of us showing up to client presentations with plans that are only beautiful should be long gone. Instead we need to talk about the impacts of our ideas, and in our region, that means considering water. We have to discuss how much water will it take to establish the landscape, how much water is required to maintain the designed landscape, and what the plan is should we experience a drought leading to reduced or total elimination of water for outdoor use. Our clients are smart and quickly understand their responsibility once they are given the facts. I find they generally

## SYNOPSIS

Human-built landscapes provide an opportunity for the introduction of technology, like water-saving smart irrigation, and proper design and plant selection that ensure the wisest use of water resources while serving as aesthetically-pleasing landscapes.



*An example of landscape renovation shows the replacement of high-water-consumption grasses (left) with a grass better suited for the semi-arid climate (right). Courtesy of Zach Johnson*



*An example of lawn renovation shows the replacement of high-water-consumption grasses (left) with a grass better suited for the semi-arid climate (right). Courtesy of Zach Johnson*

become excited about making decisions which will best position their landscape when water becomes less available.

I recently completed a landscape design for a large commercial project in Denver. Like many industrial and commercial projects, the client never really used their landscape other than to fill a space in front of their buildings. The existing landscape was largely Kentucky Bluegrass. Beyond being visually boring, it was only irrigated, mowed, and fertilized, never loved by human feet. The client understood this and wanted to create a space which was beautiful, interesting and most important, used far less water. To the client's credit, they could have simply covered this space in rock and never looked back, but they wanted something else, something that would send a message to their customers and neighbors. So the design process began,

back and forth with ideas, images, and drawings, until the both parties were pleased. The Kentucky Bluegrass was removed, smart irrigation technologies were incorporated, and what I call an urban prairie was installed. It included native and introduced grasses as well as flowering perennials and small shrubs, all able to withstand very limited quantities of water once established. It is safe to say the new landscape looks very different than the original Bluegrass landscape. Even after going through an exhausting design process with clear images of what the new landscape would look like, upon construction, it was met with some amount of surprise. It was no longer a lawn, but "lawn" was the word that continued to describe the space. It was new and different—very different. As part of the education process, small interpretive signs were placed throughout the landscape which helped

both employees and visitors to the site better understand exactly what we were up to. Slowly, key management at the site began to embrace the landscape, but it is safe to say others are still warming up to the new look. People are complex, and embracing change takes time. Our goals were met, and we have saved enormous amounts of water through the use of technology and thoughtful plant selection, while the clients better understand their responsibilities when it comes to landscapes in Colorado.

Built landscapes provide countless benefits for society. As water becomes increasingly more scarce, we must continue to design and build landscapes that recognize this fact and while finding ways to ensure enduring, aesthetically appealing outdoor spaces. Incorporating new and existing water conservation tools and working together will go a long way toward accomplishing our goal. 

# Adapting Irrigated Cropping Systems to Drought

Allan A. Andales, Soil and Crop Sciences, Colorado State University  
José L. Chávez, Civil and Environmental Engineering, Colorado State University

In recent years, Colorado has experienced several dry and warm growing seasons that affected irrigated agriculture. Farms that did not have access to sufficient water supplies were forced to reduce the irrigated acres or curtail irrigations on existing crops. The recent drought of 2012 resulted in an estimated 124,461 acres of prevented planting and 98,086 of failed crop acres. Although 2014 and 2015 have turned out to be good water years for the state, drought years like 2012 can still be expected. There is a need for innovative management options that can adapt irrigated cropping systems to drought and reduce adverse impacts on crop production.

An interdisciplinary team is conducting a three-year field demonstration project that was started in 2014 and will continue until 2016. The main goal of the project is to demonstrate soil, crop, and water management practices that can adapt irrigated cropping systems in the Central Great Plains to drought and can improve water use efficiency. The project also aims to develop a farmer-friendly decision support tool that empowers producers to plan and evaluate water-conserving practices into site- and management-specific approaches while considering the effects of drought and climate change. The project is being

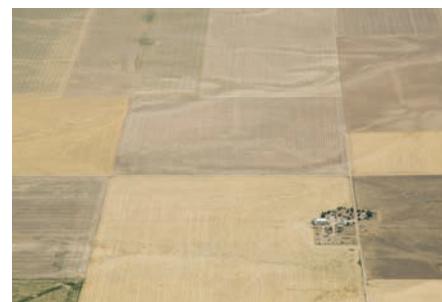
funded by the U.S. Department of Agriculture (USDA) Natural Resources Conservation Service (NRCS) Conservation Innovation Grant program (CIG); additional funding and resources are provided by Dupont Pioneer, Biochar Solutions, John Deere Water, 21<sup>st</sup> Century Ag Equipment, Colorado Water Conservation Board, West Greeley Conservation District, and Northern Water.

Field demonstrations are being done at the CSU Agricultural Research Demonstration and Education Center (ARDEC) in northeast Fort Collins and at the Limited Irrigation Research Farm (LIRF) in Greeley, Colorado. The USDA-Agricultural Research Service (ARS) provides support for managing the LIRF site. A combination of water, soil, and crop management options are being demonstrated. Intensive monitoring of soil water content, crop consumptive water use, crop growth and yield, crop water stress, irrigations, and greenhouse gas emissions from the soil are being done to document the effects of the management practices. The focus of the field demonstrations has been on corn, which uses large amounts of water and is a major irrigated crop in Colorado (Figures 1 and 2).

## Water Management Options

A combination of irrigation levels and irrigation scheduling techniques are being demonstrated.

- » Limited irrigation: Limited-irrigation scenarios are being compared to full irrigation, which supplies the full evapotranspiration (ET; also called consumptive water use) requirement of the corn crop. A drought scenario supplies only 50



Aerial view of drought affected Colorado farm lands, 89 miles east of Denver, July 21, 2012. USDA photo by Lance Cheung.

percent of the full ET requirement throughout the growing season. The other scenarios demonstrate targeted water stress during the less sensitive vegetative phase of the corn crop, when reduced or no irrigations are applied from the time corn has five leaves until it has 10 leaves. In these scenarios, full irrigations are applied during crop establishment and the critical reproductive phase.

- » Irrigation scheduling by soil water balance: The Water Irrigation Scheduler for Efficient Application (WISE) online tool ([wise.colostate.edu](http://wise.colostate.edu)) is being used to estimate daily soil water depletions, which can indicate the required amount (inches of water) and timing of irrigations. WISE keeps track of daily additions (rainfall or irrigation) and depletions (ET or drainage) of water in the root zone using daily weather data from automatic weather stations ([www.coagmet.com](http://www.coagmet.com)) and soil water holding capacity. Proper irrigation scheduling can increase application efficiencies

## SYNOPSIS

A wide variety of practices and technologies can help farmers improve water efficiency and prepare for drought periods in the Great Central Plains. A research team is demonstrating the effectiveness of several soil, crop, and water management practices and tools for this purpose.

Allan Andales



Figure 1. Corn plots include different hybrids, irrigation levels, and soil amendments. The white box in the foreground contains a data logger for continuously recording soil water content. In the background is a linear move sprinkler system that applies different amounts of irrigation.

Jeff Hathaway

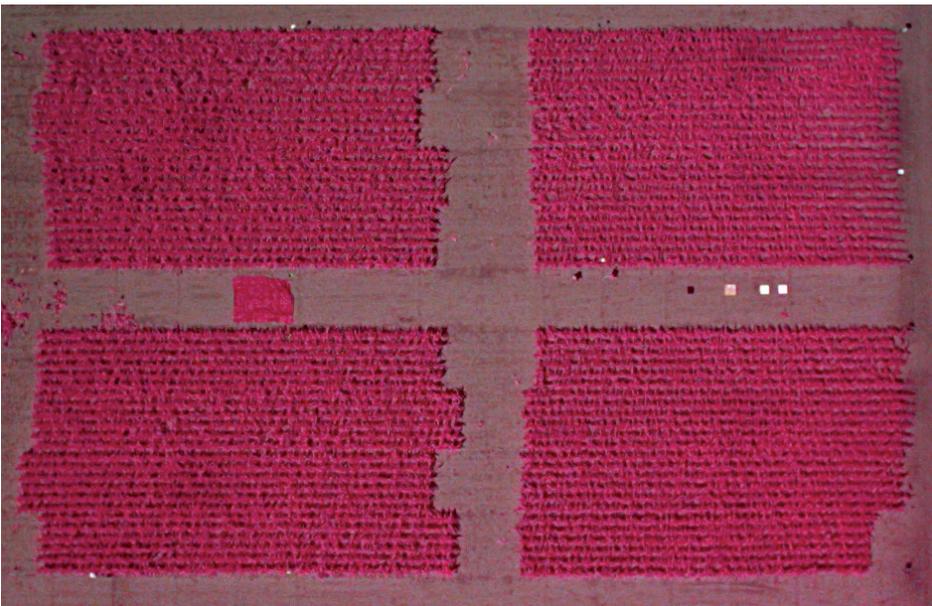


Figure 2. A multispectral image of four corn plots at the study site was captured from an unmanned aerial vehicle. Multispectral images contain information on light intensities at different wave lengths and can be used to estimate crop consumptive water use across a field.

and improve yields by reducing water loss through surface runoff and deep drainage and reducing water stress during critical growth periods.

- » Irrigation scheduling using Crop Water Stress Index (CWSI): The CWSI ranges from zero (no water stress) to 1.0 (maximum water stress) and uses the difference between crop canopy temperature and air temperature as an indicator of stress. Plants that have enough water tend to

have cooler leaf temperatures compared to water-stressed plants, because evaporation of water from the leaves has a cooling effect. Hand-held infrared thermometers (IRT) are being used to measure canopy temperatures that are used to obtain CWSI values. The CWSI can be used to estimate water-stressed ET rates (inches per day) from non-stressed ET rates. The estimated water-stressed ET rates can then be used to

determine irrigation water requirements and thus become a tool to schedule irrigation.

- » Remote sensing of ET: Multispectral images captured from a manned aircraft or unmanned aerial vehicle (UAV), along with ground-based radiometers, are being used to estimate actual crop ET rates from the fields. The ET rate for each pixel in the image can be calculated by estimating the energy balance of the crop surface and solving for how much energy is used for evaporating water from the crop surface. Remotely-sensed ET can also be used to determine irrigation water requirements and can show spatial differences between stressed and non-stressed crops.
- » Variable Rate Irrigation (VRI): A VRI center pivot sprinkler system at CSU-ARDEC is equipped with 30 zones (three nozzles per zone, with each zone controlled by a separate valve) and is being used to demonstrate variable rate irrigation across the field. Irrigation amounts are being varied according to management zones in the field that were mapped using a combination of technologies that help identify spatial differences in soil and crop characteristics linked to soil water holding capacity. The spatial mapping approaches include soil electrical conductivity (EC), grid soil sampling, yield mapping, and other methods. VRI seeks to match the irrigation application rate to actual soil infiltration and water holding capacities that vary across the field, resulting in reduced losses from surface runoff, deep drainage, and leaching of nutrients.

### Soil Management Options

Soil water holding capacity and soil water evaporation are affected by the soil physical properties and the amount of crop residues maintained on the soil surface. The following approaches to conserve soil water are being demonstrated in this project.

- » Soil amendments: Biochar is black carbon produced from the combustion of organic matter. The use of wood-derived biochar is of special interest in Colorado because of the extensive areas of pine forests that have been killed by bark beetles. Wood-derived biochar was applied and incorporated in the top six inches of soil in selected plots at ARDEC to explore its benefits primarily for increased soil water holding capacity. This treatment is being compared to manure application, to a combined biochar and manure treatment, and to soil with no amendments. Soil water content as well as greenhouse gas fluxes from these plots are being measured to document the effects of the soil amendments on water holding capacity and greenhouse gas emissions.
- » Strip tillage: This tillage method prepares a seedbed in narrow strips and maintains surface crop residues between the strips. Ten-inch wide strips on 30-inch centers are tilled to a depth of eight inches and the space in between strips is not tilled. This reduced tillage method takes advantage of the mulching effect of residues to

reduce soil water evaporation, reduce soil erosion, and improve interception of snow.

### Corn Variety Options

Two drought tolerant Pioneer Aquamax varieties are being compared to the closest two related hybrids without drought tolerant traits. The growth and yield of these four corn varieties are being documented to show how they interact with the various soil and water management options described above. Regular measurements of leaf number, canopy height, leaf area, and developmental growth stage are being made. At maturity, samples are taken from the different treatments to determine total biomass and grain yield.

### Decision Support Tool

An existing field-scale decision support tool called COMET-Farm ([cometfarm.nrel.colostate.edu/](http://cometfarm.nrel.colostate.edu/)) was co-developed by CSU and USDA-NRCS as a whole farm and ranch carbon and greenhouse gas accounting system. It is being expanded to estimate the effects of agricultural conservation practices, including drought mitigation strategies, on-crop water use, soil water storage, and water availability. These expanded capabilities will allow farmers or land managers to evaluate the effects of various management options on water availability and crop water use efficiency, especially under drought or climate change conditions.

### Future Work

The drought adaptation strategies described above will continue to be demonstrated and evaluated until the end of the 2016 growing season. The project team aims to have a suite of complementary soil, crop, and water management practices and tools that can adapt irrigated cropping systems in the Central Great Plains to drought and improve water use efficiency. The information gathered through this project will be transferred to producers, consultants, resource managers or conservationists, and extension agents.

### Acknowledgements

This project is funded by the USDA-NRCS with additional support from Dupont Pioneer, Biochar Solutions, John Deere Water, 21<sup>st</sup> Century Ag Equipment, Colorado Water Conservation Board, West Greeley Conservation District, and Northern Water. The project director is Neil Hansen (now at Brigham Young University). Co-investigators on the project are Francesca Cotrufo, Keith Paustian, Raj Khosla, José Chávez, Allan Andales, Robin Reich, and Louis Longchamps. Joel Schneekloth and Wilma Trujillo are involved in outreach activities. Cooperators on the project include Bill Curran (Dupont Pioneer), Jonah Levine (Biochar Solutions), Greg Hart (John Deere Water), Jon Altenhofen (Northern Water), and Justin Childears (21<sup>st</sup> Century Ag Equipment). 



*Strip tillage method takes advantage of the mulching effect of residues to reduce soil water evaporation, reduce soil erosion, and improve interception of snow.*



The Cache la Poudre River pictured near Fort Collins.

## Ag/Urban Water Sharing Feasibility in the Poudre Basin

MaryLou Smith, Policy and Collaboration Specialist, Colorado Water Institute

### Background

The people of Colorado have said they value agriculture: for food and fiber, wild-life habitat, open space, and rural culture. But we want water to drink, bathe in, and grow lawns with too. More people moving here means more domestic water will be needed, even if urban water conservation reduces per capita consumption.

Domestic water providers have to make sure their customers have the water they need. When they sell a tap, they promise a secure source of water. Over the years, they have purchased water from farmers to provide for long range growth and drought security. Much of that water is rented back to farmers—except in times of drought, and until area growth requires that water be used for base supply. Farmers in some areas who sold their water shares have come to rely on the rental water to continue their agricultural operations.

Why have farmers been willing to sell their water? Some sell for a retirement nest egg—when they have no family members to keep the farm going. Some sales took place during years when commodity prices were low for an extended period and farmers badly needed income. Though some of this water is sold from farms remote from cities, much of the market activity occurs as development grows over farm land.

Farmers want to retain the right to

sell their water and to see a good return on their investment. At the same time, many farmers and city dwellers believe the permanent transfer of water from agriculture will have negative long-term impacts. While some of the sales keep the water within the Poudre basin, increasingly, buyers are looking for water to send south of the basin. Current market forces and the need for more urban water have placed a bull's eye on Poudre basin agricultural water.

Faced with this dilemma across the state, the Colorado Water Conservation Board (CWCB) and others working on the first Colorado Water Plan are counting on an alternative kind of market transaction materializing between agricultural and urban interests such that we can have urban growth and agriculture too. CWCB has funded projects to study the feasibility of what they call Alternative Transfer Methods, or ATMs. The concept is to allow farmers to lease water temporarily to cities while keeping ownership of the water in agriculture.

One way these leases can be done is through an interruptible supply agreement, where farmers agree to lease some of their water in at most three out of 10 years to cities. They can plant crops that require less water (crop changes), take some of their land out of production temporarily (fallowing), or purposefully

apply less water than the crop needs for optimal yield (deficit irrigation). The concept is that the money the farmer makes from the leased water will make up for lost crop production and the cost of interim management practices.

Are any of these ideas feasible in the Poudre basin? Starting in early 2013, irrigation companies and domestic water providers who named themselves the Poudre Water Sharing Working Group (PWS) met monthly to find out.

All the major water users on the Poudre River are members of PWS.

Agricultural members include North Poudre Irrigation Company, Water Supply and Storage Company, New Cache la

### SYNOPSIS

Can agricultural irrigation companies and domestic water providers in the Poudre basin work together to meet future urban water needs while keeping agriculture viable? That's the question the Poudre Water Sharing Working Group met for the past two and a half years to answer. Their query was funded by the Colorado Water Conservation Board, and a report was submitted in May of this year (visit [cwi.colostate.edu](http://cwi.colostate.edu) for the full report).

Poudre Irrigating Company, and Larimer/Weld Irrigation Company.

Domestic water providers include the City of Fort Collins Utilities, City of Greeley, and the Tri-Districts—a group of special districts who supply domestic water to customers outside the City of Fort Collins Utilities service area, some of which fall within the City of Fort Collins growth management area.

Tri-Districts is made up of Fort Collins-Loveland Water District, East Larimer County Water District, and North Weld County Water District. Because the major water users have C-BT water as part of their water portfolio, a representative from Northern Water is also part of the group.

With the help of a research team led by CSU, PWS:

- » Developed relationships and trust
- » Shared information and data about our respective missions and operations
- » Wrote descriptions of alternative transfer methods we thought might work in the Poudre basin
- » Surveyed irrigation company shareholders to assess whether they might use these methods
- » Developed prototype agreements that could be used for these methods
- » Discussed the need for regional cooperation for strategies like shared infrastructure

### What Did They Learn?

- » Two of the irrigation companies are already largely urban-owned. The idea of using short term leases and “water swaps” with domestic water providers as they have in the past is more appealing to them than the formality of an interruptible supply agreement.
- » Two of the irrigation companies are still primarily farmer owned and have fewer shareholders selling water, though some sales activity is going on. They are less interested in alternative water markets because they are seeing good profit from operations and have very little interest in “diversifying” by entering a temporary lease water market to take pressure off agricultural sales.
- » The City of Greeley recognizes that much of its cultural and economic strength comes from agriculture, so they are motivated to keep agriculture strong. But they and the Tri-Districts require reliable supplies for considerable anticipated urban growth and feel safer buying that water. They are satisfied with the actions they are taking to secure water for growth, primarily through the transition of water from agricultural to urban as agricultural lands are bought for urban development and as they purchase water from farmers and rent it back until they need it for drought or future growth. They believe the current system works well for farmers and cities and that perhaps by the time the water they are purchasing is needed for base supply and is no longer available for rent back to farmers, there will be other solutions available through technology to reduce negative repercussions to agriculture.
- » The City of Fort Collins Water Utility service area is bounded by Tri-Districts and other suppliers and has the water it needs for expected growth, though they lack sufficient storage to hold water for use in drought periods. Their supply and demand policy reads, in part: “The City will also work towards water sharing arrangements that provide water for municipal uses when critically needed and that allow for continued agricultural use of water at other times, in a manner that preserves irrigated agricultural lands over the long-term.”
- » One ATM that surfaced for discussion is the concept variously named “buy and supply” or “land and water district.” An entity, perhaps public, would be formed to provide an alternative market for those who want to sell their land



Stephen Smith

Members of the Poudre Water Sharing Working Group meet.

and water and desire to see it stay in agriculture. The entity would buy at the same market price as a farmer could sell to an in-basin or out-of-basin buyer. Simply stated, the entity would put the land under a conservation easement or similar legal agreement that has built in agreements for some of the water to be made available for urban use, likely on a rotational basis. Like any new and untested concept, this idea generated more questions than answers, but some of the members of the group, along with several individuals and organizations outside the group, intend to further investigate the idea.

- » A fair number of the irrigators and water shareholders surveyed were willing to consider water sharing agreements as they become available. The majority were supportive of attempts to reduce “buy and dry,” which is a term used to denote the permanent removal of water from agriculture.
- » There are significant barriers to agricultural producers understanding their options for water transfers. Within the group, significant time was spent “chewing on” water sharing methods to understand the benefits that could result for both agricultural and municipal interests. Straightforward access to information about transfer methods and context about when various methods could work in site-specific situations is lacking. Education is complicated because water transfer transactions typically occur with individuals and not the irrigation company, although the company has a role in educating its shareholders.
- » There is general concern about water moving out of the Poudre basin, though some in the group pointed out the irony that our basin benefits from significant transbasin diversions from the

West Slope. There is recognition that the water market will continue to be a driver for water transfers; however, there is also concern from some in the group that the free market will result in a situation that ultimately is less optimal for the entire system and in particular for agricultural viability.

- » The unique aspects of the North Poudre Irrigation Company, with its Colorado-Big Thompson units, provide water sharing opportunities that cannot be easily duplicated. This provides a good example of how water sharing agreements must consider specific local constraints and opportunities, rather than broad concepts that do not clearly identify benefits and costs. This need for local focus points out the need to provide education and encourage dialog at a local level.

### What Do They Recommend?

- » Domestic water providers and irrigation companies should continue to look for ways to work together. There is potential for shared expansion and use of storage and conveyance infrastructure beyond what is currently provided through exchanges.
- » Focus groups or an irrigation company summit should be held to give irrigation company shareholders an opportunity to learn about alternative markets for their land and water should they decide to sell.
- » Additional options for ongoing education about water transfer methods are needed, preferably from a neutral source that is easily accessible to agricultural producers and organizations that represent producers. Education needs to be provided at different levels, including concepts down to details

that allow agricultural producers to relate to their personal situations. Summaries of success stories for projects throughout the state would help illustrate potential for additional success. Similarly, analysis of barriers and failures will provide perspective when evaluating new opportunities.

- » Though there are concerns and questions about the “buy and supply” concept, those interested in it should continue to investigate it with other interested parties outside the group.
- » Continued educational outreach to the public and relevant groups about the multiple benefits and values provided by irrigated agriculture and the need to continue work on alternative transfer methods and related activities that will keep it viable should be undertaken.

Now the work started by the Poudre Water Sharing Working Group will continue as a newly adopted initiative of the Poudre Runs Through It Study/ Action Work Group. That group brings together agricultural, urban, environmental, business, and recreational stakeholders along the river from Fort Collins, Windsor, Timnath, and Greeley. Their purpose is to learn from each other and collaborate on actions that meet the dual goals of “working river, healthy river.”

Members of both groups hope the relationships built between irrigation companies and domestic water providers and their two and a half year effort to better understand the feasibility of ag/urban water sharing arrangements for the Poudre basin will result in keeping agriculture viable even as our population grows.

The author facilitated the meetings of the Poudre Water Sharing Working Group and served as project manager of its research team. For questions, you may contact her at [MaryLou.Smith@colostate.edu](mailto:MaryLou.Smith@colostate.edu). For more information, visit [cwi.colostate.edu/ThePoudreRunsThroughIt](http://cwi.colostate.edu/ThePoudreRunsThroughIt). 

# The Alliance for Global Water Adaptation: Sustaining Freshwater Resources in a Shifting Climate

*John H. Matthews, Secretariat Coordinator, Alliance for Global Water Adaptation and Senior Water Fellow, CSU Water Center  
Alex Mauroner, Research Assistant, Alliance for Global Water Adaptation*

Water has always been a challenging resource to manage—humans often face having too much or too little, or water at the wrong time. And water runs throughout our ecosystems and economies in ways that mask the challenges for managing and sustaining water as a resource that spans institutions and sectors: power, flood control, cities, agriculture, fisheries, and forests. The infrastructure we build to manage that water can last very long periods and require large investments. Large dams in China, Turkey, India, and Yemen have operated for well over 1,000 years—more than 2,000 years in the case of the Dujiangyan irrigation facility near Chengdu, China. Because water infrastructure lasts a long time, we have to envision how climate change will affect our investments in water management.

While the earth's climate has always changed, the current period of climate change is dramatic and accelerated compared to many previous shifts. The full water cycle—precipitation, evaporation, groundwater recharge,

snowpack accumulation, and the timing of flows—are all both sensitive to climate and difficult to predict. Moreover, the widespread use of water infrastructure for delivering power, food, urban water supply and sanitation, flood and drought control, navigation, and natural resources management means that assumptions about current and future climate conditions are “locked” within concrete, stone, and rebar for decades, even centuries. Our cities, homes, and even whole regional economies can become “stranded” in a climate that makes managing water difficult and expensive without foresight.

Defining what climate-resilient water management operations and infrastructure look like has been an area of increasing concern for engineers, water scientists, economists, and governance specialists. In 2010, the Alliance for Global Water Adaptation (AGWA; [alliance4water.org](http://alliance4water.org)) was created to address the emerging need for climate adaptation focused on freshwater issues. The goal of AGWA is to manage freshwater resources even as changes in climate affect hydrological cycles. AGWA is structured as an informal network of regional and international development banks, government agencies and ministries, diverse non-governmental organizations (NGOs), and members of the private sector. The group is hosted by two co-chairs: the World Bank's Water Partnership Program, and the

Stockholm International Water Institute (SIWI) Climate Change and Water Program. Groups such as the U.S. Army Corps of Engineers' Institute of Water Resources, Deltares, and the Dutch Water & Environment Ministry are very active in AGWA. John Matthews,

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**The Alliance for Global Water Adaptation operates under the belief that water can act as a unifying theme to climate change adaptation and mitigation while integrating energy, water, food production and agriculture, and ecosystems and the environment.**

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affiliated with CSU's Water Center, coordinates the secretariat.

AGWA operates under the belief that water can act as a unifying theme to climate change adaptation and mitigation while integrating energy, water, food production and agriculture, and ecosystems and the environment. AGWA convenes experts, decision makers, and institutions within the water community to work together to synthesize the emerging

## SYNOPSIS

The Alliance for Global Water adaptation works on freshwater issues related to climate change. Their projects include decision-making tools, guides, and educational campaigns that promote wise water use and planning.



The Yuzui Water-dividing dike is part of the Dujiangyan irrigation system near Chengdu, China. The system dates back more than 2,000 years.



A woman carries water near Ganges in Uttar Pradesh, India.



A farmer in China's Yangtze Basin near Shanghai.

body of practice for climate-resilient water management. This goal, of course, includes working toward sustainable food production and water conservation. With a strong focus on both technical implementation and policy, AGWA uses a diverse set of initiatives to address issues associated with agriculture and water conservation.

Through a series of workshops hosted by the National Socio-Environmental Synthesis Center (SESYNC) run by NSF and the University of Maryland, AGWA has developed a new risk management methodology that incorporates both engineering and ecological perspectives into a novel framework. Known as Eco-Engineering Decision Scaling (EEDS), this methodology has direct implications on the future of agriculture and water conservation. EEDS allows water managers to explore tradeoffs in stakeholder-defined engineering and ecological performance metrics across a

John Matthews (3)



Bonneville Dam on Columbia River along Oregon-Washington border.

range of management actions and future hydrological and climate states. This means that even in the face of uncertain water futures across the globe, including Colorado, water managers can make informed decisions based upon whatever criteria they value. Often environmental costs (and sometimes benefits) are understated or thought about after the fact in water management planning.

The new EEDS methodology helps to ensure that environmental health (e.g., sustainable water supplies, water quality, biodiversity) is maintained even in the face of uncertain climatic futures when assessing water management options such as new irrigation or drainage systems.

AGWA's efforts in EEDS are being led in part by Colorado State University's own N. LeRoy Poff with



The Alliance for Global Water Adaptation held a press briefing on *Watercourse Lessons for Mitigation and Adaptation Toward a Climate Deal* at the United Nations Framework Convention on Climate Change Lima COP in December, 2014.



The inaugural episode of the #ClimateIsWater series features Brad Udall of Colorado State University's Colorado Water Center.

strong contributions from Theodore Grantham of the U.S. Geological Survey's Fort Collins Science Center. More information will be available through an upcoming publication in *Nature Climate Change* and a forthcoming website being developed by AGWA and SESYNC. Visit [alliance4water.org](http://alliance4water.org) to find out more.

Another effort at providing water managers and stakeholders with guidance in climate change adaptation is an AGWA tool known as the "AGWA Guide." Over the past few months, the secretariat have been developing this set of resources; however, this toolkit is still in development at the time of publication and set to be released later this month. The AGWA Guide will be a stand-alone website for technical decision makers interested in a self-taught course in climate adaptation and robust water management. The site will be a collection of text, interviews, videos, and technical readings illustrating the AGWA approach to long-term

sustainable water management. Once published, it will be freely available for the benefit of practitioners, investors, decision makers, and resource managers in the water community.

Sustainable agriculture and water conservation requires knowledgeable water managers, but it also requires substantial support on the policy level. AGWA's Policy Team, led by SIWI, works under the premise that sustainable water and climate change policies need each other in order to be successful for mitigation and adaptation. The Policy Team is a network of AGWA members, governments, and like-minded organizations such as branches of the United Nations Framework Convention on Climate Change (UNFCCC). Many of AGWA's efforts in the policy realm deal with the lead up to the UNFCCC COP 21 in Paris this December, where the goal is a new international climate agreement. Strong attention will be paid to the water-food-energy nexus. After all, any potential outcomes of COP 21 must include a path toward sustainable agriculture and water conservation if they are to be effective.

AGWA is also using the power of media to influence and promote sustainable water policy. For the last several months, AGWA has been producing a series of online videos and social media campaigns called

#ClimateIsWater. The inaugural episode featured Brad Udall, Senior Water and Climate Scientist of the Colorado Water Institute. He discusses the effect of climate change on the people and places around Colorado, with particular emphasis on the Colorado River. Each episode receives hundreds of views and has been building an increasing following via social media and online forums. All videos are available to view or download from the AGWA Blog ([alliance4water.org/About/blog/index.php](http://alliance4water.org/About/blog/index.php)) and their own Vimeo channel ([vimeo.com/channels/918234](http://vimeo.com/channels/918234))

Agriculture and water conservation will continue to remain critical issues in the realm of climate change, likely even more so as the global population along with corresponding food and water demands increase drastically in the coming decades. We must work to develop sustainable management practices that address both climate adaptation and mitigation concerns. AGWA is poised to guide water managers toward sustainable pathways through its vast network, its technical projects across the globe, and its strong presence in the policy arena. Together with the help and support of institutes like the Colorado Water Institute, we can work to ensure that agriculture and other water-related sectors make strides to lessen their footprint and adapt to a changing climate. 

# Unusually Low Evaporation Means More Water for Colorado This Year

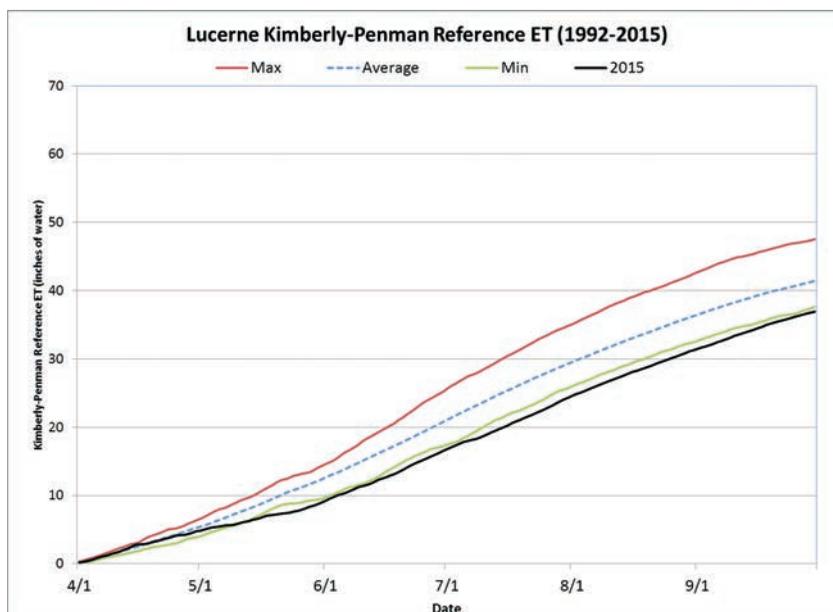
*Nolan Doesken, State Climatologist, Colorado Climate Center, Colorado State University*

A few people saw it coming. Despite an unseasonably warm March and early April (2015), the National Weather Service’s Climate Prediction Center (<http://www.cpc.ncep.noaa.gov/>) stuck to their guns in forecasting a cool, wet spring for Colorado and neighboring states. Sure enough, it began with a nice widespread soaking storm April 16-18, followed by five more large, slow moving, multi-day storms, each separated by just a few days, that left much of our state soaking wet and lushly green. After these came several more weeks of scattered but locally heavy thunderstorms followed by one more cool, cloudy, rainy week in early July. What had been anticipated as

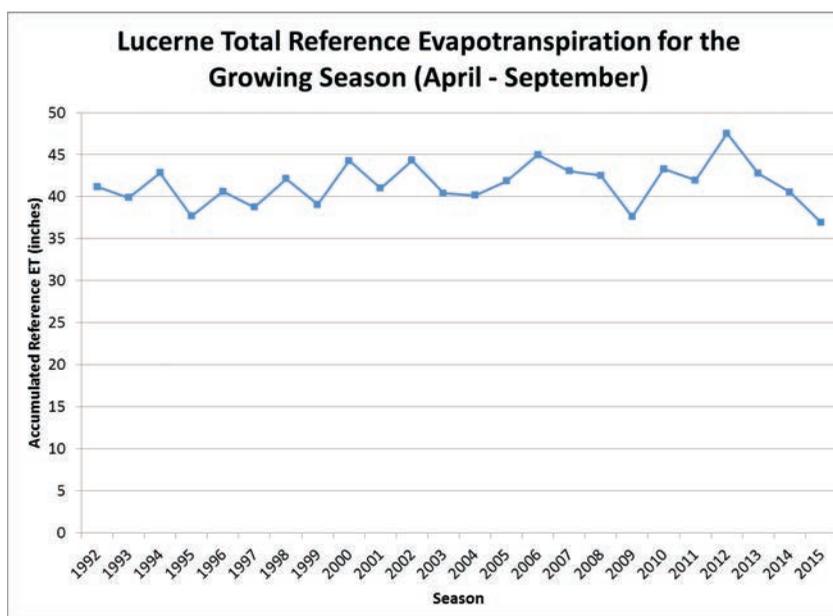
**This year, with the abundance of soil moisture from May to at least mid-July, dryland vegetation has thrived.**

another very poor runoff season for the Colorado River Basin ended up close to the average, much to the delight of water users throughout the Colorado River Basin. East of the mountains, both the South Platte and Arkansas Rivers flowed at or above flood stage for several consecutive weeks until hotter, drier summer weather finally made its inevitable appearance later in June and July.

The heavy rains got all the attention—and deservedly so. In May alone, dozens of



Reference ET for the 2015 growing season was lower than the minimum from 1992 to present.



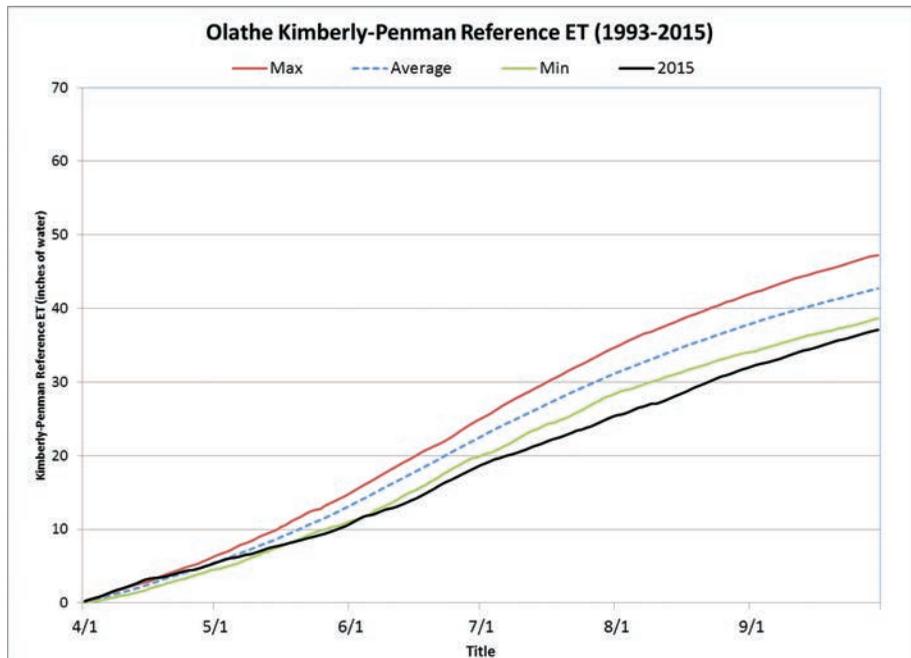
Evapotranspiration (ET) was low on the front range in 2015. The Lucerne station is near Greeley, Colorado. Total reference ET for the 2015 growing season was lower for Lucerne than it has been since the early 1990s.

As plants grew abundantly, they also returned more moisture than average back into the atmosphere. That's actually part of the answer to the question I've gotten a lot this year: "Isn't it more humid than usual?" The answer is YES.

locations from Cañon City and northeast toward Weld, Morgan, Logan, and Yuma Counties measured eight inches to locally more than 13 inches for the month. The Colorado Springs airport experienced its wettest month in recorded history, with a May total of 8.13 inches. June added four to nine more inches of rain to many of these same areas. Even on the West Slope, where early summer months—May, and especially June—tend to be dry and sunny, the rains this year seemed endless with two-month totals of five to eight inches at locations such as Steamboat Springs and Durango (300-plus percent of average).

The heavy rains were only part of the equation, however. With cool temperatures in May and persistent cloud cover, high humidity, and surprisingly light winds from late April to early July, evaporation rates were low. Heavy precipitation in combination with low evapotranspiration meant that a higher fraction of precipitation than usual was available for groundwater recharge and surface runoff. Farmlands as well as urban landscapes required almost no supplemental water throughout the spring and early summer. This helped explain the much higher than expected flows in most of Colorado's rivers and streams in May and June as well as the very high reservoir levels.

Historically, evapotranspiration has been roughly estimated based on correlations with air temperatures, latitude, and time of the year. But with automated weather stations now able to measure temperature, humidity, wind speed and direction, and also the solar energy reaching the ground quite accurately it is possible to use principles of



Reference evapotranspiration was low in 2015 for the West Slope of Colorado, as represented by the Olathe, Colorado station.

physics and mathematical equations to computationally estimate evapotranspiration rates and evaporative stress that plants are experiencing. CSU's Colorado Agricultural Meteorological Network (CoAgMet) was designed, in part, to estimate evapotranspiration. Over the past 20 years, this network has grown to nearly 75 stations representing most of Colorado's irrigated croplands.

Using CoAgMet data, the following graphs show how 2015 reference evapotranspiration rates (from a fully-watered alfalfa crop) compare to recent years. Through mid July, it was the lowest reference ET year on record in parts of the state. Keep in mind, however, that these reference ET estimates only go back to the early 1990s. 1995, 1997, and 1999 also had relatively low spring/early summer evapotranspiration rates. In the 1980s, Colorado had several years with both high snowpack and cool wet springs with suppressed evaporation. Those years all had large runoff volumes. Since 2000, however, many years have had higher spring and summer reference ET rates as measured by CoAgMet weather stations.

Does this mean that less water than average returned to the atmosphere? Here is where things get a bit more complicated. The answer is that it depends. Thanks to the cloudy, humid, and relatively calm weather, irrigated crops and turf required less irrigation water and returned less water than average back up to the atmosphere. However,

the majority of Colorado is forest, range, and dryland cropland. These areas are often dry and can only evapotranspire as much water as is available at the soil or in the root zone of the soil. This year, with the abundance of soil moisture from May to at least mid-July, dryland vegetation has thrived. As plants grew abundantly, they also returned more moisture than average back into the atmosphere. That's actually part of the answer to the question I've gotten a lot this year: "Isn't it more humid than usual?" The answer is YES.

The Colorado Climate Center provides daily, three-day, and seven-day estimates of evapotranspiration for many parts of Colorado. By knowing how much rain fell, and by estimating the amount of water that crops are using each day, farmers are able to estimate when and how much irrigation water is needed. See [ccc.atmos.colostate.edu/~coagmet/](http://ccc.atmos.colostate.edu/~coagmet/). It's even possible to get text messages sent directly to your phone to help track water use. There is also a great irrigation management tool available through eRAMS: [erams.com/resources/Apps/Irrigation%20Scheduler](http://erams.com/resources/Apps/Irrigation%20Scheduler).

*Note: The Colorado Climate Center produces a comprehensive update of climatic conditions, water supplies, and drought status weekly on Tuesdays. If you would like to be on the email list to receive weekly climate updates, please contact Nolan Doesken at [nolan@atmos.colostate.edu](mailto:nolan@atmos.colostate.edu) or call (970) 491-8545.*



# The Threat of Invasives in Colorado's Cottonwood-Dominated Riparian Zones

*Ryan Lockwood, Public and Media Relations Coordinator, Colorado State Forest Service*

*Note: This summer, the Colorado State Forest Service released a new Quick Guide titled Cottonwood Management in Colorado: Ecology, Rehabilitation, Wildfire and Other Considerations. The following article is adapted from the complete guide, which offers greater detail and specific management tips, available online at <http://csfs.colostate.edu>.*

Adapted to thrive on Colorado's eastern plains, in mountain valleys, and along riparian areas throughout the state, cottonwoods represent the largest native broadleaf trees in the state, and are the most pervasive deciduous trees found at lower elevations. Colorado cottonwoods can grow to more than 80 feet in height, flourishing in wetter soils near rivers, lakes, irrigation ditches, and other lowland areas. Managing these natives can help ensure numerous benefits that include wildlife habitat, recreation, stream bank stabilization, and stormwater uptake. But they are increasingly threatened by non-native competitors and their resulting impacts, including a greater prevalence of wildland fire.

## Cottonwood Ecology

Groves of cottonwood trees, or bosques, are located in riparian zones—areas adjacent to rivers, streams and lakes—in Colorado and throughout the western U.S. These ecosystems are usually a patchy mosaic of plains cottonwood trees (*Populus deltoides*), narrowleaf cottonwood trees (*Populus angustifolia*) and/or Rio Grande cottonwoods (*Populus deltoides ssp. wislizenii*) that grow in conjunction with shrubs, such as willows, and various grasses and forbs. Narrowleaf cottonwoods grow at the highest elevations, between 5,000 and 8,000 feet, while plains cottonwoods can be found from approximately 3,500 to 6,500 feet. Rio Grande cottonwoods grow on the West Slope of the Continental

Divide between 4,000 and 6,000 feet.

In the riparian zones where cottonwoods are found, the vegetation is influenced by shallow groundwater and is different from the vegetation found in the adjacent, dryer upland zones. Typical riparian zones are very diverse in species, and many plants within them require large amounts of water to survive. These zones provide high-quality fish and wildlife habitat, offer shade to lower water and soil temperatures, and have vegetation that absorbs flood waters and improves water quality by filtering out pollutants.

Modern watershed management has reduced occurrences of seasonal floods, while variables such as drought and changes in land use have left many riparian forest floors littered with large amounts of dead branches, logs, and leaf layers. Historically, cottonwood groves present in floodplains relied on periodic flooding to wash away debris and promote tree regeneration. A lack of naturally occurring, regular flooding thus reduces cottonwood reproductive success. When these areas are dry, the accumulation of debris also can become hazardous fuel for wildfire, without flooding events that can bury flammable forest floor debris with sediment to make it less likely to carry fire.

Many cottonwoods located in Colorado riparian areas with altered stream flows are mature and/or in decline. Due to changing factors in these ecosystems, including drought, water management, and extensive wildlife browsing or overgrazing by livestock,

cottonwoods are not surviving in some areas where they historically thrived.

## Benefits of Cottonwoods and Riparian Vegetation

Riparian ecosystems associated with cottonwood groves contain numerous smaller native shrub and tree species. These species vary depending on elevation, with higher-elevation species that include coyote willow, black willow, red osier dogwood, river birch, rocky mountain maple, and thin leaf alder; and lower-elevation species that include boxelder, silver buffaloberry, skunkbush, three-leaf sumac, and golden currant. Benefits of cottonwoods and other riparian trees/shrubs include:

- » Reducing erosion, with root systems that hold soil in place
- » Capturing and filtering sediment
- » Providing wildlife habitat
- » Slowing floodwater runoff
- » Increasing water infiltration

Cottonwood-dominated riparian zones provide critical habitat for wildlife because they offer food, water, and shelter. This is especially true in the arid Southwest, where rivers and streams may be the only sources of water. Standing dead trees also can provide homes for cavity-nesting birds and squirrels, and many endangered species like the Southwestern willow flycatcher depend on riparian areas for survival.

## Competition from Invasive Species

In the past, many tree species were introduced to the West. While most of these species were beneficial for erosion control and thrived under irrigation, a few escaped cultivation and became

invasive. Trees are considered invasive if they are exotic or non-indigenous species that grow aggressively and replace native vegetation in environments in which they did not evolve. Invasive plants often have no natural enemies to limit their reproduction (e.g., insects that feed on them) and thus displace native vegetation and can cause environmental damage. In Colorado, the most prominent invasive tree species in riparian areas are Russian-olive and tamarisk.

Russian-olive, a medium-sized tree native to portions of Europe and Asia, was introduced into North America as a shelterbelt and windbreak tree during the late 1800s. Russian-olives have silvery-green foliage and tiny yellow flowers in spring, and produce olive-like fruit in late summer or early fall. This tree proved to be especially suitable for the harsh growing conditions of the Great Plains, and ultimately, it escaped cultivation. Russian-olive has invaded riparian areas, fields, and open areas, where it competes with and displaces native vegetation, including cottonwoods. Due to extensive historical planting and the dispersion of seed by birds, this invasive tree has become widely distributed across Colorado and other western states and is now on the noxious plant list for Colorado.

Tamarisk, or salt cedar, is a species of small- to medium-sized trees native to southern Europe, northern Africa, and central Asia. Like Russian-olive, tamarisk was originally introduced to North America during the late 1800s as an ornamental tree and for use in shelterbelts, windbreaks, and stream-bank stabilization. Tamarisk readily adapted to the semi-arid climate of the West, invaded riparian areas—especially in the Great Plains and Great Basin regions, and displaced native forests of cottonwood and willow. Tamarisk thickets alter the ecology and hydrology of riparian areas. These trees have a high evapotranspiration rate, creating excess water loss. Sites invaded by tamarisk typically dry out over time, resulting in reduced stream flows.

When considering any treatment for invasive tree or shrub species,

including Russian-olive and tamarisk, land managers should choose an option that best meets individual management objectives. Options may include tree removal, use of chemical treatments, and replanting native species. Chemical treatments such as herbicides can be effective if product directions are carefully followed, but they can be time-consuming and costly, may not be practical or effective for all situations, and may be of concern if used near bodies of water. It is essential to research the best possible treatments for a specific area before taking action, as well as to assess the site's potential for native re-vegetation. If adequate stands of native vegetation already exist on a site, it may not be necessary to actively re-vegetate.

### The Role of Wildfire in Riparian Zones

Historically, flooding was the major natural disturbance in riparian zones. With human-structured flood controls that create heavy fuel conditions, wildland fire is becoming more prevalent as another form of disturbance in these ecosystems, which evolved with very little fire influence.

Cottonwood trees are not a highly fire-resistant species. They can survive low-intensity wildfires, but moderate-intensity fires have the potential to kill cottonwood trees. Yet in some cottonwood-dominated riparian ecosystems, wildfires have replaced periodic flooding as the main disturbance. Although after a wildland fire severely burned cottonwoods sprout new suckers from the root system that could become next-generation trees, these suckers often lack hardiness and do not survive. As a result, Colorado cottonwood stands are being replaced by ecosystems dominated by non-native, invasive shrubs.

The accumulation of branches and leaf litter in these invasive-dominated systems creates large amounts of hazardous fuels. Woody invasive plants, such as tamarisk and Russian-olive, reproduce prolifically from roots following fire and thrive with repeated fires on the landscape. As excess fuels from shrubs in riparian areas increase, the frequency and intensity of



Riparian zone. Courtesy of the Colorado State Forest Service



Dead and downed debris can offer fuel for a wildfire. Courtesy of the Colorado State Forest Service

riparian wildfires increases, creating a spiraling condition that is increasingly hostile to native cottonwoods. Woody invasive plants also add ladder fuels, or lower fuels beneath larger trees that allow fire to spread to the upper tree canopy, which increases the chance of a high-intensity crown fire.

### Cottonwood Grove Restoration

To restore a cottonwood grove to a healthy, more natural state, the CSFS offers recommendations to landowners and land managers. These include:

- » Leaving a buffer strip of grass and shrubs along the river/stream for bank stabilization
- » Retaining pockets of dense native vegetation, including cottonwoods and shrubs, for forest regeneration and wildlife habitat
- » Creating or retaining small brush piles for wildlife habitat and to encourage seedling regeneration

For more information about the management and restoration of riparian cottonwood groves, go to [csfs.colostate.edu](http://csfs.colostate.edu). 

# Ideas Old and New at the Western Water Symposium and Barbecue

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

Wrangling with our predecessors. Wrestling with water regulations. Reviewing the maps that got us here. And trying to figure out where to go.

More than 100 people learned about such looming legacies at the Western Water Symposium and Barbecue, held July 27 at Colorado State University's Morgan Library to benefit the Water Resources Archive. Combining historical insight with future water challenges generated new ideas and impassioned discussions.

Maps fascinate, with so many embedded details and dreams. Susan Schulten, history professor at the University of Denver, began the day by discussing the development of western maps and how some of those details and dreams came to be embedded. Our arid West was one of the last regions of the continental U.S. to be accurately charted by cartographers. A significant swath, which included what is now Colorado's eastern plains, came to be labeled the "Great American Desert," indicating it was unsuitable for habitation, except by Indians already there.

By the time gold was discovered in the Rockies in 1858, boosters encouraging the fortune seekers erased both the fear-inducing Indians and the uninhabitable desert from their maps to imply peace and safety for settlers. At the same time, scientists were increasingly depicting data geographically, creating the first maps showing concepts such as average precipitation across the country, images now taken for granted, but at the time showing aridity in a new way. Schulten's historical review of maps demonstrated that western development was molded by mapmakers and the legacy of that development remains today.

Making peace with our predecessors was the theme for Patty Limerick, history professor at the University of Colorado

Boulder. While we are often beneficiaries of the water leaders and entrepreneurs who went before us and can learn from their examples, they were not always honorable people. Acknowledging that and accepting it can be quite a struggle. Limerick focused on examples from Denver Water, whose history she has written. Denver Water's formative leaders were David Moffat and Walter Cheesman, names easily recognized on existing water facilities. The two in part achieved rapid progress for Denver's water system, and therefore the city itself, by being ruthless businessmen driving out all other competition.

A more blatant and recent example of an important but complicated water leader is Glenn Saunders, the intimidating lawyer for Denver Water from the 1930s to the

perspective was brought to Colorado. Ara Azhderian, water policy administrator at the San Luis and Delta-Mendota Water Authority in California, examined the changing values surrounding water. He discussed how government regulation, primarily for protection of the environment and endangered species, complicates agricultural practices. In a world where regulations affect the water supply as much as does Mother Nature, Azhderian thinks management needs to move to the level of ecosystems rather than working species by species.

His ideas for reform include addressing the high degree of scientific uncertainty and streamlining the permitting process. Azhderian also suggested there could be solutions in

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**More than 100 people learned about such looming legacies at the Western Water Symposium and Barbecue, held July 27 at Colorado State University's Morgan Library to benefit the Water Resources Archive.**

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1970s. He believed that civilization was best served by the advancement of Denver, showing an arrogance which may be an admirable quality in a leader. However, he also publicly stated his belief in the superiority of whites over Indians. History is full of such complex characters, and dismissing them as simply being "of their time" does a disservice, in Limerick's opinion. She spoke of wanting to use reverse osmosis, a common water filtration practice, on historical figures to gently remove what is bad in them and retain and use what is good. We are left to work on intergenerational peace negotiations with people from the past who are still very much with us today.

After the lunch break, a California

"small ball" projects—those which are large enough to have meaning but small enough to achieve. He is concerned that ours might be the first generation to leave water projects worse off than we received them. Azhderian believes some issues get disproportionate attention, so the balance of shifting values should be re-examined and restored.

With three stimulating discussions complete, and the fourth canceled due to speaker Pat Mulroy's illness, the day's emcee, Colorado Supreme Court Justice Greg Hobbs, channeled the momentum into an extended panel discussion. Topics ranged from Abraham Lincoln's role in shaping the West to

thoughts of how we start over. Issues of litigation and agriculture also entered the discussion via audience questions.

The symposium concluded with Justice Hobbs giving a brief historical review of the Colorado River and then having a lively discussion with Colorado Water Institute Director Reagan Waskom about the draft Colorado Water Plan and the future of water in the state. They uncovered a clear divide between the physical reality farmers face and legal reality.

Throughout the day, excellent speakers with engaging presentations sparked both new ways of combining old ideas and brand new thoughts. Discussions continued during the reception and evening barbecue. Tours of the Water Resources Archive gave guests an opportunity to view unique documents at the heart of the learning and debate.

In concluding her presentation, Limerick quoted Kenneth Jackson, former president of the Organization of American Historians: "Our critics say we are strange because we like to sit in libraries and read about dead people. But you know it is



*Archivist Patty Rettig, former Colorado Supreme Court Justice Greg Hobbs, and two of his law clerks, Heidi Ruckriegle and Katie Schaefer. Courtesy of the Colorado State University Libraries*

foolish to limit your acquaintances to those people who by sheer chance happen to be alive in the same place and time as you are."

Colorado is fortunate to have knowledgeable and curious citizens and water professionals alike, willing to come together for a day, learn about dead people and their contributions, and discuss

how all of us will extend their legacies to create a better future.

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



# SAVE THE DATE

## Thursday, January 28, 2016

### Water Tables 2016

[lib.colostate.edu/wt16](http://lib.colostate.edu/wt16)

Reception, dinner and presentation to benefit the Morgan Library Water Resources Archive

In conjunction with the Colorado Water Congress  
Hyatt Regency Denver Tech Center  
Denver, CO





Jamestown experienced a traumatic flood event beginning on September 11, 2013, lasting for three days. 17 homes were completely destroyed and 45 homes were damaged.

## The 2013 Colorado Flood Oral History Project

*Ruth M. Alexander, Council Chair, Public Lands History Center*

The floods that swept across Northern Colorado in September 2013 were extraordinary in their severity and scope. Floodwater damaged and destroyed homes and businesses, mountain towns and transportation networks, ditches, dams and bridges, oil and gas drilling sites, farmland, and natural areas across seventeen counties. Eight people lost their lives. This was a hydro-geologic event, as heavy monsoonal rainfall over many days produced both devastating floods and perilous landslides. State and local officials have estimated the monetary cost of the flood to be over two billion dollars.

Recognizing the significance of the flood to the state of Colorado, the mission of the 2013 Northern Colorado Oral History Flood Project was straightforward: we sought to gain knowledge about the 2013 flood from those who experienced it directly so that water managers, government officials, and citizens might handle flood

mitigation, preparation, management and recovery more effectively in the future. Colorado's water and emergency managers proved themselves to be individuals of remarkable skill and dedication during the flood and in the period of acute recovery. Looking toward the future, they hope that "lessons learned" from the 2013 flood will become the basis for improvements in policy and practice. This oral history project emerged to support these interests and grew out of a collaboration between the Colorado Water Conservation Board (CWCB), the Water Resources Archive at CSU's Morgan Library, and CSU's Public Lands History Center. Funded by the Colorado Water Conservation Board, the 2013 Northern Colorado Oral History Flood Project aligned closely with the CWCB's commitment to conserving, developing, protecting, and managing Colorado's water resources for present and future generations. More specifically, it sought

to facilitate the CWCB's interest in promoting long-term flood protection for the people, towns, homes, landscapes, and industries of Colorado.

Ruth M. Alexander, Professor of History and Council Chair of the Public Lands History Center, served as principal investigator on this project. Naomi Gerakios (M.A. History) was the project's research coordinator. Gerakios arranged and conducted the oral history interviews, with help from History M.A. students Tessa Moening, Zach Lewis, and Mitchell Shaefer. Alexander and Gerakios wrote a final report on the project for the CWCB and the WRA.

The interviews conducted for this project highlighted the work and perspective of individuals who held direct professional or official responsibility for flood mitigation, preparation, response, and recovery in 2013. In contrast to post-flood oral history projects in Boulder and Lyons that focus on victims of the



Army Chief Warrant Officer 4 Troy Parmley looks at floodwaters from recent rainfall while flying a UH-72 Lakota helicopter as part of flood relief and recovery operations near Fort Collins, Colo., Sept. 18, 2013. U.S. Army photo by Sgt. 1st Class Jon Soucy.

flood, this project selected a group of informants weighted heavily toward those with direct responsibility for flood management and recovery during the 2013 disaster. Among this group were climate scientists; water and stormwater managers; municipal and county administrators; dam engineers; emergency managers; search, rescue, and recovery personnel; disaster relief personnel; and wildland, park, and resort managers. We included a small number of interviews with victims of the flood who required the services of rescue and recovery specialists in order to balance the perspective provided by informants who experienced the flood in a professional capacity. The collected interviews (thirty in number, some involving multiple informants) offer significant qualitative data that may help professionals and officials in all areas of flood management prepare for and respond to future flood events. Scholars and researchers who wish to evaluate the 2013 flood will likewise find the interviews to be a rich resource. In addition, the

interviews provide a valuable resource for citizens of Colorado who may wish to learn about the potential ravages of floodwaters and about the choices communities can make to lessen their vulnerability to flooding. The digital recordings and transcriptions of the 2013 Northern Colorado floods will be held as a permanent collection in the Water Resources Archive at Colorado State University. The collection will demonstrate the CWCB's investment in documenting the history of flooding and in promoting a comprehensive understanding of flood events.

It should be noted that this project built on a precedent set in the late 1970s. Between 1976 and 1978, David McComb, now an Emeritus Professor of History at Colorado State University, conducted oral histories of 41 individuals affected by the 1976 Big Thompson flood. The informants included both flood victims and people who participated in rescue and recovery. The recordings and transcriptions of the 1976 flood are in a permanent collection at CSU's Water Resources Archive. They became the

basis for McComb's book, *Big Thompson: Profile of a Natural Disaster* (1980) and have been used by many researchers, along with the published book, over the past several decades.

The project's key findings were as follows:

1. Communities defined by geographic watershed, municipality, and county must work collaboratively to create and implement master plans for maximal watershed protection and floodplain management based on the best available scientific data and sound administrative practices. Buy-in from multiple stakeholders is essential. State offices and agencies play a critical role in facilitating the development of watershed coalitions and other watershed planning efforts at the municipal and county level.
2. Communities must improve communication capabilities within and across agencies,



An aerial view shows flood damage in Colorado, Sept. 14, 2013, due to heavy rains. U.S. Army photo by Staff Sgt. Wallace Bonner

jurisdictional boundaries, and with the public. Communication technologies must be continually assessed for situational effectiveness. Communication needs to be assessed with regard to all stages of flood management, from mitigation and preparation to rescue, relief, and recovery (short and long-term).

3. The core features of effective preparation for flooding include: educational outreach to the public; multiple communication technologies and media; regular mock disaster training; team building; and mutual aid agreements reaching from the local to the county, state, and regional levels. All of these elements of flood preparation need continual assessment and improvement.
4. Successful rescue and relief builds on effective training, communication, and mutual aid. It also requires the ability to suspend disbelief in the face of

extraordinary damage and the capacity to work “off-script” to invent solutions to unforeseen and unimaginable problems.

5. Effective recovery requires skilled coordination and innovation. Services and programs reach from the national level down to the state and across counties, municipalities, towns, and rural enclaves. Recovery programs do not always overlap or intersect cleanly. They do not always reach clients in need. Recovery managers as well as clients reported frustration with existing systems. Improvements in recovery programs appear to depend often on individuals who are willing and able to innovate and to build bridges across organizations that might otherwise work at cross purposes.
6. Recovery must aim for long-term resilience that is social, civic, and environmental. Climate change is likely to increase our

exposure to high hazard weather events. Recovery that sustains communities, governance, civic engagement, and ecosystems will facilitate resilience in future disasters.

7. The commitment, good will, and skill of Colorado’s water and emergency managers is extraordinary. So too, Colorado is fortunate to have citizens who are invested in effective disaster mitigation, preparation, relief, and recovery through voluntary efforts. The good efforts of individuals and organizations emerge, fundamentally, from our human capacity to make choices, and to engage in scientific discovery and moral reasoning. We need to honor and support these capabilities so they will protect us (and the natural systems on which we depend) from harm whenever possible and will work to maximum benefit for all when disaster strikes. 

# Research Awards: March 16, 2015 – July 15, 2015

**Arabi, Mazdak**, Civil and Environmental Engineering, Colorado Department of Public Health and Environment, Data and Standards for Colorado Reg 85, \$199,900

**Atadero, Rebecca A**, Civil and Environmental Engineering, North Dakota State University, Incorporating River Network Structure for Improved Hydrologic Design of Transportation Infrastructure, \$29,000

**Atadero, Rebecca A**, Civil and Environmental Engineering, North Dakota State University, Numerical Analysis of Soil-Structure Interaction for Debris Flow Mitigation Systems, \$49,000

**Bailey, Ryan T**, Civil and Environmental Engineering, Colorado Water Conservation Board, Modeling the Influence of Conjunctive Water Use on Flow Regimes in the South Platte River Basin using the South Platte Decision Support System, \$49,234

**Bailey, Ryan T**, Civil and Environmental Engineering, Research Corporation of the University of Guam, Increasing Coastal Water Security for Climate Change in Selected FSM State Outlying Islands, \$22,326

**Bestgen, Kevin R, Fish**, Wildlife and Conservation Biology, Colorado Division of Parks and Wildlife, Anthropogenic Changes to Colorado's Eastern Plains Streams and Their Impact on Connectivity for Native Fishes, \$16,904

**Bestgen, Kevin R, Fish**, Wildlife and Conservation Biology, DOI-Bureau of Reclamation, Abundance Estimates for Colorado Pikeminnow in the Green River Basin, Utah and Colorado, \$258,562

**Bestgen, Kevin R, Fish**, Wildlife and Conservation Biology, DOI-Bureau of Reclamation, Evaluating Effects of Non-Native Predator Removal on Native Fish in the Yampa River, Colorado, \$222,198

**Bestgen, Kevin R, Fish**, Wildlife and Conservation Biology, DOI-Bureau of Reclamation, Monitoring Effects of Flaming Gorge Dam Releases on the Lodore/Whirlpool Fish Community, \$151,509

**Bestgen, Kevin R, Fish**, Wildlife and Conservation Biology, DOI-Bureau of Reclamation, Identification and Curation of Larval and Juvenile Fish by Colorado State University Larval Fish Laboratory, \$612,498

**Cabot, Perry Edmund**, CSU Extension, Colorado Water Conservation Board, Colorado Water Bank: Agricultural Field Studies and Estimates of Saved Consumptive Use, \$180,000

**Caldwell, Elizabeth D**, CEMML, DOD-ARMY-Corps of Engineers Fort Worth, Stormwater Management Plan and Wastewater Compliance Study, \$111,734

**Caldwell, Elizabeth D**, CEMML, DOD-ARMY-Corps of Engineers Omaha, Municipal Stormwater Research and Support for Environmental Compliance Branch, Fort Drum, New York, \$229,626

**Carlson, Kenneth H**, Civil and Environmental Engineering, Colorado Department of Natural Resources, Expansion of Colorado Water Watch, \$100,000

**Clements, William H**, Fish, Wildlife and Conservation Biology, Colorado Division of Parks and Wildlife, Evaluating Restoration Effectiveness in the Arkansas River, \$53,955

**Cooper, David Jonathan**, Forest and Rangeland Stewardship, DOD, Assessment of Road Crossing Impacts to Ephemeral Streams on Military Lands throughout the Southwestern United States, \$129,442

**Cooper, David Jonathan**, Forest and Rangeland Stewardship, USDA-USFS-Forest Research, Developing Tools for Assessing the Potential Effects of Water Development on National Forests in the Western United States, \$40,000

**Doesken, Nolan J**, Atmospheric Science, Colorado Division of Emergency Management, An Assessment of Weather and Climate Monitoring Systems in Colorado-Current Systems, Gaps and Future Needs, \$66,558

**Fassnacht, Steven**, Ecosystem Science and Sustainability, Colorado Water Conservation Board, Evaluating the Time Series Discontinuity of the NRCS Snow Telemetry (SNOTEL) Temperature Data across Colorado, \$40,000

**Gates, Timothy K**, Civil and Environmental Engineering, Colorado Water Conservation Board, Data Collection and Analysis in Support of Improved Water Management in the Arkansas River Basin, Phase 2, \$50,000

**Gates, Timothy K**, Civil and Environmental Engineering, USDA-NIFA, Water Quality and Productivity Enhancement in an Irrigated River Basin through Participatory Conservation Planning and Analysis, \$329,977

**Herron, Christopher Michael**, CEMML, DOD-ARMY-Corps of Engineers Omaha, Preble's Meadow Jumping Mouse Habitat Restoration, \$726,361

**Hooten, Mevin B**, Cooperative Fish and Wildlife Research, Colorado Division of Parks and Wildlife, Optimal Plains Fish Monitoring, \$75,780

**Khosla, Rajiv**, Soil and Crop Sciences, Universite Laval, Variable Rate Irrigation Based on Water Management Zones and Soil Moisture Sensors, \$21,340

**Kummerow, Christian D**, CIRA, DOC-NOAA, Hydrometeorological and Water Resources Research, \$178,114

**Laituri, Melinda J**, Ecosystem Science and Sustainability, DOI-NPS-National Park Service, Water Rights Activity Assessment, \$7,098

**Lemly, Joanna**, Colorado Natural Heritage Program, EPA, Lower Arkansas River Basin Probabilistic Wetland Condition Assessment, \$130,469

**Loomis, John B**, Agricultural and Resource Economics, University of Colorado, Routes to Sustainability for Natural Gas Development and Water and Air Resources in the Rocky Mountain Region, \$13,835

**MacDonald, Lee H**, Natural Resource Ecology Laboratory, USDA-USFS-Forest Research, Sediment Delivery to Streams from Wildfires and Roads, \$24,518

**Manning, Dale Thomas**, Agricultural and Resource Economics, University of Nevada, Rural to Urban Water Transfers, Climate Change, and the Future of Rural Agricultural Economies in the Semi-Arid West: A Comparative Regional Analysis, \$243,851

**Nelson, Peter August**, Civil and Environmental Engineering, NSF, CAREER: Experimental and Theoretical Investigation of Sediment Supply and Sorting in Meandering Rivers, \$209,283

**Norton, Andrew P**, Bioagricultural Sciences and Pest Management, Colorado Water Conservation Board, South Platte Phreatophyte Survey, \$99,733

**Ojima, Dennis**, Natural Resource Ecology Laboratory, DOI-USGS, Wind River Indian Reservation's Vulnerability to Impacts of Drought and the Development of Decision Tools to Support Drought Preparedness, \$77,454.87

**Pritchett, James**, Colorado Water Institute, San Luis Valley, Economic Impact Analysis of Decreased Crop Production Due to Reduced Groundwater Irrigation in the San Luis Valley, \$67,912

**Rathburn, Sara L**, Geosciences, DOI-NPS, Phase I Restoration Design, Implementation, and Effectiveness Monitoring: Upper Colorado River, Rocky Mountain National Park NPS RMCESU, \$47,794

**Rathburn, Sara L**, Geosciences, USDA-USFS-Rocky Mountain Research Station, Mechanisms and Controls on Post-Fire Sediment Delivery: The High Park Burn in South Fork Cache la Poudre Basin, \$60,000

**Reddy, Anireddy N**, Biology, DOE, Global Analysis of Epigenetic Regulation of Gene Expression in Response to Drought Stress in Sorghum, \$437,801

**Roesner, Larry A**, Civil and Environmental Engineering, Urban Drainage and Flood Control District, Develop the Colorado Center for Stormwater Management, \$13,667

**Sale, Thomas C**, Civil and Environmental Engineering, Chevron Corporation, Technology Development Initiative 2015: Proposal for Thermal Monitoring, Sediments, LNAPL Processes, and Upstream Soils, \$300,000

**Sale, Thomas C**, Civil and Environmental Engineering, DOD, Basic Research Addressing Contaminants in Low Permeability Zones, \$83,835

**Schneekloth, Joel**, CSU Extension, Syngenta, Agrisure Artesian Water Use Efficiency under Different Irrigation Programs - Full Season, \$45,802

**Sharvelle, Sybil E**, Civil and Environmental Engineering, City of Fort Collins, SWMM Conversion Project for McClellands Basin, \$19,190

**Stevens, Joseph E**, Colorado Natural Heritage Program, DOI-NPS, Missouri National Recreation River Vegetation Inventory, \$233,946

**Sueltenfuss, Jeremy**, Colorado Natural Heritage Program, EPA, Colorado Wetland Tools 4: Watershed Planning Toolbox, \$93,321

**Weiner, Cary S**, CSU Extension, USDA-Rural Development, Solar and Wind Assessments for Pivots (SWAP), \$50,088

**Winkelman, Dana**, Cooperative Fish and Wildlife Research, Colorado Division of Parks and Wildlife, Whirling Disease Resistant Rainbow Trout Introductions, \$12,000

**Wohl, Ellen E**, Geosciences, DOD-ARMY-Corps of Engineers Omaha, The Active Channel and the Ordinary High Water Mark, \$28,709

**Wohl, Ellen E**, Geosciences, National Geographic Society, Organic Carbon Storage in Beaver Meadows, \$7,270

**Wohl, Ellen E**, Geosciences, NSF, Floodplain Carbon Storage in Mountain Rivers, \$15,749



# Water Calendar

## December

**14-18 2015 AGU Fall Meeting;**  
*San Francisco, CA*  
Now in its 48th year, the AGU Fall Meeting is the best place to present your research; hear about the latest discoveries, trends, and challenges in the field; and network and make connections that can enhance your career.  
[fallmeeting.agu.org/2015](http://fallmeeting.agu.org/2015)

**15 2015 Ag Water Summit;**  
*Loveland, CO*  
We have the Colorado Water Plan... Now what is the future of Colorado Agriculture?  
[coagwater.colostate.edu](http://coagwater.colostate.edu)

**16-18 Colorado River Water Users Association Annual Conference;**  
*Las Vegas, NV*  
[crwua.org](http://crwua.org)

## January

**8-9 2016 CWWCA Annual Conference;**  
*Denver, CO*  
[cwwca.org/2015/09/15/2016-cwwca-annual-conference](http://cwwca.org/2015/09/15/2016-cwwca-annual-conference)

**28 Water Tables 2016;**  
*Denver, CO.*  
[lib.colostate.edu/archives/water/water-tables/2016/](http://lib.colostate.edu/archives/water/water-tables/2016/)  
Reception, dinner and presentation to benefit the Morgan Library Water Resources Archive

**27-29 Colorado Water Congress Annual Summit;**  
*Denver, CO*  
The Colorado Water Congress Annual Convention attracts 500+ attendees that convene for networking and collaboration on the important water issues of the day.  
[cwatercongress.org/annual-convention.html](http://cwatercongress.org/annual-convention.html)

## February

**5 Poudre River Forum;**  
*Loveland, CO*  
Learn about the river, what it does for us, and what it needs from us.  
[cwi.colostate.edu/thepoudrerunsthroughit/index.shtml](http://cwi.colostate.edu/thepoudrerunsthroughit/index.shtml)

**9-11 Tamarisk Coalition's 13th Annual Conference;**  
*Grand Junction, CO*  
Where students, scientists, practitioners, consultants, agencies, conservation organizations, and others in the riparian restoration field meet.  
[www.tamariskcoalition.org/about-us/events/2016-conference](http://www.tamariskcoalition.org/about-us/events/2016-conference)

**8-10 Colorado Rural Water Association Annual Conference and Exhibition;** *Denver, CO*  
The conference offers a wide-range of programs with over one hundred individual classes and nearly 30 hours of contact time available.  
[coloradoruralwater.sharepoint.com/Pages/2014ConferenceAttendeeRegandInfor.aspx](http://coloradoruralwater.sharepoint.com/Pages/2014ConferenceAttendeeRegandInfor.aspx)

## April

**24-27 NGWA 2016 Groundwater Summit: Solving Groundwater Challenges Through Research and Practice;**  
*Denver, CO*  
Model, explore, characterize, bank, inject, extract, treat, and predict all your subsurface needs with everything groundwater at the 2016 NGWA Groundwater Summit: Solving Groundwater Challenges Through Research and Practice.  
[ngwa.confex.com/ngwa/2016gws/cfp.cgi](http://ngwa.confex.com/ngwa/2016gws/cfp.cgi)

## August

**24-26 Colorado Water Congress Summer Conference and Membership Meeting**  
It's a don't miss event for those who wish to stay informed about water issues in Colorado while engaging in numerous professional development activities.  
[cwatercongress.org/summer-conference.htm](http://cwatercongress.org/summer-conference.htm)



William Cotton/ CSU Photography, Communications & Creative Services

**Anthropogenic organic compounds in source water of select community water systems in the United States, 2002-10;** 2014,

Scientific Investigations Report 2014-5139; Joshua F. Valder, Gregory C. Delzer, James A. Kingsbury, Jessica A. Hopple, Curtis V. Price, David A. Bender

**From streets to streams: Assessing the toxicity potential in urban sediment;** 2014, Integrated

Environmental Assessment and Management (10) 474-475; William R. Selbig

**USGS investigations of water produced during hydrocarbon reservoir development;** 2014,

Fact Sheet 2014-3104; Mark A. Engle, Isabelle M. Cozzarelli, Bruce D. Smith

**Practical limitations on the use of diurnal temperature signals to quantify groundwater upwelling;** 2014, Journal of

Hydrology (519) 1739-1751; Martin Briggs, Laura K. Lutz, Sean F. Buckley, John W. Lane

**Groundwater levels in the Denver Basin bedrock aquifers of Douglas County, Colorado, 2011-2013;** 2014, Scientific Investigations Report

2014-5172; Rhett R. Everett

**Selenium in the upper Blackfoot River watershed, southeastern Idaho, 2001-12;**

2014, Scientific Investigations Report 2014-5203; Christopher A. Mebane, Greg Mladenka, Lynn Van Every, Marshall L. Williams, Mark A. Hardy, John R. Garbarino

**Estimated use of water in the United States in 2010;** 2014, Circular 1405; Molly A. Maupin,

Joan F. Kenny, Susan S. Hutson, John K. Lovelace, Nancy L. Barber, Kristin S. Linsey

**Summary of estimated water use in the United States in 2010;** 2014, Fact Sheet 2014-3109;

Nancy L. Barber

**Effects of distributed and centralized stormwater best management practices and land cover on urban stream hydrology at the catchment scale;** 2014, Journal

of Hydrology (519) 2584-2595; John V. Loperfido, Gregory B. Noe, S. Taylor Jarnagin, Dianna M. Hogan

**Flow and sorption controls of groundwater arsenic in individual boreholes from bedrock aquifers in central Maine, USA;**

2014, Science of the Total Environment (505) 1291-1307; Qiang Yang, Charles W. Culbertson, Martha G. Nielsen, Charles W. Schalk, Carole D. Johnson, Robert G. Marvinney, Martin Stute, Yan Zheng

**River chloride trends in snow-affected urban watersheds: Increasing concentrations outpace urban growth rate and are common among all seasons;** 2014, Science of the Total Environment (508) 488-497;

Steven R. Corsi, Laura A. DeCicco, Michelle A. Lutz, Robert M. Hirsch

**Steady-state numerical groundwater flow model of the Great Basin carbonate and alluvial aquifer system;** 2014, Scientific

Investigations Report 2014-5213; Lynette E. Brooks, Melissa D. Masbruch, Donald S. Sweetkind, Susan G. Buto

**Rising air and stream-water temperatures in Chesapeake Bay region, USA;** 2015,

Climatic Change (128) 127-138; Karen C. Rice, John D. Jastram

**Nitrogen speciation and trends, and prediction of denitrification extent, in shallow US groundwater;** 2014, Journal of

Hydrology (509) 343-353; Stephen R. Hinkle, Anthony J. Tesoriero

**Variably-saturated groundwater modeling for optimizing managed aquifer recharge using trench infiltration;** 2014, Hydrological Processes; Victor M. Heilweil, Jerome Benoit, Richard W. Healy

**Water-level changes and change in water in storage in the High Plains aquifer, predevelopment to 2013 and 2011-13;** 2014,

Scientific Investigations Report 2014-5218; Virginia L. McGuire

**Fluvial sediment fingerprinting: literature review and annotated bibliography;** 2014, Open-File

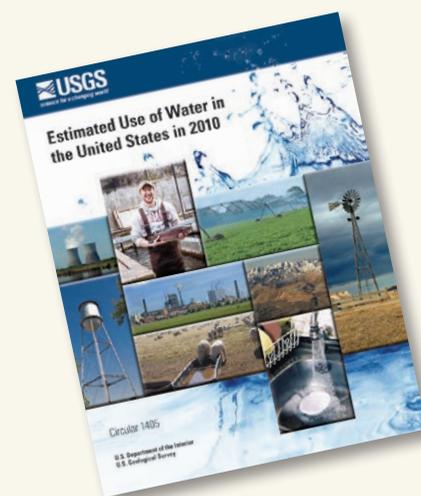
Report 2014-1216; Joyce E. Williamson, Adel E. Haj Jr., John F. Stamm, Joshua F. Valder, Vicki L. Prautzch

**Links between N deposition and nitrate export from a high-elevation watershed in the Colorado Front Range;** 2014, Environmental

Science and Technology (48) 14258-14265; M. Alisa Mast, David W. Clow, Jill Baron, Gregory A. Wetherbee

**Estimation of potential evapotranspiration from extraterrestrial radiation, air temperature and humidity to assess future climate**

**change effects on the vegetation of the Northern Great Plains, USA;** 2014, Ecological Modelling (297) 86-97; David A. King, Dominique M. Bachelet, Amy Symstad, Ken Ferschweiler, Michael Hobbins



# Four States Irrigation Council Scholarship Awarded to CSU's Carter Stoudt

The Four States Irrigation Council awarded a \$2,000 scholarship for the 2015-2016 academic year to one recipient interested in a career in irrigation or water-related fields and enrolled at a university or college in Colorado, Kansas, Nebraska, and Wyoming. The recipient, Carter Stoudt, is a student in Colorado State University's Department of Agricultural and Resource Economics.

Four States Irrigation Council is a collaborative forum for the discussion of interstate irrigation-related issues and problems and the exploration of these. Participants from Colorado, Kansas, Nebraska, and Wyoming meet annually in Fort Collins in January. "We are pleased to be offering this scholarship to a well-deserving CSU student as the first in what we hope to be a long line of annual scholarship awards," says Brian Werner, member of the Four States Irrigation Council Board of Directors.



**Carter Stoudt**

**Major:** Environmental and Natural Resource Economics

**Minor:** Sustainable Water Interdisciplinary Minor

**Graduating:** May 2017

*My academic career goals are not set in stone at this point. I know that I want to use the knowledge I have gained to increase water efficiency in the agricultural industry. This may come in the form of research opportunity or through working with agricultural firms to efficiently allocate water for different uses. Either way, I know I will have a positive impact on the industry that provides the world with so many necessities.*

*I became interested in agriculture when I moved to the rural town of Cedaredge, Colorado in 2009. I was exposed to what farming was really like and how important agriculture can be to a small town. When I came to CSU, I found my niche in the department of Agricultural and Resource Economics. With the help of my advisors, I found a major that combines my love for agriculture, specifically agricultural water use, and my mathematical skills. I cannot thank my advisors enough for their commitment to guiding me to success.*

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## Brad Udall Brings Water and Climate Expertise to CSU Faculty

Lindsey Middleton, Editor, Colorado Water Institute

Brad Udall joined the Colorado Water Institute in 2014 as a Senior Water and Climate Research Scientist/Scholar, and he is the first and only specialist in this field to work for the institute. Udall has a B.S. in Environmental Engineering from Stanford University and an MBA from Colorado State University. He was a consulting engineer and later Principal at Hydrosphere Resource Consultants, then was Executive Director of the Eagle Valley Land Trust for four years. From 2002-2012, he was Director of the University of Colorado Western Water Assessment, and for one year, he was Director of the Getches-Wilkinson Center at the CU Law School. He remains a co-principal investigator at the Department of Interior's Southwest Climate Science Center. His work is generally focused on water and climate research and policy.

"I like to say that I have a checkered past," jokes Udall. "I have worked for private industry, for non-profits, and now I work for higher education." During his time with Hydrosphere, Udall worked on water rights modeling on the South Platte, Rio Grande, North Platte, and Snake Rivers, and also took part in early Colorado River climate change and drought studies. At the Western Water Assessment, Udall focused much of his work on climate change. Under his direction, the organization also focused on providing other

climate products for decision makers such as tree-ring stream flow reconstructions and seasonal climate forecasts.

His interest in climate change and water led to Udall authoring the water chapter of a 2009 national assessment on climate change as part of a large Federal Advisory Committee. He also served on the Water Research Foundation's Expert Panel on Climate Change and contributed to the Intergovernmental Panel on Climate Change Fifth Assessment Report. In 2006, as part of a federal effort in the Colorado River Basin to plan for drought and water shortages, Udall contributed to an analysis of climate risks in the basin. "It was the first time [the Bureau of] Reclamation had dealt with climate change in an EIS process," he says.

Udall's experience with Colorado's river basins will serve him well in his capacity with CWI—he is working on climate and water related sustainability issues in the West, with a focus on water and climate policy issues in the Colorado and Rio Grande basins.

Within the Colorado River Basin, Udall is investigating the unprecedented drought that began in 2000. "The cause of this current drought is not what many people think it is," says Udall. "Precipitation deficits during the current drought are less than half of deficits during a similar 1950s drought, so this begs the question of the real cause." The current working hypothesis is that temperatures in the basin are now substantially higher than the 20<sup>th</sup> century average, and those temperatures are causing additional evapotranspiration, thus reducing Colorado River flows. He expects to publish this research in the near future.

Climate change is an important topic of expertise that Udall brings to the table at CWI and CSU. "I'm just learning about CSU's talents in this field, and they are phenomenal," says Udall. Some CSU faculty have dedicated their research careers to understanding topics like agricultural sustainability and agricultural contributions to greenhouse gas emissions and their



Brad Udall

mitigation. From an agricultural standpoint, says Udall, CSU stands poised to contribute significantly to climate research as well as assist farmers and ranchers to prepare for a changing climate.

Udall argues that water and climate change are interconnected. "Most people think climate change is mostly about increasing temperatures, but climate change is water change," he says. "Higher temperatures will significantly change the water cycle, and they are already affecting nearly all aspects of that cycle including water quantity, quality, and the timing of runoff," he continues. He is optimistic about addressing this issue. "I look forward to working with the water institute to put climate change where it belongs, which in my mind is front and center in how we think about water," he says. 



### Bradley H. Udall

Senior Water and Climate  
Research Scientist/Scholar  
Colorado Water Institute  
Colorado State University  
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Google Voice: 720.984.2723



## Visit Our Websites

*CSU Water Center:* [www.watercenter.colostate.edu](http://www.watercenter.colostate.edu)

*Colorado Water Institute:* [www.cwi.colostate.edu](http://www.cwi.colostate.edu)

## Colorado Water Online

Visit the CWI web site to access a PDF version of our current newsletter. To download past issues of our newsletter, click on *Newsletter Archives*.

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



*Aerial view of the Fort Lyon Canal in the lower Arkansas River basin—  
photo by Bill Cotton/CSU Photography, Communications & Creative  
Services, Colorado State University*