

# Colorado Water

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Front Cover: Trout Lake, Colorado. Photo by Mountain Belle  
This Page: Boulder Creek, Lost Lake, Eldora, Colorado. Photo by Kim Hudson

# Editorial

by Reagan Waskom, Director, Colorado Water Institute

Viewed from space, it is hard to imagine that water shortages could exist on our blue planet. Yet we know that scarcity and poor quality of freshwater threaten human well-being and ecosystems around the globe. Over 97 percent of global water is too salty for human use, and of the freshwater, a large majority is frozen. However, the problem is largely one of distribution, as there is enough accessible freshwater on the planet to satisfy our needs.

Management and governance of water must of course continually evolve to keep pace with the growing needs for human and environmental freshwater, but what is the role of technology and innovation in this endeavor? Will technology eventually solve our water problems? Perhaps someone will invent solar-powered, high-output desalination with a very small footprint and zero liquid brine discharge! I am not certain that would totally alleviate all water problems, as floods and other inconvenient events would still trouble us, but it certainly would help reduce water scarcity.

Advances in water technology are mostly incremental rather than revolutionary; however, I would never rule out the possibility of a big game changing new technology. Thousands of innovators are actively working on developing and commercializing better water treatment, wastewater reuse methods, membranes, sensors, and various devices to increase efficiency. Even simple and inexpensive technological advancements are likely to play a role in solving water challenges, particularly in developing countries.

Opportunities for innovation in our drinking water, stormwater, and wastewater systems abound. Much of the U.S. water infrastructure, including water reservoirs, pipeline networks, and treatment plants, is reaching the end of its design life. As we rebuild, we have a choice—rebuild the same systems, or integrate new technologies to upgrade efficiency and decrease environmental footprint. As an example, the recent flood in the St. Vrain, Thompson, Poudre, and S. Platte rivers damaged many diversion structures. These headgates could be rebuilt differently, perhaps enabling fish passage, real time flow data, water quality monitoring, and reduced spillage. Such technologies exist; does the opportunity?

The global water market is currently worth \$450 billion; the U.S. market is the largest in the world at \$107 billion, growing at an annual rate exceeding 10 percent. Many great ideas are in development and many lie dormant until commercialization becomes feasible. Often, the low cost



of water, slow payback, and the conservative nature of the utility sector are cited as barriers to commercialization of new technology. But almost any technological innovation, by definition, should be more efficient and cost effective than its predecessor.

Major trends in innovation include water reuse and technologies that derive value from waste. San Diego has invested over \$300 million in water reuse systems. Beijing has committed \$5 billion and aims to reuse or recycle 100 percent of its city wastewater. The U.S. is the second largest desalination market in the world after Saudi Arabia. Challenges in desalination needing innovation include brine disposal, pretreatment optimization, energy conservation, and overall productivity of membrane systems. Shale gas development is also ramping up the need for water treatment and recycling technologies. Water efficiency products include biogas recovery systems, smart meters that help manage demand, ultrasonic sludge pre-treatment, pipe rehabilitation and relining systems, and water derivative products like water-free toilets.

The university has an important role in water innovation. Recently developed water clusters offer opportunities for collaboration to commercialize products. Water technology clusters are established to become catalysts for innovation, developing and commercializing new technologies and attracting new business and high quality jobs. The Colorado Water Innovation Cluster, initiated and currently hosted by the City of Fort Collins, has a goal of linking the talent and expertise of the university and the private sector to grow the water resource and technology sector of Colorado. CSU is a key partner in this Cluster, and CSU faculty and students have many opportunities to engage in the science, research, and education surrounding water technology.

# The Colorado Water Innovation Cluster

## Showcasing Colorado Technologies and Innovation

Judy Dorsey, Executive Director, Colorado Water Innovation Cluster

*The Colorado Water Innovations Cluster works within the sectors of higher education, local government, and the private sector to promote research and growth in water-related areas.*

*Members include the City of Fort Collins, Colorado State University, and several local private organizations and groups.*

*Projects include instream flow efforts, gravity-fed irrigation, the Water Innovation Network, and others.*

Over the past five years, Colorado has made national headlines for becoming a center of innovation for the clean energy industry, attracting thought leaders and cleantech companies to the state to collaborate on next-generation solutions, from energy efficiency and energy storage to renewable energy. Organizations such as the Colorado Clean Energy Cluster have spurred on the industry, providing leadership and leverage to help companies, higher education institutions, and local governments develop real-world solutions and grow the state's clean energy economy in the process.

Taking its cue from the clean energy industry, Colorado has taken the lead on another pressing issue for the state, region, and country—water. The state is already home to hundreds of companies providing products and services to meet client needs around water. Capitalizing on the success of the “cluster” based approach, which seeks to leverage the innovation and technologies of companies and organizations working in a given region, a number of companies, Colorado State University, and the City of Fort Collins have come together to tap into Colorado’s “water economy” by forming the Colorado Water Innovation Cluster (CWIC).

### About the Cluster

The CWIC is a 501(c)3 non-profit organization formed in 2010. With a vision to be a global leader in water innovation, its mission is to foster such innovation, along with commercialization and economic vitality. The organization stimulates collaboration and leverages community resources to support economic development and the growth of primary jobs in Colorado. Utilizing the “triple helix” approach—one that includes higher education, local government, and the private sector—the CWIC brings together resources from all three sectors to drive greater reach and impact, demonstrate real projects, and provide local benefits and economic development opportunity.

### Cluster

members are Colorado-based academic, governmental, and commercial organizations with a primary focus on water-related activities within their respective organizations. Among the CWIC's current members are representatives from academia (Colorado State University), local government (City of Fort Collins), and the private sector, including engineering, legal, and consulting firms.

Like the Colorado Clean Energy Cluster, the CWIC's efforts are focused around specific projects, or “initiatives,” to focus efforts on tackling real-world issues and challenges. The CWIC's projects are proposed by members and pursued by the Cluster as a whole, ranging from agricultural water rights management to water infrastructure asset management and beyond.

### CWIC Members

Aqua Engineering  
Bendelow Law Office LLC  
City of Fort Collins  
Colorado State University  
Fort Collins Utilities  
In-situ, Inc.  
Lamp, Rynearson & Associates  
Lehi Water  
Metro State University – One  
World One Water  
Regenesis Management Group  
Riverside Technology, Inc.  
Rocky Mountain Innosphere  
Rubicon Water  
Schneider Electric



Figure 1. *Rubicon FlumeGate installed in Weld County, CO.*  
Photo by Randy Pfizenmaier

Among the goals of CWIC are to feed the pipeline of high quality projects, engage in such projects with the water innovation community, expand partnerships, and increase the number of transactions in the market related to water innovation.

“The CWIC is looking to be a catalyst and focus on innovative and entrepreneurial ways to grow the water resource and technology sector of Colorado’s economy through actionable initiatives and showcase projects,” says Judy Dorsey, Executive Director of CWIC. “Our members are excited about rolling up their sleeves to highlight the tremendous talent in Colorado and make important contributions to the field.”

### **Spotlight Project: Lake Canal**

One of the CWIC’s first two initiatives is the Lake Canal Alternative Agricultural Practices and Instream Flow Demonstration Project. The project is a proof-of-concept for CWIC member Regenes Management Group and its technology, which offers an alternative to permanent “buy and dry” agricultural water transfers. In partnership with the City of Fort Collins and The Nature Conservancy, the goal of the project was to demonstrate how an Interruptible Water Supply Agreement (IWSA) could be used to provide water for uses outside the Lake Canal service area in a manner that does not adversely impact other water right holders.

With funding from a Colorado Water Conservation Board grant for demonstration projects, the project not only supported the region’s environmental stewardship efforts, it also demonstrated the potential effectiveness of multi-stakeholder and public-private partnerships to address significant water challenges. Using techniques such as fallowing

and deficit irrigation, it potentially provides water for the Poudre River in the late season when the river’s flows are reduced. The project also addressed the various legal, technical, and social issues that must be considered when using an IWSA for water transfers.

“As the economic value of water increases globally, the technology to improve water management in urban, industrial, and agricultural settings will assume even greater importance.”

### **Spotlight Technology: Rubicon**

Another CWIC member, Rubicon Water, is working to improve the productivity of the world’s farmers in an environmentally sustainable way by delivering advanced technology to optimize gravity-fed irrigation. Rubicon products include a modular family of solar powered control gates and flow meters as well as management software developed for irrigation districts. Rubicon’s intelligent solar powered control and flow measurement hardware can be remotely controlled and managed, enabling irrigation districts to operate and manage their water resources with a high level of efficiency and control. Rubicon products can interact and work together to help irrigation districts deliver accurately measured, constant high-flow, on-demand water to

farmers while minimizing system losses.

Becoming a member of CWIC has allowed the company to contribute its ideas and technologies in a collaborative setting, while also receiving feedback on how it can evolve its products and solutions for future applications.

The company has more than 10,000 gates and meters installed in integrated water management systems across 10 countries, including the gate installed in Central Colorado Water Conservancy District (Figure 1). And as the economic value of water increases globally, the technology to improve water management in urban, industrial, and agricultural settings will assume even greater importance.

### **Spotlight Partner: Colorado State University**

Colorado State University is an important partner for CWIC, represented on the board by innovators in mechanical engineering, civil and environmental engineering, and the Colorado Water Institute. These members have collaborated tirelessly on CWIC’s major current initiative, the Water Innovation Network.

Over the coming months, the CWIC will be continuing to advance this initiative, which involves the creation of a world-class infrastructure to conduct state-of-the-art research, education, and training in water-related topics. The Network’s infrastructure includes cloud-based data management, analytical tools, and monitoring stations at eight locations along the Cache la Poudre River, with over 50 more installations planned. The goal of the Initiative is to give researchers, educators, and planners around the world access to data and tools to develop and

demonstrate innovative technologies for sound management of water resources.

CSU and CWIC are a natural partnership, and the triple helix approach is beneficial to CSU, the community, and local business partners as well as to the water industry as whole.

### What's Next for the Cluster

CWIC has just wrapped up a successful three-part workshop series, the goal of which was to engage stakeholders and develop new initiatives to advance water innovation in Colorado. These workshops were valuable engines for project development and recruitment of new partners to CWIC. The first of these workshops, held on May 29, was based on discussing creative next steps for CWIC's Water Innovation Network initiative. The

second workshop, held on July 10 in partnership with the Colorado Clean Energy Cluster, was focused on the intersection of water and energy, and attracted many stakeholders from both fields. This workshop resulted in three new projects in the water-energy nexus space. The final workshop in the series, held on July 24, was a discussion of alternative agricultural practices and built upon lessons learned through the Lake Canal project mentioned above.

After these very successful workshops, the CWIC is following up with attendees to determine their level of involvement in the resulting next-step projects and initiatives.

The CWIC has other initiatives in the pipeline that it hopes will grow its scope and presence, in Colorado and nationwide. In October 2013, CWIC will be host to the water track Net

Zero Cities in Fort Collins, which will bring together up to 500 civic leaders, technology solution providers, and other thought leaders from around the globe to discuss how cities can work towards net zero energy, water, and carbon from technology, policy, and engagement perspectives. CWIC is also exploring how it can support development of much-needed tools and planning frameworks to help companies, governments, and organizations pursue net-zero water concepts from both a quality and quantity perspective.

"Water is a next frontier in sustainability and as an organization we feel we're just getting started on exploring this frontier" says Dorsey. "But we feel we're well positioned to not only shine light on Colorado's water innovations, but to help solve problems on a global scale." ●

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Photo by Kim Hudson

# Achieving Water Demand Reductions Through a Simple, Low Cost System to Treat Graywater for Use in Toilets

*Sybil Sharvelle and Larry A. Roesner,  
Department of Civil and Environmental  
Engineering, Colorado State University*

*The authors are working on a graywater recycling program that collects and treats water from sinks and showers for flushing toilets in Aspen Residence Hall on CSU campus.*

*Such a system makes use of House Bill 1044, and could be applied to other similar multi-resident buildings.*

*If residents of the hall agree to participate, the system will be in place in 14 residences of Aspen Hall.*

Colorado State University (CSU) professors Sybil Sharvelle and Larry A. Roesner have been national leaders in the area of graywater reuse conducting research on effects of graywater use for irrigation on soil and plant health, developing guidance for separation of graywater from blackwater for reuse and assessing regulatory, public health, and treatment issues associated with graywater reuse. Graywater is considered to be water collected from showers, baths, hand wash basins, and laundry machines (excludes kitchen and toilet wastewater).

Sharvelle and Roesner are currently working on testing a treatment system they have developed to facilitate use of graywater collected from showers and sinks to flush toilets in Aspen Residence Hall, located at CSU in the Academic Village, the university's newest residence hall community. The development of this system is particularly timely with the passing of House Bill 1044 in 2013, which allows graywater reuse in the state of Colorado. Regulations for graywater reuse in the state are currently under development by Colorado Department of Public Health and Environment.

In most households, toilet flushing accounts for nearly 25 percent of indoor water demand. At the same time, nearly 25 percent of wastewater generated is from showers, baths, and wash basins. Therefore, this water can be collected and treated for use in toilets. Of note is that laundry water generally accounts for an additional 25 percent of wastewater generated in the household, so if all sources of graywater are collected, there is enough graywater to both flush toilets and supply water for outdoor irrigation. Reuse of graywater for toilet flushing has the ability to reduce demand for indoor potable water by 25-30 percent. Since the use of toilets is year round (unlike irrigation), this is a very attractive approach for reducing water demand. In addition, when graywater is reused, energy for water and wastewater treatment is saved, less water is treated to potable quality, and wastewater flows are reduced.

The goal of the graywater treatment system developed by Sharvelle and Roesner is to ensure safe use of treated graywater for toilet flushing while cost and energy input to the system remains low. Graywater reuse for toilet flushing is unlikely to be adopted on a wide scale if cost





Figure 2. Schematic of graywater treatment system for toilet flushing.

and energy for treatment systems are high. However, graywater can contain pathogens, and treatment is required to mitigate public health risk. The system in place at Aspen Hall that collects graywater consists of two holding tanks and another tank for disinfection of graywater (Figure 1). The graywater holding tanks are two 300-gallon polyethylene vertical cylindrical closed-top storage tanks, with a capacity of 250 gallons given the location of overflow to sewer. Each tank is equipped with

an overflow to convey excess gray water to the sanitary sewer in the case that excess graywater is collected. Water from the holding tanks flows by gravity through a coarse filter through a meter and into a 60-gallon polyethylene closed-top disinfection tank (Figure 2). Chlorine is injected into the line immediately after the meter at 20 mg/L so that pathogens are inactivated and a residual of 1.5 mg/L or larger is maintained to prevent regrowth of pathogens in the distribution system or toilets that are flushed with treated graywater. The treated graywater is dyed blue so as to indicate that it is nonpotable. Researchers at CSU have been

studying the efficacy of graywater treatment for the last year. Based on collected data, all stakeholders are comfortable with the level of treatment demonstrated and have agreed to begin flushing toilets in 14 residences of Aspen Hall with treated graywater as long as the residents agree to participate in the project.

Based on the success of this project, CSU may consider installing more graywater treatment systems for toilet flushing in new residence halls. Ultimately, the technology developed at CSU may be adopted on a large scale in multi-residential units throughout Colorado and the United States. This research and technology development underway at CSU is paving the way for more sustainable management of water resources. ●

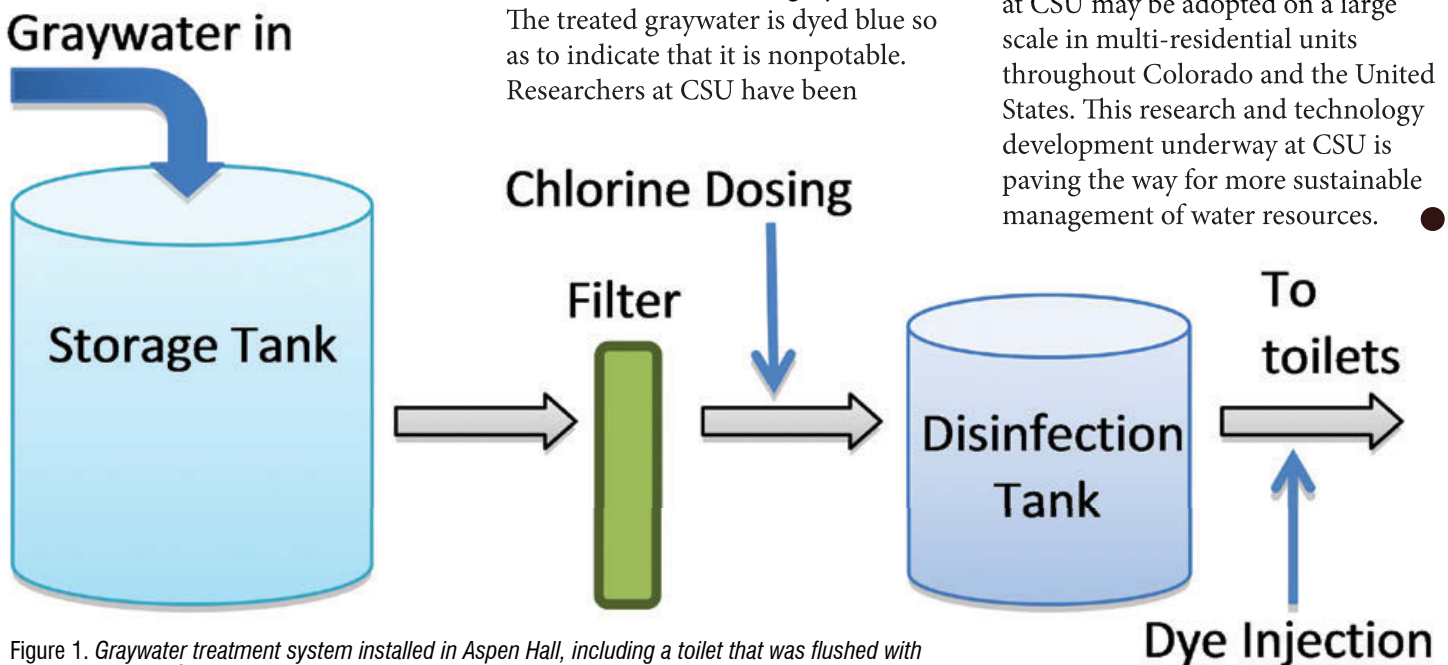


Figure 1. Graywater treatment system installed in Aspen Hall, including a toilet that was flushed with treated graywater for research and demonstration purposes. Courtesy of Sybil Sharvelle

# Colorado Water Watch to Monitor Groundwater Near Fracking

*Kenneth Carlson, Department of Civil and Environmental Engineering, Colorado State University*

*Colorado Water Watch is a public-private partnership study to monitor groundwater relative to fracking sites in real-time. Results, including a website and community outreach, are expected in early 2014.*

**F**rac on or Frac off? There's no getting around it—hydraulic fracturing, or “fracking,” is controversial. While it is endorsed by some as a game-changer for energy independence, job creation, and lower energy prices; others are calling for a temporary moratorium or a complete ban on fracking due to environmental concerns. Best practices, both mandated and voluntary, have been identified and put in place to mitigate the risks associated with fracking operations in Colorado. However, the efficacy of these practices has not been verified over time and public concerns about environmental impact including water quality continue.

*Colorado Water Watch* is a real time monitoring project designed to monitor any changes in baseline groundwater quality. Initially the project is limited to a relatively small area of the Denver Julesburg basin for proof-of-concept.

Currently *Colorado Water Watch* is:

- Installing a real-time groundwater monitoring network in proximity to significant hydraulic fracturing and oil and gas development activity in the Denver Julesburg basin

- Establishing the baseline groundwater quality in the selected monitoring sites by utilizing COGCC mandated testing from EPA certified labs
- Using multi probe sensors in the selected monitoring sites, capable of detecting any deviations indicating a change in baseline groundwater quality over time, in terms of lab verified surrogate techniques
- Offering a public access website that includes data from on-going real-time monitoring, and tools for analyzing groundwater quality data. The public access website will be available early 2014.

## What is being measured “real-time”?

It is not feasible (technically or economically) to measure the multitude of possible contaminants continuously and in real-time and therefore, this project will rely on surrogate measurements. Electrical conductivity, strongly correlated with TDS, will be one of the surrogate measurements and oxidation-reduction potential (ORP) will be another. TDS is believed to be a sensitive indicator of produced fluid contamination of aquifers and ORP has shown to be sensitive to dissolved methane concentrations.



## What happens if a change in water quality is detected?

The use of surrogate measurements is aimed at detecting deviations from baseline, not determining in detail what has changed and what might have caused it. If a deviation from baseline event is detected, a team from CSU will be deployed to the groundwater well to collect a sample for an in depth lab analysis that will characterize the event in terms of risk, cause, and additional response.

## Who is doing the project?

Colorado State University (CSU) will coordinate the installation of the monitoring network and develop the Web-based public interface. CSU will also be responsible for data collection, quality assurance and security. The project Steering Committee, which consists of senior leaders of industry, state government, CSU and environmental groups, will oversee content, timing and release of information.

Bill Ritter (chair)	Director, Center for New Energy Economy, CSU
Hank Gardner	Associate Vice President of Research, CSU
Ken Carlson	Director, Center for Energy Water Sustainability, CSU
Mike King	Executive Director, Colorado Department of Natural Resources
Ginny Brannon	Assist. Director for Water and Energy, Colorado Department of Natural Resources
Jim Milne	Environmental Engineering Manager, Colorado Oil and Gas Conservation Commission
Tisha Schuller	President and CEO, Colorado Oil and Gas Association
Karin Sheldon	President, Western Resource Advocates
Brian Lockard	Environmental Engineering Manager, Noble Energy

## Isn't this just another university research project collecting data?

The key difference in this project is the goal: provide critical information and education to a broad audience to address concerns related to the impact of fracking on drinking water quality?

## When will the project begin reporting results?

We expect to have a live website by the beginning of 2014 followed by public outreach activities such as presentations



at community meetings and workshops with municipal governments.

## The oil and gas industry is not the only risk to groundwater in the study area. How will this be accounted for?

It will be made clear that the water quality monitoring is not specific to one industry. The oil and gas industry is taking the initiative and supporting this testing in a proactive manner but this does not mean that any deviations from baseline are due to oil and gas activity. If deviations from baseline are detected, additional sampling will be completed and extensive water quality analysis conducted to determine the source of contamination.

## Who is providing the funding for the project?

The primary sponsor of the project is the Colorado Department of Natural Resources. Additional financial partners in the project are Colorado State University and Noble Energy.

## Will the real-time monitoring network concept that is being tested be the basis for future rules and regulations?

It is not the intent or goal of this project to use the data collected as the basis of future rules and regulation. It may be determined, however, that a real time monitoring network provides sufficient value to replace or supplement existing monitoring requirements.

## How are environmental interests being represented with the project?

The project Steering Committee has a senior leader from Western Resource Advocates (WRA). WRA will also be represented on the Technical Committee along with possibly other environmental groups as the monitoring network is designed and implemented.

For more information, contact Ken Carlson at [kenneth.carlson@colostate.edu](mailto:kenneth.carlson@colostate.edu)



*The Sangre de Cristo Mountain Range outside of Westcliffe, CO. Photo by Jessica Feis*

# Reconstructing a Water Balance for North Crestone Creek

## Streamflow Variability and Extremes in a Snowmelt Dominated Internal Drainage Basin

*Niah B. H. Venable, Ph.D. Student, EASC-Watershed Science Program, Colorado State University  
Faculty Sponsor: Steven Fassnacht, ESS-Watershed Science Program, Colorado State University*

*Historic and paleo-data were used to complete streamflow and precipitation reconstructions for the North Crestone Creek watershed in southern Colorado.*

*Several conclusions were drawn for time periods ranging from 65 to 426 years ago relating to drought conditions, above average precipitation, streamflow, and other factors.*

### **Streamflow in the Closed Basin of the San Luis Valley**

The San Luis Valley in Colorado is a semi-arid region that relies on streamflow from the surrounding mountain ranges for agricultural productivity and to recharge the important aquifer systems of the basin. The (North) Crestone Creek watershed (area of about 28 square km) is characteristic of the many small watersheds that drain the Sangre de Cristo Mountains on the eastern side of the valley into the geologically unique alluvial aquifer overlying the Rio Grande Rift. The creek has no diversions and little

human disturbance above the gage, and flows from its upper reaches with elevations over 4,000 meters above sea level through mixed aspen-conifer forests to the gage site at 2,553 meters above sea level. The valley downstream of the gage site is endorheic and has no natural outflow to other significant bodies of open water or rivers; however, the mountain runoff replenishes the aquifer for Rio Grande streamflow augmentation through Closed Basin Project reclamation pumping, and maintains water levels in local well fields for domestic and agricultural use, especially in and around the town of Crestone. The

streamflow also supports narrow riparian corridors and playa lakes. These provide valuable habitat for waterfowl, migrating birds, and other animals and plants in a dry region.

In the last decade, drought conditions throughout much of the western United States have exacerbated water resource availability problems in a region that continues to grow in population and diversify in land and water use needs. Water management is a concern, especially in a warming climate, and has prompted much research related to streamflow variability with a desire to make that research available to water managers for use in establishing a wider range of conditions than the historic record alone can provide to assess the reliability of water supply systems.

## Tree-Ring Based Reconstructions and Hydrologic Variability

The objectives of this study were to investigate the range of hydrologic variability and extremes of Crestone Creek using a variety of readily available online hydrologic ([www.ncdc.noaa.gov/cdo-web/search](http://www.ncdc.noaa.gov/cdo-web/search) and [www.water.state.co.us](http://www.water.state.co.us)) and paleo-climatic data sources ([www.ncdc.noaa.gov/paleo](http://www.ncdc.noaa.gov/paleo)). Streamflow and precipitation reconstructions were created from tree-ring data for Crestone Creek and the surrounding watershed. Reconstructions are scenarios of possible streamflow and precipitation over the previous several hundred years. Stepwise multiple linear regression was used to model the relation between the proxy climate data and the climatic variables of interest. The resulting models were applied to the proxy record to generate estimates of the climate variables over the length of record.

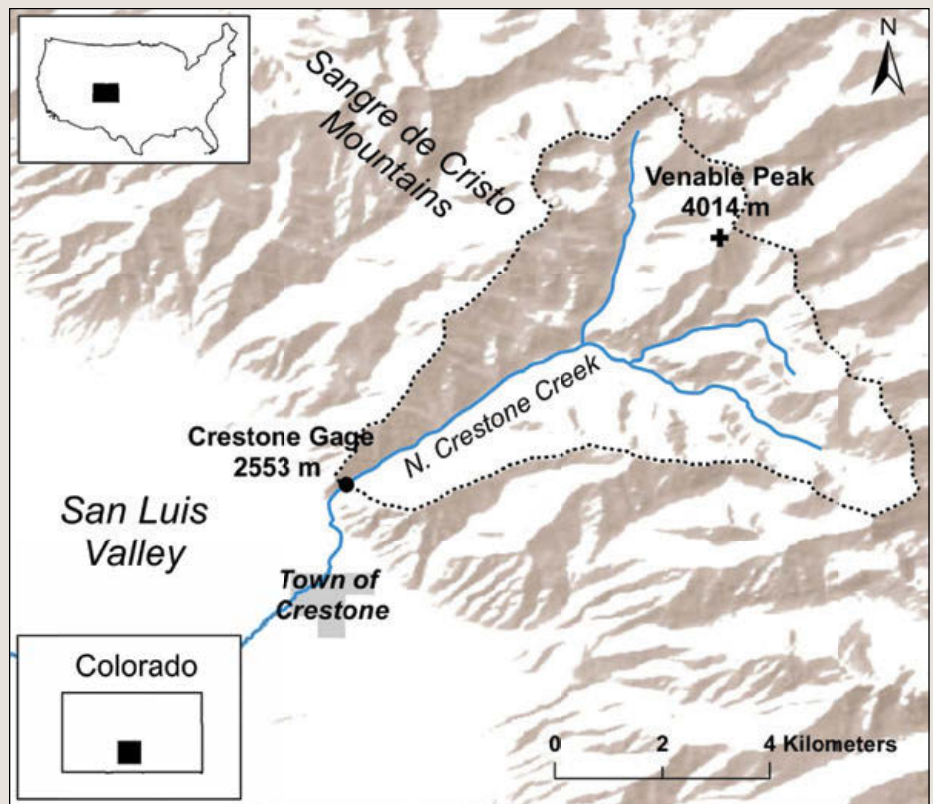


Figure 1. Location map of the Crestone Creek watershed and stream gage in the San Luis Valley of southern Colorado.

Reconstructed streamflow compared favorably to other published reconstructions for the upper Rio Grande from the San Luis Valley and highlighted extended periods of dry conditions prior to the instrumented period. Reconstructed precipitation combined with reconstructed northern hemisphere temperature anomalies from additional climate proxy data was decomposed using monthly mean trends from the observed period of record for inputs into a water balance model. This was used to evaluate changes to runoff and other hydrologic state variables over a period longer than the historic record and also showed that the droughts in the last decade are at least as intense (lower than average flows) as those in the paleo-record.

Nine tree-ring chronology sites located between about 50 and 100 km from the Crestone Creek watershed in the San Juan, Sangre de

Cristo, and Wet Mountains were selected as potential predictors for reconstructing the hydrologic variables. The chronologies were composed of tree-species known to be sensitive to soil moisture conditions, and spanned several hundred years each extending until at least 2002. The tree chronologies selected for the final streamflow reconstruction included Chokecherry Canyon, Cathedral Creek, and Temple Canyon. These are taken from Pinyon pine (*Pinus edulis*) and Douglas-fir (*Pseudotsuga menziesii*) trees. The final precipitation reconstruction predictors selected were Chokecherry Canyon, Princeton PSME, Natural Arch, and Platt Bradbury. The tree species represented in these chronologies are Ponderosa pine (*Pinus ponderosa*), Pinyon pine (*Pinus edulis*), and Douglas-fir (*Pseudotsuga menziesii*) trees.

Historical streamflow and precipitation data for Crestone Creek are highly variable on annual to decadal time scales. Daily streamflow data were analyzed from 1948 to 2012 over a water year (WY), which spans October 1 of a preceding year through September 30 of the following year. It is a common and useful measure of annual streamflow for the study area, which receives much of its precipitation during the cool season (October-April) in the form of snow. The most

intense droughts, or those with the greatest departure from the annual mean volume of flow of 10.2 MCM (cubic meters  $\times 10^6$ ) occurred in WY 2002 (2.0 MCM) and 1950 (3.7 MCM). The longest droughts were in the 1950s and currently, the drought of the 2000s, spanning about seven years and most of the last decade, respectively. Prolonged periods of relatively wet years with above mean flow were observed in the late 1940s and in the 1980s to the mid-1990s.

Precipitation and temperature data for the watershed were extracted

from PRISM (Parameter-elevation Regressions on Independent Slopes Model) monthly data grids ([www.prism.oregonstate.edu](http://www.prism.oregonstate.edu)) at an approximate 4 km  $\times$  4 km resolution ( $\sim 2.5$  arc min). The variability in the precipitation data was similar to that of the streamflow data, with the lowest annual precipitation occurring in WY 2002 and 1950. Periods of higher precipitation also tracked periods of higher streamflow, as in the wet years of WY 1965 and 1992.

Streamflow was reconstructed for the period of WY 1577-2002,



Figure 2. Photo of the author (Niah Venable, right) and her advisor (Steven Fassnacht, left) at the Colorado Division of Water Resources NOCRESCO stream gage on North Crestone Creek in the Rio Grande National Forest.

Photo by Steven Fassnacht

capturing 70 percent of the variance of the gage data and showing several distinctive drought periods. The precipitation reconstruction from WY 1636-2002 captures less of the variance of the precipitation record, at 46 percent. The differing lengths of the two reconstructions are related to the lengths of the final chronologies selected as predictors in the regression models. While hydrologic reconstructions tend to underestimate high values and overestimate low values, they do well capturing the hydrologic

state of the system (i.e., dry or wet conditions), and are very useful in examining drought duration. These are key factors for water managers to consider for water allocation and availability issues. The paleo-record highlights extended periods of drought longer than those seen in the historical record. This is particularly true for the 1727-1745 drought of nearly 20 years with only five single years above mean streamflow conditions occurring, and for the drought of 1578-1592, a fifteen year sequence interrupted by only

three years of marginally above mean flows. Single year drought conditions (intense drought) can also be devastating, as seen in 2002. The year of 1645 was reconstructed as one of the most intense low flow years in the entire 426-year streamflow reconstruction.

## Historical and Paleo-Water Balance Modeling

Water balance modeling was performed using inputs from the historical (WY 1895-2002) PRISM

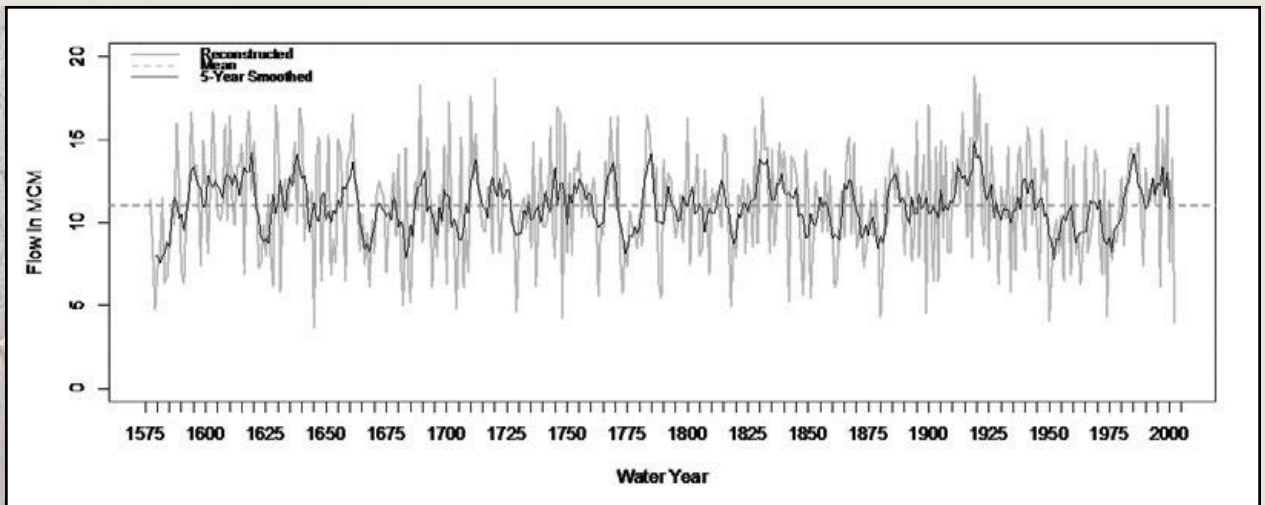


Figure 3. Full reconstruction of water year flows from 1577-2002 for Crestone Creek. Annual flows (grey line) were smoothed using a five-year moving average for display purposes (black line).

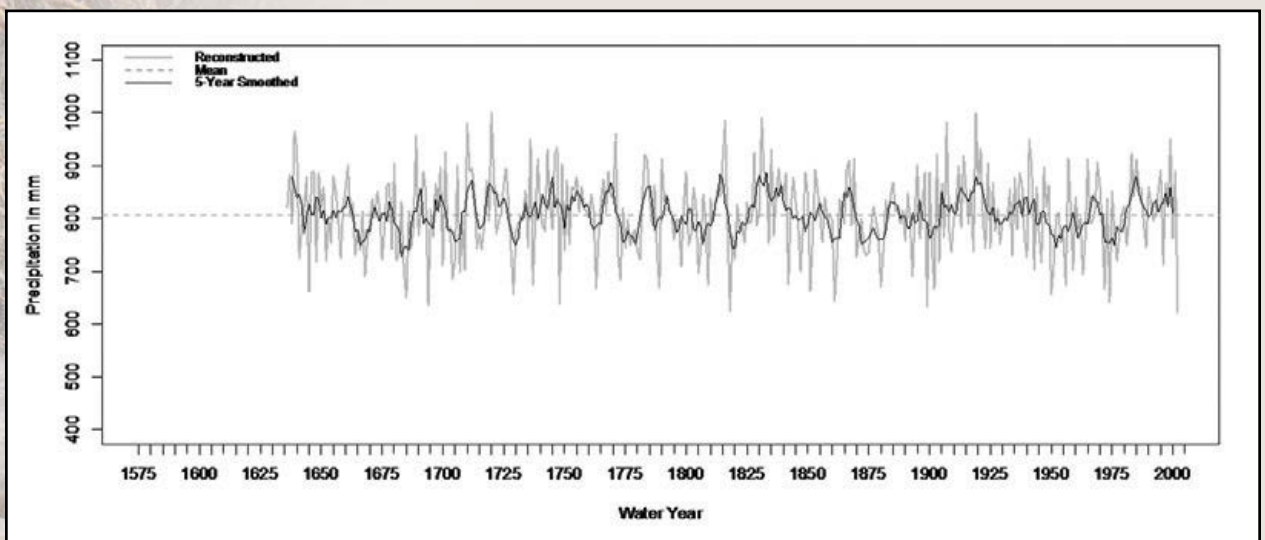


Figure 4. Full reconstruction of water year annual precipitation from 1636-2002 for Crestone Creek. Annual precipitation values (grey line) were smoothed using a five-year moving average for display purposes (black line).

Table 1. Description of tree-ring site chronologies used as potential regression predictors.

Chronology	Species	Elev. (m)	Time Span (yrs. A.D.)	Latitude	Longitude
Cathedral Creek <sup>a</sup>	<i>Psuedotsuga menziesii</i>	2895	1366-2002	38° 05'	107° 00'
Chokecherry Canyon <sup>b</sup>	<i>Pinus edulis</i>	2575	1450-2003	37° 33'	105° 34'
Cochetopa Dome <sup>a</sup>	<i>Pinus ponderosa</i>	2835	1437-2002	38° 15'	106° 40'
Natural Arch <sup>b</sup>	<i>Pinus edulis</i>	2667	1508-2002	37° 49'	106° 23'
Platt Bradbury <sup>c</sup>	<i>Pinus ponderosa</i>	2835	1632-2004	37° 28'	106° 18'
Princeton PSME <sup>a</sup>	<i>Psuedotsuga menziesii</i>	2956	1169-2002	38° 48'	106° 14'
Sargents <sup>a</sup>	<i>Psuedotsuga menziesii</i>	2621	1275-2002	38° 24'	106° 26'
South Fork <sup>a</sup>	<i>Pinus ponderosa</i>	2591	1566-2002	37° 40'	106° 39'
Temple Canyon <sup>b</sup>	<i>Pinus edulis</i>	1900	1577-2003	38° 24'	105° 18'

temperature and precipitation data and the paleo-data reconstructed from WY 1636-2002. These models are widely used and are ideal for exploring basic hydrologic principles and process interactions in a particular area. This study used the Thornthwaite Monthly Water Balance Model with a monthly time-step to examine changes to runoff and other hydrologic and state variables for the Crestone watershed. The model tends to underestimate periods of higher flow and overestimate runoff in periods of lower flow, similar to the streamflow reconstruction.

When comparing modeled flows for drought years 1645 and 2002, the tree-ring reconstructed annual flows for the two years were very similar, with slightly less streamflow in 1645. The water balance model however, suggested that 2002 was a drier year than 1645, with less runoff, higher evapotranspiration, and lower snow storage and soil moisture. Even though the different analysis methods (reconstruction and/or water balance modeling) result in slightly different scenarios of low flow conditions, they agree

on hydrologic state and the general severity of drought events. One of the benefits of using annual values decomposed to a monthly time-step in a model is the ability to compare scenarios of additional modeled output variables. This could be useful in studies directed at understanding watershed processes and landscape change besides variation in streamflow or runoff amounts.

### Summary

This study used readily available historic and paleo-data to examine hydrologic variability and extremes in streamflow and precipitation for North Crestone Creek and the surrounding watershed over time periods ranging from 65 years up to 426 years. Streamflow and precipitation reconstructions were generated using stepwise regression methods and results were compared to hydrologic variability and extremes in the historic period of observation. Water balance modeling at a monthly time-step was performed using historic and paleo-derived model inputs and compared to the reconstructed results. The study also contributed to the development of hydrologic and

dendroclimatologic data analysis proficiency for the author and an increased understanding of water management issues in Colorado.

### Acknowledgements

This student research project was supported by the Colorado Water Institute through the National Institutes for Water Research State Program Project Award 2012CO262B. We thank the staff of the Colorado Water Institute for their flexibility and assistance in administering this project, Dr. P. R. Brown of the Rocky Mountain Tree-Ring Laboratory for providing dendrochronological insight and support, and R. M. Records for ongoing dialogue about water and climate variability issues.

For more information on tree-ring based streamflow reconstructions in the U.S., visit the TreeFlow website at: [www.treeflow.info](http://www.treeflow.info). For additional questions please contact the author ([niah.venable@colostate.edu](mailto:niah.venable@colostate.edu)). ●



# Comprehensive Flow Analysis Using Cloud-Based Cyberinfrastructure

Tyler Wible and Mazdak Arabi, Department of Civil and Environmental Engineering, Colorado State University

*In order to facilitate a better understanding of streamflow analysis and take advantage of recent improvements in Web technology, a cloud-based Web tool was developed to analyze the multiple aspects of streamflow and water quality data.*

## Introduction

Streamflow data are widely used by water managers, engineers, scientists, and policy makers to support a variety of environmental and water resources decisions. Water data at varying spatial and temporal scales provide information for flood control, drought management, water allocation, water quality control, and ecological assessment. Despite the development of complex models of the environment, analyses of water data from stream monitoring locations remain essential for sustainable management of water resources and environmental protection.

In the United States, extensive historic and real-time water quantity and quality data for many rivers and streams may be obtained from the U.S. Geological Surveys (USGS)

National Water Information System (NWIS), U.S. EPA STORET, and other similar agencies. However, lack of accessibility along with limited scalability of water analytics impede the broader use of these data by interested stakeholders. Existing technologies have extensive hardware requirements, require installation of platform-dependent software, and often require substantial training.

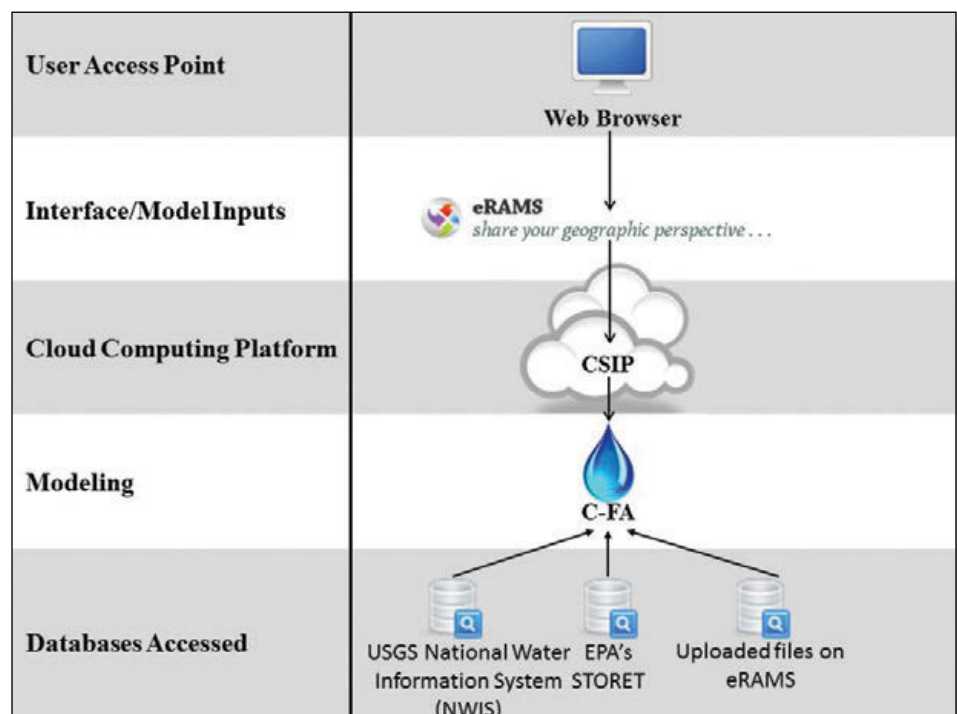
However, these Web-based tools offer few if any ways to analyze the streamflow data. To work around this deficiency a person would have to find, download, and install software to analyze the streamflow data. Additionally, there are numerous aspects to streamflow analysis, and currently, no comprehensive software package to analyze all of them. This then requires someone to become

proficient in each individual streamflow analysis software package, its installation procedure, computer requirements, and the creation and format of its input files.

In light of recent advances in Web development and modeling services, the next step in streamflow analysis is a Web-based platform-independent software tool. This tool could also auto-extract data from the aforementioned databases. One option for a flexible, scalable, Web-deployment of environmental models is the use of Infrastructure-as-a-Service (IaaS) clouds. Cloud-based modeling inside a Web tool offers a platform-independent package requiring no software from the user beyond their Web browser.

## Infrastructure Outline

The purpose for this study was to develop a Web-based, platform-independent, stream water analysis tool. The result of this work is the Comprehensive Flow Analysis (CFA) tool designed and implemented on the environmental Risk Assessment and Management System (eRAMS) platform ([www.erams.com/flowanalysis](http://www.erams.com/flowanalysis)). The eRAMS technology provides a platform for seamless integration data with complex modeling systems using a cloud computing infrastructure. Major components



The Comprehensive Flow Analysis tool infrastructure

Cache La Poudre river,  
near Greyrock Trail.  
Photo by Laura Bojanowski

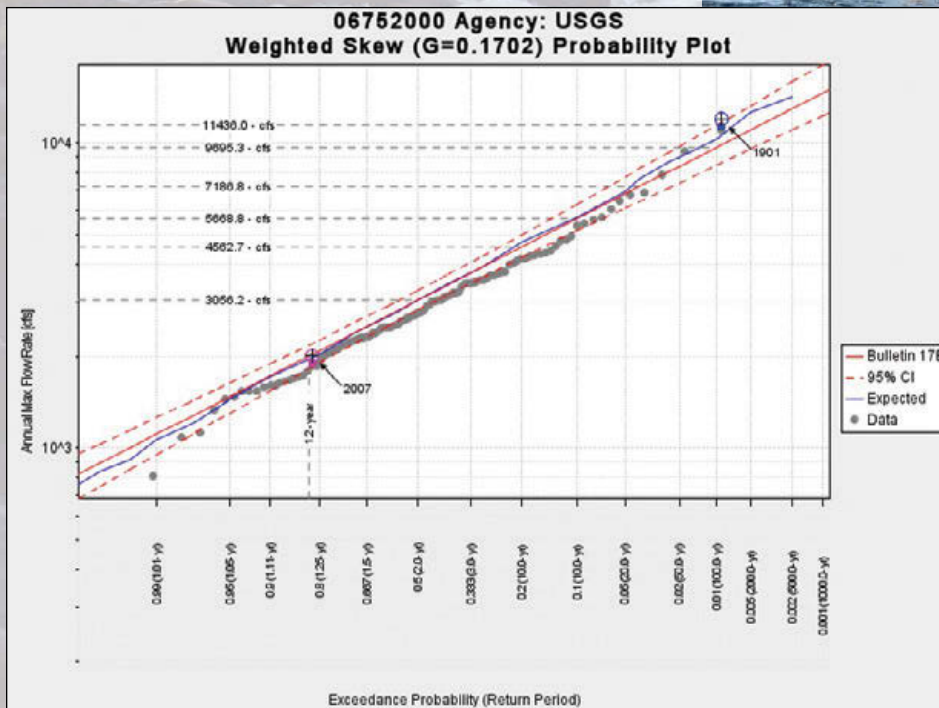
of eRAMS include a content management tool, a collaboration platform, a mapping and geospatial analysis tool, and platform for model integration. eRAMS uses the Cloud Service Integration Platform (CSIP) to access the flow analysis models of CFA. The combination of cloud based computing from CSIP with the website services of eRAMS allows Web-based access to the streamflow analysis models of CFA from any desktop, laptop, smart phone, or tablet devices.

## Analysis Capabilities

The CFA's streamflow analysis models allow a person to examine the various aspects of streamflow, including flood and drought frequency, duration curve analysis of streamflows, as well as base flow separation tools which isolate the influence of groundwater on stream discharge.

The first model in CFA is a simple time series analysis which graphs and summarizes basic statistics on streamflow or water quality concentrations. The next model in CFA is a flood analysis method based on the procedures outlined by the USGS for flood frequency analysis. The flood model calculates the recurrence interval of historic floods as well as predicting confidence limits for future flood magnitudes based on the historic data.

An opposite, but equally important, aspect of river flood flows is the consideration and analysis of droughts from streamflow records. For this reason a generalized

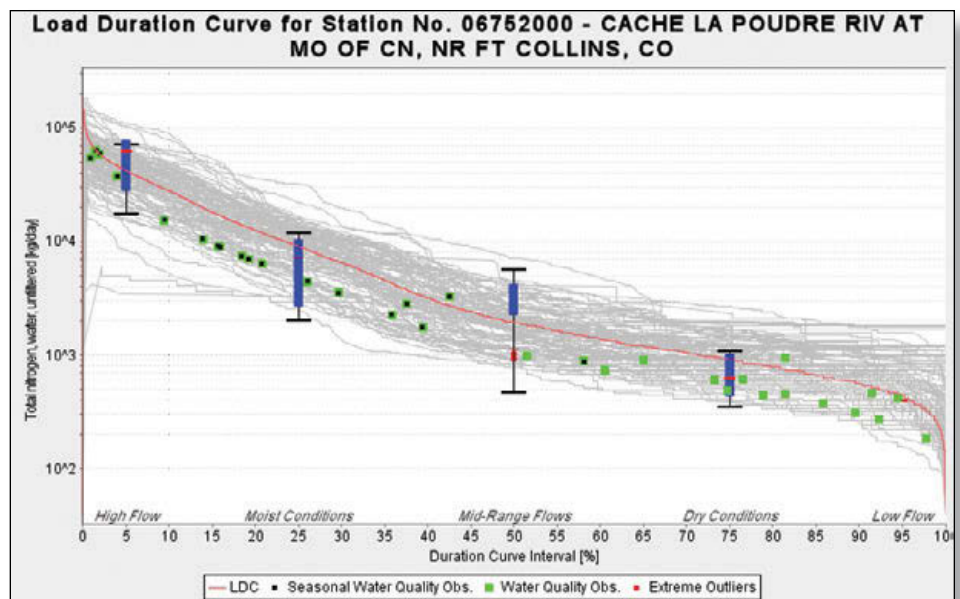


An example of flood modeling, a tool based on USGS procedures for flood frequency analysis

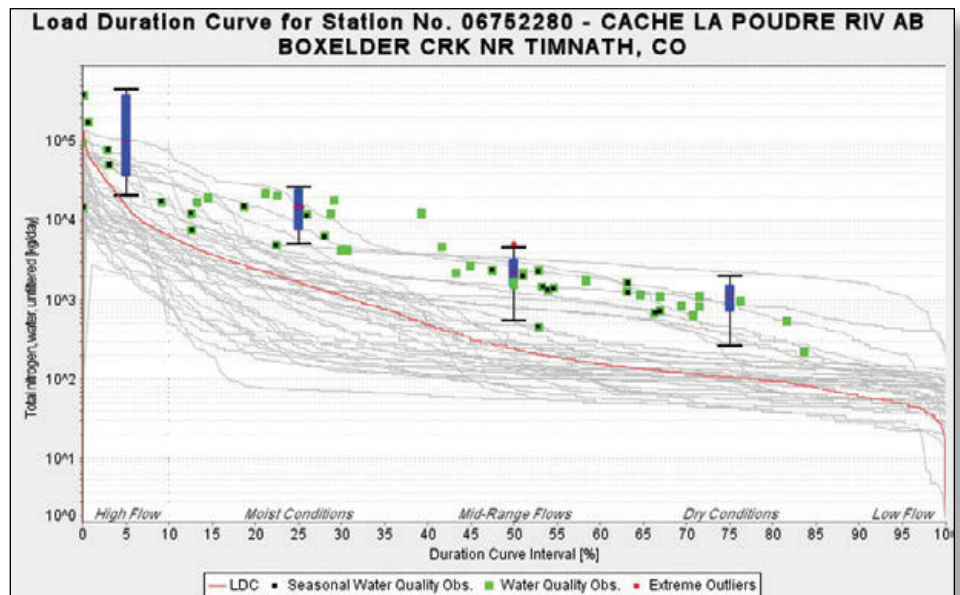
drought analysis tool was included in CFA. The drought analysis method included in CFA fits Auto-Regressive (AR) or Auto-Regressive-Moving-Average (ARMA) model to annual streamflow data. The purpose of fitting the regression model to the data is to increase the size of the dataset while maintaining its statistical properties, mean, and standard deviation. After fitting the regression model, a 100,000 year forecasting is performed using the fitted model to create a dataset sufficiently large to 'observe' high recurrence interval droughts. The forecasted dataset is then analyzed and summarized based on the drought deficit (deficit = supply – demand), its length (years), and its average recurrence interval.

Another useful aspect of streamflow analysis is river base flow, the groundwater contribution to streamflow. CFA includes the base flow separation tool BFLOW, developed by Jeff Arnold, which is an automated digital filter base flow separation tool that performs a multi-pass separation of base flow from total streamflow. A final model included in CFA is a duration curve analysis tool. This tool uses the frequency with which a given flow value is exceeded to determine a percent exceedence and create a flow duration curve—how long (duration) a flow is exceeded. This flow duration curve can also be combined with water quality observations to create a load duration curve, useful in determining total maximum daily loads of pollutants into the river.

These CFA models were developed so that a person could take a river, like the Cache La Poudre River in Fort Collins, and examine something like the impacts of nutrient loading before and after the river passes through the city. Let us do just that using CFA's Load Duration Curve tool. First, look at the river monitoring station at the mouth of the Poudre River canyon upstream of Fort Collins, USGS 06752000. If we compare the results for total nitrogen loading on the river to the EPA's legal standard of 10 mg/L, notice that almost all of the samples are below the legal limit, which is desirable, before the river enters the city. The red line is the total average limit over the history of



Models can show comparisons, such as the graphs of nutrient loading before (above) and after passing through Fort Collins. Red lines represent the total average historical limit.



streamflow discharges; the grey lines are per year limits. However, if we examine the same information for the river monitoring station just downstream of Fort Collins, USGS 06752280, notice that almost all of the nitrogen samples are above the EPA's limit, indicating that the city increases the concentration of nitrogen in the river (see graphs).

## Closing Remark

The purpose of this work was to develop a standardized, publicly available, Web tool for flow analysis. Beyond this, the tool was designed so that public utility companies, watershed modelers, water resource managers, and average citizens can use the tool to learn more about the watershed they live in. ●

# Colorado State University Water Resources Archive Digitizes 43,000+ Water History Documents

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

100+ years of Colorado water history added to the Web by massive digitization project.

More than 43,000 pages of primary source materials related to water use and history in Colorado are now freely available online. The Colorado State University Water Resources Archive recently scanned and posted the items that include reports, images, oral histories and data thanks to a \$50,000 grant from the Colorado Water Conservation Board (CWCB). This is the fourth such grant from the CWCB to the Archive.

The unique project took just under a year to complete and added material from 15 previously undigitized collections and 24 total collections to the Archive's online offerings. Scanned materials relate to today's water issues, and include groundwater research and administration, snow hydrology, agricultural water use, the 1976 Big Thompson flood and early water leaders. Digitization also preserved more than 200 rare glass plate images of Colorado and several thousand slides of dams and waterways in the western United States.

Patrons can browse documents or find specific items with simple keyword searches on the Archive's website, [lib.colostate.edu/archives/water](http://lib.colostate.edu/archives/water). Online access to archival materials is intended to aid those without the time or money to travel to Fort Collins to view documents but who want to educate themselves about water.



*Irrigating and setting cabbage plants in the late 1800s. This photograph was captured in the glass-based format of the day by F. E. Baker. This and more like it in the Archive's Delph Carpenter Papers were digitized as part of the CWCB project.*

Courtesy of the Water Resources Archive

Some highlights from the recently digitized materials include 41 oral history interviews from survivors and emergency responders of the 1976 Big Thompson flood, USGS Civil Engineer Robert Glover's diaries from 1923 to 1984, and data and reports from Colorado's portion of the 1979-1981 six-state High Plains-Ogallala Aquifer study. Those interested in Colorado history will also find 79 images of farms, towns, and mountains in the 1890s from the Delph Carpenter collection particularly fascinating.

The Water Resources Archive, part of the University Libraries, is Colorado's only

repository dedicated specifically to preserving the history of water in the state and the American West. Most of the documents in the Archive are unique and unavailable elsewhere. Holdings, contained in nearly 2,000 boxes, cover more than a century of water history and provide access to the studies, debates, and legislative deals that have shaped Colorado's water legacy. ●

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**Colorado State University**



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**Bill Ritter**  
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**Jeff Immelt**  
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Colorado State University

# Measuring the Weather

*Nolan Doesken and Wendy Ryan, Colorado Climate Center,  
Department of Atmospheric Science, Colorado State University*

If there is anything that is taken for granted these days, it's weather data. Everyone seems to have a favorite website to get current weather information. And whether it's [weather.gov](http://weather.gov), [weather.com](http://weather.com), or [wunderground.com](http://wunderground.com), it doesn't take long before you're literally inundated with weather data (Figure 1). That gives the clear and immediate sense that top quality weather stations measure flawlessly pretty much everywhere you go.

I wish it were so, but that the reality is much more complicated. For many decades, the old U.S. Weather

Bureau and its workhorse weather instruments were pretty much the only game in town when it came to weather data. Basic weather stations consisted of a large metal rain gauge two feet tall and eight inches across that could stand up to just about any weather (Figure 2). Temperatures were measured with glass thermometers filled with either mercury (for measuring the daily high temperatures) or alcohol (for measuring the low temperatures). These thermometers, mounted inside a wide painted slatted wooden box, provided many decades of baseline weather data. At higher level stations,

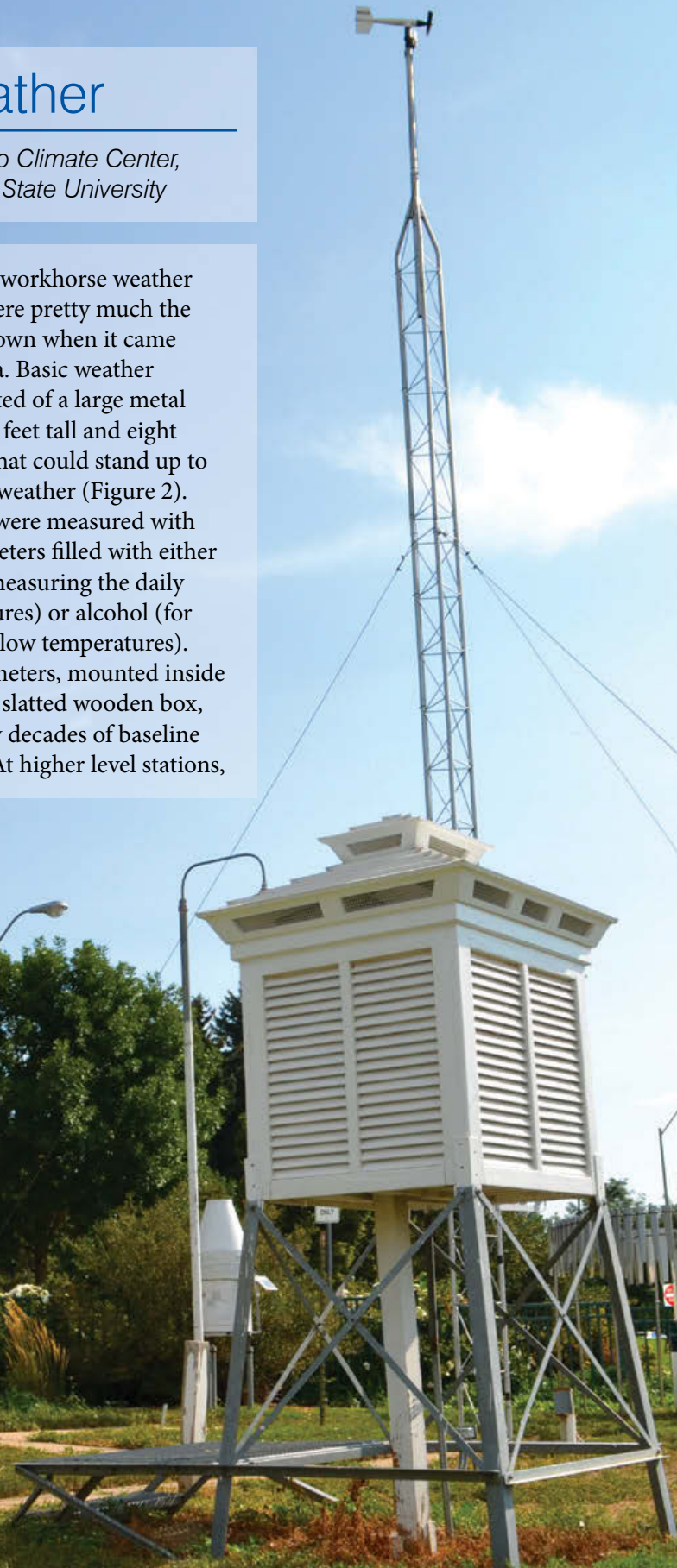


Figure 3. Historic Fort Collins weather station located on CSU campus. Photo by Kim Hudson

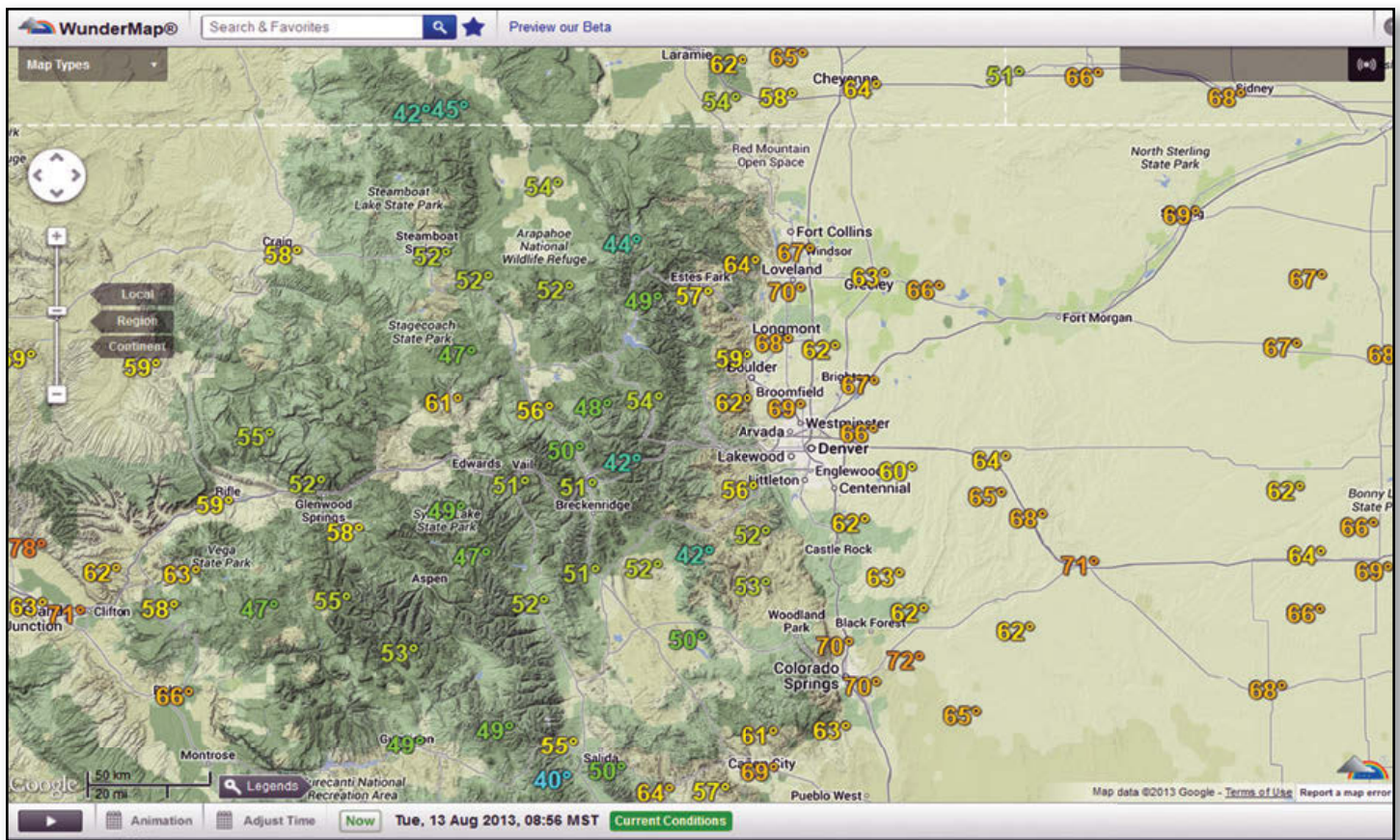


Figure 1. Weather Underground provides a wide variety of weather data to users. Their interactive WunderMap® allows users to turn on and off visibility of features like temperature, wind, radar, satellite imagery, forecasts, fire, photos, etc.

additional instruments would be a special recording rain gauge to weigh rainfall as it landed and estimate rainfall rates, a heavy duty wind vane, a three-cup anemometer to measure wind direction and speed, a sling psychrometer to measure humidity, an elegant looking mercurial barometer to track changes in atmospheric pressure, and perhaps a high powered focused light to illuminate clouds at night and estimate their height above ground. Trained weather observers would take periodic measurements day and night and then telegraph or teletype the reports in a cryptic code. It was a really big deal to assemble those reports, then plot and analyze weather maps to help track approaching storms or clearing weather. We still have most of these classic weather instruments in use or on display at our campus weather station northwest of the Lory Student Center at CSU.

Technology has changed a great deal about observing the weather. The crafted mechanical weather instruments of the early 20<sup>th</sup> century gradually gave way or were supplemented by combinations of ever more affordable plastic and electronic sensors. Now, for a few hundred dollars, almost anyone can purchase and install some sort of weather station that measures the basics—temperature, humidity, wind, pressure, and precipitation. For a little extra you can add an estimate of incoming solar radiation and you can even get soil moisture sensors. The public fascination with weather can now be satisfied quickly. Thousands of similar weather stations are now interconnected by the marvels of the Internet. [Wunderground.com](http://Wunderground.com) makes it possible for anyone from a business decision maker to a weather hobbyist to view weather conditions nearly instantaneously from all over the world. The data aren't always

perfect or consistent, and weather stations may be installed under trees or on tall roofs, making it impossible to compare data. But on first look, it seems that we have got weather observations figured out. Even affordable home weather stations may have a special feature to combine temperature, humidity, sunshine, and wind for the past 24 hours and give you an estimate of how much water was used by your crops or lawn in the previous day or week. All in all, it's really quite amazing.

Our campus weather station now combines the old and the new. We have multiple thermometers, hygrometers, barometers, pyranometers, atmometers, anemometers and, of course, a whole slew of different rain gauges. (Figure 3) We even have a set of ultrasonic sound wave transceivers bouncing sound waves down and back up to detect and measure the depth and rate of accumulating snow. Some weather



Figure 2. Jason Huitt, a weather observer at the CSU Weather Station, checks CSU's National Weather Service eight inch standard rain gage used at hundreds of Cooperative sites across the country for measuring precipitation.  
Photo by Kim Hudson

stations have replaced their classic anemometers with tiny sonic sensors that detect the movement of air to estimate wind speed. Light beams, lasers, and other wave sensors can estimate anything from cloud height and thickness to how far the eye can see (visibility) and can even count the number and size of individual rain drops. And thanks to dataloggers, cell phones, and IP addresses, current data can be quickly posted and shared on the Web. Weather radar—developed during World War II to track planes and ships has routinely been used to track storms and precipitation for over 50 years and is now used to estimate rainfall intensity and amounts. Our forefathers who proudly tracked the weather 100 and even 50 years ago would be shocked and amazed to see what we do today.

But interestingly, some basic questions that would seem super easy are still surprisingly hard to answer. How

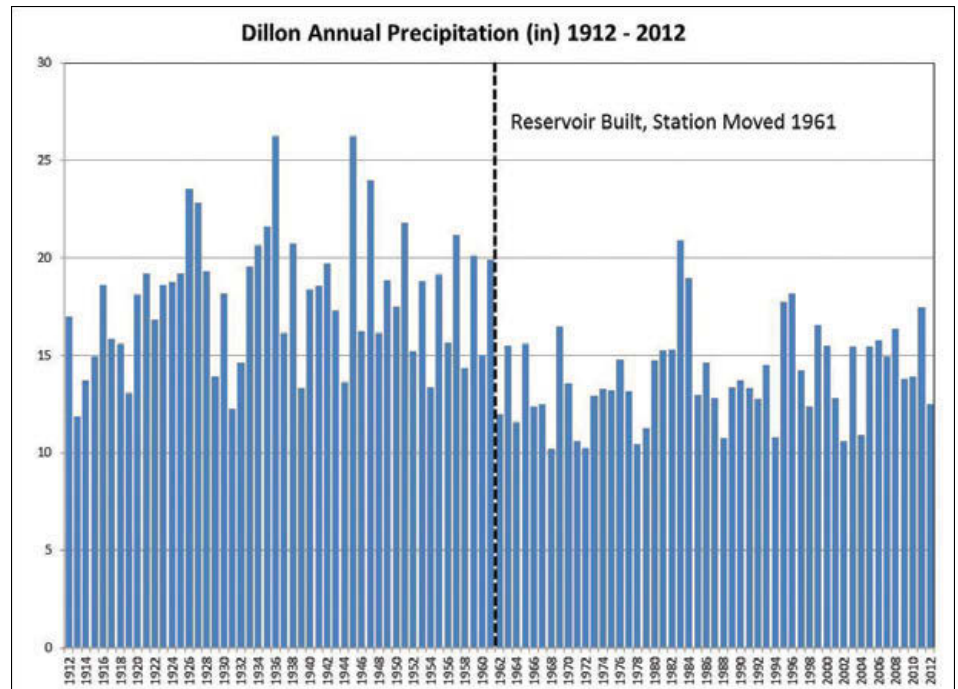


Figure 4. This time series shows a discontinuity in precipitation measurements after the the Dillon reservoir was built and the station therefore moved in 1961.

much warmer are we than 100 years ago? How much rain did we get yesterday up on Trail Ridge Road? Are we experiencing stronger winds now than 50 years ago? How much snow fell this past winter at Limon?

Why are these questions hard to answer? There are many reasons. It turns out that newer style thermometers and housings don't measure exactly the same thing as old liquid-in-glass thermometers. Also, as weather stations migrated towards electronics, instruments were often installed for convenience and not for ideal measurement exposure. For example, many home weather stations are installed on rooftops rather than being a standard height above grass. Once the National Weather Service ceased to be the primary data collector, standards for weather observations were forgotten or ignored. Also, there are so many special purpose weather stations now (flood warning, road weather, fire weather, agricultural, air quality, airport, etc.), and different types of instruments and instrument locations make sense for different applications. For agricultural weather, wind speed

is measure about six to 10 feet above the ground. For fire weather, the wind is measure at 20 feet, and for aviation purposes and weather forecasting, the preferred height is 33 feet. That really makes a big difference, and you can't compare one to another. Keeping track of all of these differences is tough, but in the end it makes it very difficult to compare 2013 weather to 1913. Figure 4 demonstrates a known measurement discontinuity over time.

And for all the conversations we have about rain and snow, it turns out that very few expensive rain gauges are better than an old-fashioned straight sided can. Even the best of the electronic tipping bucket rain gauges commonly in use usually underestimate heavy downpours and fail to collect some or all of the windblown winter snows. As a result, rain, hail, and snow data measured manually by volunteers for the National Weather Service and CSU's Community Collaborative Rain, Hail, and Snow network in simple metal or plastic gauges tend to be more reliable, consistent, and accurate than measurements from very expensive electronic devices. There



are disadvantages of course, since data are not shared instantaneously. But for many applications what matters most is “how much rain actually fell.”

The Climate Reference Network (USCRN) was started by NOAA in order to provide future long-term homogeneous temperature and precipitation observations that can be coupled to long-term historical observations for the detection and attribution of present and future climate change. These stations were established to create a network that can be used for benchmark climate monitoring without problems such as change in observation time, station moves, equipment changes, and changing environment around the stations. These stations were installed in a grid pattern across the U.S., utilizing mainly public land that is not susceptible to land use change (Figure 5). The network collects precipitation using a Geonor vibrating wire rain gage. Each wire vibrates (similar to a guitar string) at a different frequency depending on

the weight of the precipitation bucket, and as rain falls the weight increases, which is converted to a depth of water. By using a triplicate configuration there is redundancy in case of a failure and a consensus approach can be used to determine the amount of precipitation falling. Temperature is also taken in triplicate from aspirated platinum resistance thermometers. The aspirator essentially blows air past the thermometers and does not allow them to artificially heat up from solar energy.

A book recently published, called the “Weather Observer’s Handbook” by Stephen Burt and published by Cambridge Press, is a comprehensive yet readable guide for anyone who want or needs to know more about both historic and modern weather instruments and how they compare. We will be hosting Stephen Burt for a webinar observing the weather in October 2013. To view the live or archived webinar go to: [www.cocorahs.org/Content.aspx?page=wxtalk](http://www.cocorahs.org/Content.aspx?page=wxtalk)

Recommended Data Sources to access Colorado weather data:

- CSU main campus weather station ([ccc.atmos.colostate.edu/~autowx](http://ccc.atmos.colostate.edu/~autowx))
- ARDEC weather station ([ccc.atmos.colostate.edu/~ardec/index.pl](http://ccc.atmos.colostate.edu/~ardec/index.pl))
- CoAgMET ([www.coagmet.colostate.edu](http://www.coagmet.colostate.edu))
- NWS/FAA airport weather stations ([forecast.weather.gov/stations.php](http://forecast.weather.gov/stations.php) and [www.faa.gov/pilots/flt\\_plan/weather](http://www.faa.gov/pilots/flt_plan/weather))
- NWS COOP data ([www.nws.noaa.gov/om/coop](http://www.nws.noaa.gov/om/coop))
- RAWS ([raws.fam.nwcg.gov](http://raws.fam.nwcg.gov))
- Northern Water ([www.northernwater.org/WaterConservation/WeatherandETInfo.aspx](http://www.northernwater.org/WaterConservation/WeatherandETInfo.aspx))
- CoCoRaHS ([www.cocorahs.org](http://www.cocorahs.org)) ●

**USDA Agricultural Research Service, Central Plains Experimental Range**  
**(Shortgrass Steppe Long Term Ecological Research site at Colorado State University)**  
**40.8 N 104.8 W 5422'**  
**July 6, 2003**

Figure 5. A station established within the Climate Reference Network.

# CSU Beverage Business Institute Workshops Educate on Sustainability

Lindsey Middleton, Editor, Colorado Water Institute

Fort Collins is a unique town in many ways—it houses a flourishing bike-friendly community, myriad well-attended community events, and one of a handful of the remaining drive-in movie theaters in the state, to name a few. Fort Collins also claims nearly a dozen breweries, from the well-known Anheuser Busch to the city’s increasingly popular collection of microbrews, making it one of the highest microbrewery and craft brewery per capita cities in the nation. This sector of the local economy represents about 1,000 jobs and over \$80 million according to a CSU study, and at least in part, helps define local culture and business.

Beginning in November of 2011, Colorado State University (CSU) began offering workshops as part of the newly founded Beverage Business Institute (BBI) to cater to a statewide job market that boasts some 20,000 employees. Students seeking the BBI Certificate in Beverage Business Management attend four three-day interactive workshops, featuring guest speakers who discuss business trends, marketing, distribution, sustainability, and other aspects of the brewing profession.

This August, BBI held a capstone workshop that featured speakers from PepsiCo Inc., CSU’s College of Business, Encompass Technologies (an IT firm), New Belgium Brewing, and others. Attendees of the workshop learned about trends in the types of information technology used by beverage businesses, how to build better business to business relationships, how to manage in the beverage industry, and how to operate a beverage business sustainably.

Three of the talks featured sustainability themes, including the featured speaker, Jennifer Vervier of New Belgium Brewing, as well as Matt Brooksmith of The Neenan Company.

“Brewing is a very energy-intensive process,” explained Brooksmith. Brewing companies, he said, can improve efficiency and work toward sustainability by implementing certain policies and techniques, as many breweries already have.

Located in Golden, Colorado, the MillerCoors Brewing Company is one such brewery. As founder Bill Coors has famously said, “Waste is a resource out of place.” The company operates under a zero waste objective—all waste is recycled. Hops and barley are trucked away for cattle feed, plastic goes to decking composite, and glass is recycled nearby. Instead of sending such materials to landfills, MillerCoors actually earns about \$1 million in annual revenue selling their “waste” product.

Brooksmith introduced several sustainability concepts, including such techniques as anaerobic digestion. Liquid waste produced during the brewing process contains dissolved solids, such as yeast and grains. The waste is introduced into tanks with certain bacteria that consume the solids, producing methane gas and carbon dioxide and leaving the water much cleaner and acceptable for



BBI workshop guest speaker Jennifer Vervier from New Belgium Brewing. Photo by Bill Cotton

discharge or reuse. Capturing the gas produced in this process can be very useful to this particular industry. Carbon dioxide is used in the beer crafting process, and methane can be used as biofuel—in some current cases, it powers between 15 and 40 percent of a brewery’s energy needs.

“I’m starting to see more breweries go with this,” Brooksmith said of the anaerobic digestion technique, noting that local companies like Odell have such process treatment plants in the works.

Featured speaker Vervier spoke about energy generation at New Belgium Brewing, saying that the money the company spends on electricity gets an “internal electrical tax” that is set aside only for energy efficiency and renewable energy projects.

Other New Belgium efforts that Vervier mentioned included recycling (generates nearly \$500,000 in revenue for New Belgium, and

they have an employee dedicated to finding receivers of recyclables) and the installation of water meters throughout the brewing process. Vervier says the water meters help New Belgium optimize the process and find new ways to reduce water use.

The workshop was a success, and ended with a celebration commemorating this year's graduating class. BBI structures the courses with collaboration from partners that include representatives from the malt beverage, soft drink, and wine

and spirits industries, as well as the College of Business and sustainability leaders. The partnerships extend to include research and other initiatives, as well. Currently, BBI is working on a project involving water usage in the beverage industries through a grant from the Ball Corporation, including a packaging portion led by Brian Fugate.

As an important component of many aspects of the beverage industry, especially for water-scarce Colorado, water-related research and education are making their way into BBI efforts. "When talking about sustainability

from an industry perspective, water is a topic that comes up over and over again," says BBI's Felicia Zamora, Assistant Director of the Center for Professional Development and Business Research. "Entering into its third year of the Certificate in Beverage Business Management, the BBI looks to continue adding water and water usage as a necessary topic of business practices for beverage professionals."

*Thanks to Felicia Zamora and BBI Director G. James Francis.* ●



## Recent Publications

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Conceptual and numerical models of groundwater flow in the Ogallala aquifer in Gregory and Tripp Counties, South Dakota, water years 1985--2009; Davis, Kyle W.; Putnam, Larry D.

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Assessing the use of existing data to compare plains fish assemblages collected from random and fixed sites in Colorado; Zuellig, Robert E.; Crockett, Harry J.

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Limiting the immediate and subsequent hazards associated with wildfires; DeGraff, Jerome V.; Cannon, Susan H.; Parise, Mario

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Estimates of the volume of water in five coal aquifers, Northern Cheyenne Indian Reservation, southeastern Montana; Tuck, L. K.; Pearson, Daniel K.; Cannon, M. R.; Dutton, DeAnn M.

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Geochemical evidence of groundwater flow paths and the fate and transport of constituents of concern in the alluvial aquifer at Fort Wingate Depot Activity, New Mexico, 2009; Robertson, Andrew J.; Henry, David W.; Langman, Jeffery B.

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Emergence flux declines disproportionately to larval density along a stream metals gradient; Schmidt, Travis S.; Kraus, Johanna M.; Walters, David M.; Wanty, Richard B.

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Streamflow and water-quality conditions including geologic sources and processes affecting selenium loading in the Toll Gate Creek watershed, Aurora, Arapahoe County, Colorado, 2007; Paschke, Suzanne S.; Runkel, Robert L.; Walton-Day, Katherine ; Kimball, Briant A.; Schaffrath, Keelin R.

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Development of MODFLOW-USG: an un-structured grid version of MODFLOW; Panday, Sorab

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How runoff begins (and ends): characterizing hydrologic response at the catchment scale; Mirus, Benjamin B.; Loague, Keith

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Characterization and conceptualization of groundwater flow systems: Chapter 2; Plummer, L. N.; Sanford, W. E.; Glynn, P. D.

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Defining groundwater age: Chapter 3; Torgersen, T.; Purtschert, R.; Phillips, F. M.; Plummer, L. N.; Sanford, W. E.; Suckow, A.

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Radiocarbon dating in groundwater systems: Chapter 4; Plummer, L. N., Glynn, P. D.

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Numerical flow models and their calibration using tracer based ages: Chapter 10; Sanford, W.

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Tamarix and Diorhabda leaf beetle interactions: implications for Tamarix water use and riparian habitat; Nagler, Pamela ; Glenn, Edward

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Groundwater well inventory and assessment in the area of the proposed Normally Pressured Lance natural gas development project, Green River Basin, Wyoming, 2012; Sweat, Michael J.

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Prioritization of constituents for national- and regional-scale ambient monitoring of water and sediment in the United States; Olsen, Lisa D.; Valder, Joshua F.; Carter, Janet M.; Zogorski, John S.

# Gaining an International Perspective

## The Water Resources Archive at the Eighth Water History Conference

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

For anyone interested in water history, being in the presence of a 2,000-year-old water structure is a moment to behold. Having the rare opportunity to walk inside the structure provides an even more special thrill. Fittingly, this tour experience completed a week of learning at the Eighth Water History Conference.

The conference was held the last week of June by the International Water History Association (IWHA), itself a new organization, just over a decade old. The Pierresvives Archives in Montpellier, France, served as the conference site, thus inspiring one of the conference themes: archives. It was therefore a natural fit to be the first international conference for Colorado State University's Water Resources Archive.

Three days of plenary and parallel sessions comprised the core of the conference, which was bookended by excellent tours of historical water sites. The pre-conference tour began in the archives' reading room with an examination

of historical documents. Archivists had laid out about a dozen ancient maps and other documents related to that day's tour site. A lake near the town of Montady—about an hour southwest of Montpellier—had been drained with underground pipes in the thirteenth century and has been used for agriculture ever since. The documents helped tell the story of hundreds of years of engineering, agricultural, and social history.

After riding a bus through the countryside and vineyards of southern France, about thirty water history scholars climbed a hill to an overlook and took dozens of photos of the "Étang de Montady." The unique round shape encompassing over 400 hectares in narrow wedge-shaped plots is a captivating sight. We listened to the local historian talk about the drained lake as well as the related historical themes of governance, trade, and agriculture.

We also received a lesson on the nearby Canal du Midi, a transportation canal linking the Mediterranean Sea with the Atlantic Ocean, built in the late seventeenth century.



*The Pont du Gard consists of three levels of stone arches, with the water-carrying conduit at the very top.*  
 Courtesy of Patricia J. Rettig

A significant engineering accomplishment at the time, the canal was used heavily until the arrival of the railroad. It became a UNESCO World Heritage Site in 1996 and now serves mainly for tourism.

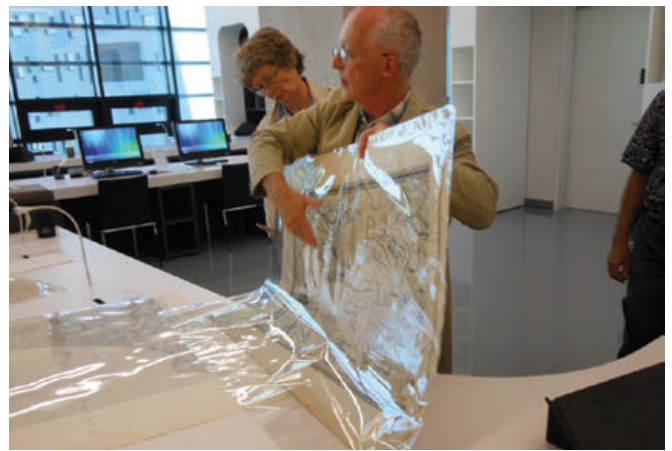
The day continued with a few other historical sites and discussions, but a highlight for me came during lunch. A man read “Colorado State University” on my nametag and immediately asked, “Do you know Neil Grigg?” Of course I said yes, and over lunch I got to know this civil engineer from Finland, Tapio Katko, who also happens to be this year’s IWHA Dooge Prize recipient.

In the remaining days of the conference, that happened two more times—I was asked if I knew David Freeman and Evan Vlachos. Indeed, CSU’s water expertise extends around the world!

I was happy to continue spreading that expertise with my presentation on the Water Resources Archive. I talked about Delph Carpenter and his importance to western water history as the “father of interstate river compacts,” as well as the significance of his historical papers in the Archive. In comments I received after the presentation, I discovered that collecting personal papers such as these is fairly rare in other countries. Government archives predominate, at varying levels of efficiency and accessibility.

We are certainly doing something special here in Colorado by collecting historical water materials. In addition to limited collecting, most other countries have ten times more history in terms of age than we do, or more. Written history for our part of the world is new in comparison. Following the tour of Montady, where I heard how they were working to reconstruct the history of that drainage and later irrigation from centuries ago, it struck me that we are working on saving just such documentation of our irrigation works right from their beginnings. Statewide, documents from the 1860s and 1870s still turn up and make their way to archives. Collecting and preserving such documentation will help researchers 100, 500, or 1,000 years from now understand what we have done and how we have done it.

Beyond a few presentations about the use of archival documents for historical water research, other conference presentations focused on the 1910 Paris flood, research on an ephemeral river in the capital of Cyprus, and a



*Photos on right (top to bottom):*

- 1. The drained lake of Montady, used for agriculture since the 13<sup>th</sup> century.*
- 2. Archives director Vivienne Miguet and historian Thierry Ruf tell the history of the drained lake at Montady with centuries-old documents.*
- 3. Thrilled water scholars walking across the Pont du Gard.*
- 4. Archivist Patty Rettig at the Pont du Gard, part of a 2,000-year-old aqueduct system built by the Romans.*

Courtesy of Patricia J. Rettig



*The Water History Conference tour group at the drained lake of Montady, 25 June 2013.  
Courtesy of Thierry Ruf*

comparison of water development in Nebraska and Palestine. There were several fascinating presentations on qanats in the Middle East, the history of hydrology and hydrologists, and water issues in the Netherlands and Australia. About 150 scholars from thirty countries attended and presented their work on their own and other countries. The scholars extended well beyond the expected set of historians to archaeologists, geographers, sociologists, and civil engineers. The diversity of the presentations and the presenters greatly enhanced the event.

On the post-conference tour, a group of nearly thirty travelled about one hour northeast of Montpellier and back 2,000 years in water history, to the Pont du Gard. This stunning structure is part of an aqueduct built by Romans in approximately 50 AD. In use for about nine centuries, the 50-kilometer aqueduct, constructed to follow the contours of the hills and span rivers or valleys as necessary, brought water to the city of Nimes from a spring twelve kilometers away. The aqueduct has experienced both neglect and restoration over the centuries and stands now as a prime and aesthetically beautiful example of the advanced technology of the Romans. It was named a UNESCO World Heritage Site in 1985.

Our group was given a guided tour of the Pont du Gard museum to learn about sophisticated Roman construction methods, water transport systems, and indoor plumbing, and then we walked the ten minutes to the structure

itself. After extensive picture taking and further historical discussion there, our group let out a collective gasp upon being told we would next be heading up to walk across the uppermost part of the structure, which is normally closed to the public. We were thrilled to have special access to the conduit where the water used to flow, walking between the thick limestone walls and peering out through breaks in the low roof. The up-close view demonstrated the skill and expertise of the engineers, stonecutters, and builders. For millennia, people have gone to extraordinary lengths to move our most precious resource: water.

The tours and sessions combined for excellent learning opportunities at the Water History Conference, accentuated by plenty of networking time during coffee breaks, three-course French lunches, and an evening banquet complete with champagne and a chocolate fountain. I feel quite fortunate to have been able to represent CSU and the Water Resources Archive internationally. I learned a great extent from global perspectives and a much longer timeline of history than I normally focus on.

The Ninth Water History Conference is being planned for 2015 in Delft, The Netherlands. I look forward to more outstanding learning opportunities and to meeting more colleagues, old and new, there at that time.

For more information on the conference or the Water Resources Archive, please contact me (970-491-1939; [Patricia.Rettig@ColoState.edu](mailto:Patricia.Rettig@ColoState.edu)) at any time. ●



# Colorado State Forest Service Nursery to Offer Deep-Pot Seedlings for Riparian Restoration

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

Restoration groups and private landowners will soon have access to deep-root seedling trees and shrubs ideal for planting in arid riparian areas.

The Tamarisk Coalition, in collaboration with the Natural Resources Conservation Service, Upper Colorado Environmental Plant Center, Colorado State Forest Service (CSFS), and several smaller local nurseries, is working to provide a sustainable supply of native plants for use in riparian restoration projects. As part of the effort, the CSFS Nursery in Fort Collins is growing deep-pot seedling trees and shrubs with funding provided by the Coalition—a Grand Junction-based organization whose mission is to advance “the restoration of riparian lands through collaboration, education, and technical assistance.” Initially, the CSFS Nursery will produce at least 2,000 deep-pot native seedlings in accordance with a service agreement between the CSFS and the Coalition. A \$13,000 sub-grant administered by the Coalition from funds provided by the Walton Family Foundation will be used for seed-stock collection, stem cuttings, and plant propagation.

“We felt that this partnership would build upon our long-standing relationship with the CSFS and would help to further the nursery’s goal of providing locally sourced resources

for riparian restoration projects,” said Shannon Hatch, restoration coordinator for the Tamarisk Coalition. “While the materials currently in production are sourced from the Western Slope, we hope that the influx of funding and experience with different growing techniques will help incentivize the CSFS’s interest in the production of more regionally sourced deep-pot materials for our partners on the eastern side of the state.”

Greg Sundstrom, CSFS Nursery manager, says that using traditional upland planting techniques to restore riparian forests has met with limited success, so the CSFS wanted to develop a more effective seedling type. Most transplanted tree and shrub species do not survive when their roots and stems are buried too deeply. However, many trees and shrubs that naturally occur in riparian areas have the ability to develop roots all along their stems—an attribute that allows them to survive when their roots are buried deeper and deeper with each flood event. By propagating specific riparian species that have taller stems than seedlings normally produced by the CSFS Nursery, in containers that

will allow longer root systems, the seedlings can be planted deeper in the potting soil. This allows the roots to be closer to the water table after transplanting.

Deep-pot seedlings allow for the development of more extensive root systems capable of extending into the capillary fringe, which is the permanent soil moisture above the water table. The new seedlings growing at the CSFS Nursery will offer a robust root system that extends 14 inches down in taller versions of the polyethylene containers already in use. This allows them to utilize moisture farther from the surface—making them ideal for arid sites with deeper soil moisture, such as arid riparian areas. The Los Lunas Plant Materials Center in New Mexico, operated by the Natural Resources Conservation Service, has observed revegetation success rates of 90 percent or more in areas where tall-pot seedlings have been planted.

“These long-stem plant materials capitalize on the characteristics of riparian plants, which allows them to be planted deeper,” said Sundstrom. “This places their roots in moisture



*Deep-pot seedling containers allow for deeper, more extensive root systems than other seedling containers.* Courtesy of CSFS

that is available in most riparian areas, resulting in higher survival rates.”

Hatch says that while many nurseries already specialize in the production of native plants, most are not geared toward large-scale production of ecotype-specific plants in ideal containers or growth forms. However,

tall-pot seedlings grown elsewhere already

are in use by the Los Lunas Plant Materials Center to revegetate arid areas that would require extensive irrigation using standard potted seedlings. Hatch says Los Lunas was a pioneer in developing tall-pot technology for the West, and has provided multiple trainings to personnel and partners with the Tamarisk Coalition.

The CSFS Nursery initially will grow four native species targeted specifically for riparian restoration, which may include skunkbush sumac, boxelder, New Mexico privet, willow

baccharis, and silverleaf buffaloberry. Approximately 500 of each of the four species ultimately chosen will be grown at the nursery. As part of the agreement with the Tamarisk Coalition, some of the seedlings will be made available for specific restoration projects on the Dolores River in southwest Colorado.

The seed stock for the first round of plants comes from several sources. The Tamarisk Coalition provided sumac and boxelder seeds previously cleaned and stored by the Upper Colorado Environmental Plant Center, which the CSFS Nursery is currently “stratifying”—ripening or preparing for planting so that the seeds can germinate. After stratification, the seeds will be planted in deep pots and allowed to grow. The CSFS Nursery also has been in contact with the Colorado Parks and Wildlife seed storage facility and the CSFS Grand Junction District to discuss the possibility of obtaining seeds or cuttings of willow baccharis and silverleaf buffaloberry from the Western Slope.

Because of the time required for the plants to develop deeper root systems and taller stems, the first round of deep-pot seedlings will not be available to the public for three years; however, they may represent the best option for riparian replanting efforts in Colorado and other arid Western states.

“The main difference in raising these seedlings will be the size of containers and the length of time we must care for them before they reach the desired size,” said Sundstrom.





## About the CSFS Nursery

Deep-pot seedlings are hard to come by. In fact, Sundstrom and Hatch are not aware of any other large nurseries in the state offering them, so the Tamarisk Coalition is allowing the CSFS Nursery to keep the proceeds from the sale of these plants, in hopes that it can reinvest the capital needed to keep producing taller pot seedlings for ongoing riparian restoration around the state.

Landowners interested in purchasing CSFS seedlings can visit <http://csfs.colostate.edu> for more information, or contact the nursery at 970-491-8429. For more information about the Tamarisk Coalition, go to [www.tamariskcoalition.org](http://www.tamariskcoalition.org).

The CSFS seedling tree nursery provides approximately 40 varieties of low-cost seedling trees and shrubs to landowners who agree to use them for conservation purposes, and delivers orders to farmers, ranchers and rural landowners throughout Colorado each spring. Approximately 5,000 Coloradans plant CSFS seedling trees each year to create windbreaks, reforest after wildfire, enhance wildlife habitat, restore riparian areas, and achieve other conservation goals. ●

*The roots of many riparian plant species originate from the stem of the plant, which allows them to survive when buried deeper with each flood event.*

Courtesy of Greg Fenchel, Los Lunas Plant Materials Center



*Tall-pot seedlings establish more successfully in riparian areas than seedlings from shallower pots.*

Courtesy of Greg Fenchel, Los Lunas Plant Materials Center



# Water Research Awards

Colorado State University  
(July 16, 2013 to September 15, 2013)

- Abt, Steven R**, Civil & Environmental Engineering, USDA-USFS-Rocky Mountain Research Station – CO, Bedload Transport in Gravel-Bed Rivers and Channel Change, \$89,348
- Bau, Domenico A**, Civil & 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 Groundwater Flow Model, \$50,000
- Bestgen, Kevin R**, Fish, Wildlife & Conservation Biology, Colorado Division of Parks and Wildlife, Fountain Creek Flathead Chub, \$74,542
- Bestgen, Kevin R**, Fish, Wildlife & Conservation Biology, Colorado Division of Parks and Wildlife, Anthropogenic Changes to Colorado's Eastern Plains Streams & Their Impact on Connectivity for Native Fishes, \$25,168
- Bestgen, Kevin R**, Fish, Wildlife & Conservation Biology, DOI-Bureau of Reclamation, Evaluating Effects of Non-Native Predator Fish Removal on Native Fishes in the Yampa River (Project No. 140), \$85,976
- Bestgen, Kevin R**, Fish, Wildlife & Conservation Biology, DOI-Bureau of Reclamation, Monitoring Effects of Flaming Gorge Dam Releases on the Lodore and Whirlpool Canyon Fish Communities, \$61,211
- Bestgen, Kevin R**, Fish, Wildlife & Conservation Biology, DOI-Bureau of Reclamation, Population Estimate of Humpback Chub in Black Rock, \$5,000
- Bledsoe, Brian**, Civil & Environmental Engineering, Colorado Water Conservation Board, Investigation of the Effects of Whitewater Parks on Aquatic Resources in Colorado: Year 3, \$43,796
- Bledsoe, Brian**, Civil & Environmental Engineering, National Academy of Sciences, Design Hydrology for Stream Restoration and Channel Stability at Stream Crossings, \$350,000
- Caldwell, Elizabeth D**, CEMML, DOD-ARMY-Corps of Engineers, Stormwater Drainage Conveyance Support, \$73,000
- Caldwell, Elizabeth D**, CEMML, DOD-ARMY-Corps of Engineers, Stormwater Management Plan and Wastewater Compliance Study US Army Garrison, Hawaii, \$94,442
- Clements, William H**, Civil & Environmental Engineering, Colorado Division of Parks and Wildlife, Evaluating Restoration Effectiveness in the Arkansas River, \$28,600
- Clements, William H**, Civil & Environmental Engineering, DOI-USGS-Geological Survey, Mechanisms of Metal Uptake & Transfer in Stream & Riparian Food Webs, \$47,588
- Johnson, Brett Michael**, Civil & Environmental Engineering, Northern Colorado Water Conservancy District, Effects of Water Clarity and Other Factors on Aquatic Life of Grand Lake, Colorado, \$65,142
- Johnson, James Bradley**, Biology, EPA-Environmental Protection Agency, Phase 2 of Building the Colorado Watershed Approach: A Strategic, Multi-Agency Approach to Development of Stream Mitigation Protocols and Aquatic Habitats, \$117,331
- Kumar, Sunil**, Natural Resource Ecology Laboratory, DOI-USGS-Geological Survey, CSU Participation in USGS-NASA Habitat Modeling Activities, \$30,947
- Kummerow, Christian D**, CIRA, Yonsei University, South Korea, A Collaborative Effort to Improve Geostationary Products of Hydrologic Variables, \$38,438
- Loftis, Jim C**, Civil & Environmental Engineering, DOI-NPS-National Park Service, Southeast Coast Network Database Program, \$72,816
- Poff, N LeRoy**, Biology, DOI-USGS-Geological Survey, Effects of Water Management and Climate Change on the Dynamics of Native and Invasive Wetland and Riparian Plants in Western USA, \$100,751
- Sueltenfuss, Jeremy**, Colorado Natural Heritage Program, Trees, Water and People, Restoration Prioritization of the Cache la Poudre Watershed, \$31,850
- Waskom, Reagan M**, Colorado Water Institute, Colorado Cattlemens Association, Upper Gunnison Ranchers Self-Assessment Tools and Results Focused Dialogue of Agricultural and Environmental Stakeholders, \$18,976
- Waskom, Reagan M**, Colorado Water Institute, Colorado Water Conservation Board, Ag Economics & Water Resources: A Specialty Workshop, \$9,746
- Waskom, Reagan M**, Colorado Water Institute, Colorado Water Conservation Board, Poudre Basin Water Sharing Working Group Efforts Leading to Agreements, South Platte Basin, \$86,940
- Waskom, Reagan M**, Colorado Water Institute, DOI-USGS-Geological Survey, MOWS - Modeling of Watershed Systems NIWR-USGS Student Internship Program, \$10,000
- Waskom, Reagan M**, Colorado Water Institute, DOI-USGS-Geological Survey, WEBB- Water, Energy, and Biogeochemical Budgets NIWR-USGS Student Internship Program, \$40,219
- Waskom, Reagan M**, Colorado Water Institute, University of Colorado, SRN: Routes to Sustainability for Natural Gas Development and Water and Air Resources in the Rocky Mountain Region, \$49,470
- Winkelman, Dana**, Cooperative Fish & Wildlife Research, Colorado Division of Parks and Wildlife, Distribution & Impacts of Gill Lice in Colorado, \$33,500
- Winkelman, Dana**, Cooperative Fish & Wildlife Research, Colorado Division of Parks and Wildlife, Whirling Disease Resistant Rainbow Trout Introductions, \$36,301

# Calendar

## October

- 2-4 2013 WaterSmart Innovations Conference and Exposition; Las Vegas, NV**  
The largest urban-water efficiency conference of its kind in the world is presented by the Southern Nevada Water Authority and numerous forward-thinking organizations.  
[www.watersmartinnovations.com/index.php](http://www.watersmartinnovations.com/index.php)
- 7 Valuing Colorado's Irrigated Agriculture: A Workshop for Water Policy Makers; Colorado Springs, CO**  
The conference hosts will bring prominent economists of national renown to share expertise on policies, methods and approaches to the valuation of irrigation water as it is managed in the endeavor of agriculture.  
[www.coagwater.org](http://www.coagwater.org)
- 8-10 2013 Sustaining Colorado Watersheds Conference; Avon, CO**  
Water: What is the New Normal?  
[www.coloradowater.org/Conferences](http://www.coloradowater.org/Conferences)
- 15-16 2013 Natural Gas Symposium; Fort Collins, CO**  
Provide diverse stakeholder perspectives on the emerging unconventional energy markets with a particular emphasis on the natural gas economy and impacts in Colorado, United States and around the globe with the goal to educate, inform and discuss complex issues while finding variable solutions. [www.naturalgas.colostate.edu](http://www.naturalgas.colostate.edu)

## November

- 6-7 2013 Upper Colorado River Basin Water Conference; Grand Junction, CO**  
Sharing Experiences across Borders  
[www.coloradomesa.edu/watercenter/UpperColoradoRiverBasinWaterForum.html](http://www.coloradomesa.edu/watercenter/UpperColoradoRiverBasinWaterForum.html)
- 13-15 NWRA Annual Conference; San Antonio, TX**  
[www.nwra.org](http://www.nwra.org)

## December

- 11-13 Colorado River Water Users Association Annual Conference; Las Vegas, NV**  
[www.crwua.org/AboutUs/FutureConferences.aspx](http://www.crwua.org/AboutUs/FutureConferences.aspx)

## January

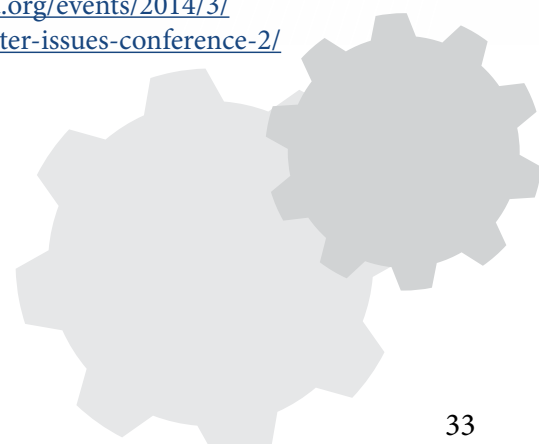
- 29-31 Colorado Water Congress 2014 Annual Convention; Denver, CO**  
The Colorado Water Congress is the premier water industry event in the state, attracting 500+ attendees that convene for networking and collaboration on the important water issues of the day. [www.cowatercongress.org/](http://www.cowatercongress.org/)

## February

- 18-19 2014 Tamarisk Coalition Research and Management Conference; Grand Junction, CO**  
Land and resource managers, private land owners, researchers, students, and others will convene in a collaborative venue to learn about and discuss the latest trends in riparian restoration and ecology.  
[www.tamariskcoalition.org/programs/conferences/2014](http://www.tamariskcoalition.org/programs/conferences/2014)

## March

- 30-2 American Water Works Association 2014 Sustainable Water Management Conference; Denver, CO**  
Presenting solutions for balancing the benefits of conservation with the costs, managing infrastructure, developing robust supply models and watershed management plans, water reuse, resource management, green infrastructure, and more.  
[www.awwa.org/conferences-education/conferences/sustainable-water-management.aspx](http://www.awwa.org/conferences-education/conferences/sustainable-water-management.aspx)
- 31-2 2014 Federal Water Issues Conference; Washington, D.C.**  
National Water Resources Association presents Federal Water Issues  
[www.nwra.org/events/2014/3/federal-water-issues-conference-2/](http://www.nwra.org/events/2014/3/federal-water-issues-conference-2/)



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At the Fort Collins OptiEnz Sensors Lab, researchers test for the concentration of organic chemicals in water samples.  
Photo by Lindsey Middleton

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