Colorado Water

Colorado State University

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Highlights

2 **Lab-on-a-Chip Analyzers for Water Quality Assessment**
Charles S. Henry and Kenneth Ogan

5 **Biosensors: A New Way to Measure Water Quality**
Ken Reardon

7 **Flavors of the Drinking Water**
Pinar Omur-Ozbek

10 **Nutrient loads to the Cache la Poudre Watersheds**
Ji-Hee Son, Kenneth Carlson and Stephen Goodwin

15 **Sociology and Changing Water Governance in Colorado**
Peter Leigh Taylor

18 **Interview With CDPHE Water Quality Control Division Director, Steve Gunderson**
Lindsey A. Knebel

20 **USDA Irrigation Lab Celebrates 100 Years**
Tom Trout

21 **History of the USDA-ARS Water Management Research Unit: 100 years of Innovation and Collaboration**
Harold Duke, Gordon Kruse, Tom Trout and Mary Brodahl

26 **CSU Student Joseph D. Vassios Receives Award**

In Every Issue

1 **Editorial**
Reagan Waskom

25 **History**
The Crane Trust: From Conflict to Cooperation
Maren Thompson Bzdek

27 **Climate Center**
Drought—Never Too Far Away
Nolan Doesken

28 **Water Outreach Update**
Deep Nitrogen Removal with Sunflowers
Joel P. Schneekloth

30 **Meeting Briefs**
Colorado and Arizona Water Institutes Plant Seeds for Agricultural/Environmental Collaboration
MaryLou Smith

32 **CSFS**
Fighting Invasive Plants in the Arkansas River Basin: It's All About Partnerships
Jana Gregg, J.R. Phillips, Patty Knupp, Colorado State Forest Service La Junta District, Dr. Dan Bean

36 **Water Resources Archive**
A Decade Later: Celebrating Student Assistants
Patricia J. Rettig

38 **Faculty Profile: Greg Perry**
Lindsey A. Knebel

40 **Water Research Awards**

41 **Calendar**

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Front Cover: Colorado State University Civil and Environmental Engineering Professor Timothy Gates and graduate student Greg Steed take measurements with a multi-probe in Cottonwood Creek west of Buena Vista, Colorado, July 5, 2011 as a part of Gates's Arkansas River basin monitoring and modeling research project. Photo By Bill Cotton

This Page: Aspen tress in Durango, Colorado. Photo by Kyle Thompson

Editorial

by Reagan Waskom, Director, Colorado Water Institute

Nutrient standards, boil water advisories, swim beach closures, mercury advisories on fish—are these mere inconveniences, unnecessary interference, or critical for protecting human and environmental health? One current perspective is that the U.S. Environmental Protection Agency (EPA) is hog-tying our economy with new rules, delayed permitting processes, and overzealous enforcement. Another point of view is that recent court rulings and agency guidelines have jeopardized crucial water resources, wetlands, and wildlife habitat.

Water quality protection was at the heart of the environmental movement in the late 1960s. The widely publicized debris fire on the Cuyahoga River in Ohio in 1969, the Santa Barbara oil spill that same year, and the DDT-caused decline of the bald eagle became symbols of the social movement that followed on the heels of several best-selling books such as Silent Spring, which warned of impending ecological disaster.

Within the next few years, the U.S. Congress passed a host of environmental laws, including the National Environmental Policy Act of 1970, which established the U. S. EPA; the Water Pollution Control Act Amendments of 1972, which became known as the Clean Water Act; the Endangered Species Act of 1973; and the Safe Drinking Water Act of 1974. These laws enacted regulations to protect water, watersheds, and wildlife. Perhaps as importantly, they provided communities with loans and funding for modernizing treatment facilities to meet standards. They also provided for water quality research, standard setting, and monitoring. Now the question is posed—have they over-reached their original mandate?

As Colorado Water Quality Control Division director Steve Gunderson remarks in his interview in this issue (page 18), water quality remains an important issue in Colorado, but regulation costs people money. Nobody seems to like this aspect, particularly when they are the ones to pay. As the U.S. economy recovers, we look for quick fixes, such as relaxing regulations. As an alternative perspective, water quality is a critical aspect of Colorado's economy, which is heavily driven by recreation, quality-of-life related growth and spending, and natural resource extraction and amenities. Both perspectives have some basis. The challenge is to protect the common-pool resources we all rely upon without unduly harming the economy.

Colorado State University has been working on water quality related research and outreach for the past half century, often in close collaboration with state water managers. This issue of Colorado Water reports on some recent advances in water quality, notably novel approaches for real-time monitoring. CSU Professor Chuck Henry reports on work his research unit is doing to create "lab on a chip" technology (page 2). Professor Ken Reardon reports on his group's development of biosensors that can be deployed in a watershed or in groundwater to monitor for changes or contamination (page 5). These technologies are not intended to replace analytical laboratories, but rather help alert us to what may be occurring real-time at sites of interest. This has applications for discharge management and protecting watersheds, as well as implications for homeland security.

Dr. Pinar Omur-Ozbek points out in her article that human senses are remarkably sensitive to odors and tastes that alert us to the possibility of contamination (page 7). Other contaminants like nitrate or viruses have no taste or odor at levels known to be harmful to humans, hence the need for analytical methods for detection. The emerging contaminants mentioned by director Gunderson in his interview pose a particularly troublesome water quality problem, as they are often synergistic at extremely low concentrations, compounding the difficulty of management and regulation.

And finally, what contemporary discussion of water quality would be complete without including the current struggle to find cost-effective ways to manage nutrients? An astounding amount of time and effort has been dedicated to this discussion in Colorado over the past couple of years as we move toward nutrient standard hearings for nitrogen and phosphorus in March of 2012. The environmental and health-related problems are real and significant, as are the costs of nutrient control. It is all about working in the midst of competing interests and limited resources to find that right balance.

Lab-on-a-Chip Analyzers for Water Quality Assessment

Charles S. Henry, Chemistry and Chemical & Biological Engineering, Colorado State University
Kenneth Ogan, President, Advanced MicroLabs LLC

Introduction

Water plays critical roles in society, from drinking and cooking, to food and industrial production, to electric power generation, and its importance cannot be understated. While the total amount of water in the hydrologic cycle is essentially constant, the availability of clean, usable water can be limiting. Thus, water is not used up, but rather, becomes contaminated with biological and chemical components, most of which must be removed before re-use. More and more notice is being taken of the water usage required in the production of products (their "virtual water" content).

Of course, the availability of clean, pure drinking water is first and foremost on most people's minds. Beginning in the 1970s with the Clean Water Act, limits have been placed on the content of water discharges, and improved water quality objectives have been mandated. The Environmental Protection Agency (EPA) regularly updates its drinking water standards and periodically adds emerging contaminants to its list of substances to be studied for possible inclusion as regulated contaminants. As we learn more about the effects of these contaminants on human health, more will be added to the P-list of regulated pollutants.

Thermoelectric power plants utilize massive quantities of water in generating electrical energy—approximately 195,000 million gallons per day (MGD) of freshwater withdrawals, or 49 percent of all water withdrawals in the U.S., according to a recent United States Geological Survey (USGS) report. This is more than that used in agricultural irrigation, and the demand for power is growing faster than our population. For example, a 500 MW power plant that employs once-through cooling uses over 12 million gallons per hour of water for cooling and other process requirements. Furthermore, some of this water must be highly purified in order to prevent corrosion of key elements in the power plant. It has been estimated that about $14.5 billion is spent annually in the U.S. to combat corrosion in steam power systems (including industrial systems), and that scale and deposits in these systems cause another $20 billion/year in lost plant efficiency and lost power generation capacity.

In all of these cases, the ability to measure the purity of the water is central to understanding how to treat the water and/or how safe water is to use. Water testing has been done in traditional chemical laboratories, laboratories that are filled with expensive equipment designed to measure very low levels of contaminants. Because of their costs, however, the availability of this equipment is typically limited to centralized facilities and contract laboratories. In some cases, this approach works well, but in others, measurements need to be made at the site of use (a drinking water treatment plant, for example). These operating environments are much more challenging and require a different approach to the measurement chemistry. As a result, only a few analyzers have been developed for this critical environment.

In the following section, we present a new method for measuring water quality across a broad range of applications, including drinking and industrial water. The new method is referred to as "lab-on-a-chip," and, as the name implies, it has a goal of taking much of what is done in a traditional laboratory and reducing it to a "chip" that is the size of a credit card. This new technology has been making significant in-roads into a number of important technology fields, including drug discovery and development and medical diagnostics, because it is faster, cheaper, and easier to use than traditional systems. At Advanced MicroLabs, we have begun to apply this exciting new technology to improving and monitoring the quality of water.

Lab-on-a-Chip Technology

As discussed above, lab-on-a-chip or LOC technology seeks to miniaturize chemical analysis instrumentation. To do this, principles of miniaturization learned in the electronics industry for the production of integrated circuits are applied to create fluidic circuits, or circuits that transport fluids instead of electrons. Figure 1 shows a picture of one type of LOC device used to measure the concentration of a persistent pollutant, perchlorate, in drinking water. The chip is roughly one by three inches in size and is made by a combination of embossing (a method common to all plastic devices) and electrical engineering.

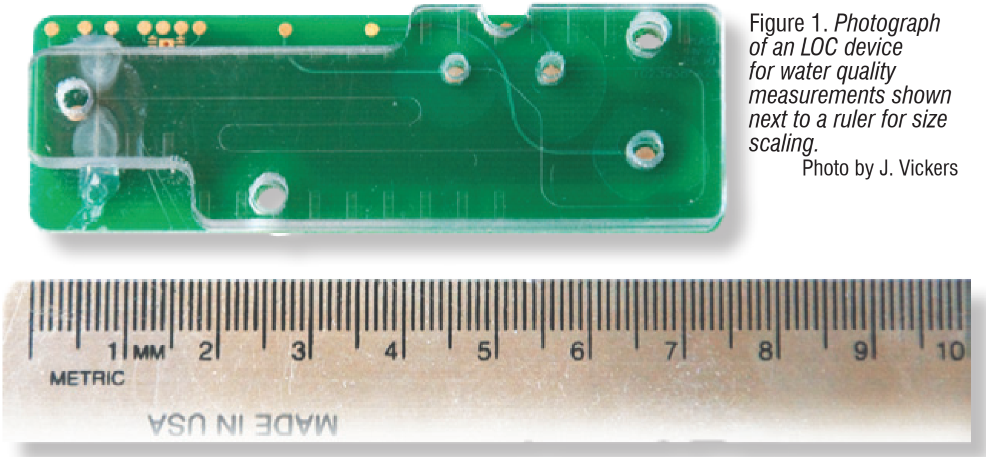


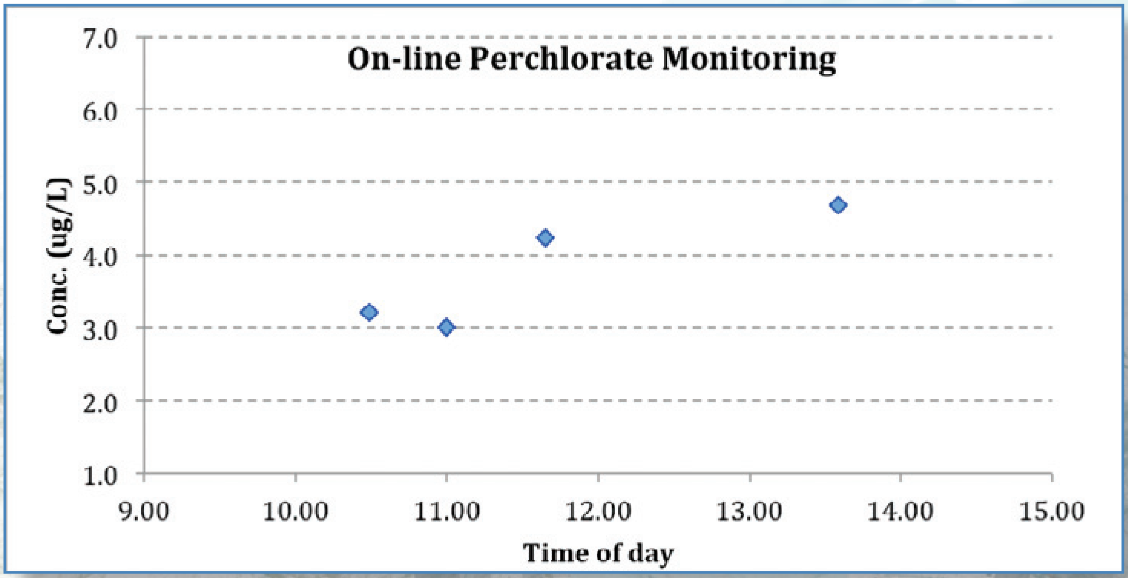
Figure 1. *Photograph of an LOC device for water quality measurements shown next to a ruler for size scaling.*
Photo by J. Vickers

LOC technology has significant advantages for water measurements. First, the overall cost per analysis is much less than traditional analysis systems. Second, by making the system much smaller than traditional analysis technologies, it can be operated much faster. As a direct result of these two features, measurements of perchlorate in-line at a drinking water site can be made for the cost of a roughly $20/measurement. Furthermore, the results can be obtained in near real-time, which enables immediate action to be taken in the case of an unexpected plume of pollutant. In the traditional approach, each measurement costs upwards of $200 to make and requires the sample to be sent to a centralized laboratory with the results coming back 1-2 weeks later (a "rush" sample might be analyzed within 1-2 days). During this time, pollutants that are at higher than acceptable levels have been passed on to the consumers.

An example of tracking water pollution in drinking water is shown in Figure 2. In this example, perchlorate is being measured online right after a treatment tank as a function of time of day. The advisory limit for perchlorate is 4 μg/L, and these results show that the concentration rises over time. The user can view the beginning of failure of the treatment system in real time. Traditional methods for measuring perchlorate take roughly two weeks between the time the sample is taken, the measurement made, and the results returned to the drinking water plant. In this time, the concentrations would have continued to increase with the water released to thousands of households and businesses. This is an example of how online monitoring enabled by LOC technology can provide a safer drinking water supply.

A similar story can be made for water quality measurements in power plants, such as the natural gas power plant shown in Figure 3. Table 1 shows water use statistics for traditional fossil fuel power plants and the impact of more effective water treatment on overall water consumption. By measuring chemicals such as chloride and sulfate at the plant in real time followed by appropriate treatment of the

Figure 2. *Plot of perchlorate concentration as a function of time for online monitoring of drinking water at a treatment plant.*



	Conventional	LOC Optimization
Average Water Consumption per kWh	0.398 gal	0.398 gal
Average Water Consumption at 350 MW	139,222 gal	139,222 gal
Average Water Consumption per Day	3,341,333 gal	3,341,333 gal
Water Treatment Optimization	0%	15%
Annual Water Consumption Saving		182,938,000 gal

Table 1. *Comparison of water usage at a conventional fossil fuel power plant and the estimated water savings through optimization of the treatment chemistry.*

water, it is estimated that the water can be used 15 percent longer before discharge. This would result in a water savings alone of 182 million gallons per year per power plant. This savings would leave more water for human use as well as maintaining river and stream levels.

Summary

LOC technology, developed as a new field of measurement science in the last 20 years, has the potential to contribute significantly to water related issues. The technology is faster, cheaper, and in many cases more flexible than traditional laboratory approaches.

Acknowledgements

The National Science Foundation and the National Institutes of Health supported this work.

Figure 3. *Photograph of a natural gas power plant.*

Courtesy of Charles S. Henry

Biosensors: A New Way to Measure Water Quality

Ken Reardon, Chemical and Biological Engineering, Colorado State University

Many situations exist in which water practitioners want to know the concentrations of organic chemicals in water, including evaluating whether a site is characterized as contaminated and/or whether a water treatment process is effective. But obtaining this information has traditionally involved collecting a water sample and analyzing it in a laboratory, usually off-site. Laboratory analyses involve various steps before the sample is analyzed in a gas chromatograph or similar instrument, and thus results are expensive and not readily available. Undesired outcomes of this situation include cases in which relatively few data are available to make important decisions (e.g., about the design of a remediation system), and that poorly functioning treatment systems are not corrected quickly.

About 15 years ago, my laboratory at CSU began to develop biosensors to make it easier to measure this aspect of water quality. Our goals were to develop sensors that could provide continuous measurements of an organic chemical concentration and that could be placed directly in the water to be measured. The ability to take the sensor to the water (rather than removing a sample of water) is important, because sampling can skew the results in several ways.

A biosensor is a device that contains a biological detection element, usually an enzyme or antibody, as well as components that allow the biological detection event to be converted into a useable signal or number. We used our knowledge of the ways in which bacteria break down pollutants to develop enzymatic biosensors, and we chose to interface this with an optical method to produce a signal, since that approach often is more sensitive and has less environmental interference than electrical methods. These sensor systems consist of three parts (Figure 1): an optical-electronic hardware unit, one or more biosensor tips, and optical fiber connectors. Sensing is done using a two-layer detection element immobilized on the end of the biosensor tip (Figure 2). One layer is a fluorescent dye, and the other layer contains specific enzymes. The enzymes catalyze a reaction with the chemical of interest (the analyte), and the products of that reaction change the fluorescence properties of the dye. Those changes in fluorescence are detected and correlated to the analyte concentration. We recently started OptiEnz Sensors LLC to commercialize this technology.

Important features of the biosensor system are:

- Versatility: By matching enzymes and fluorescent dyes, biosensors for a wide range of organic chemicals can be constructed. The biosensors can also be designed to cover different concentration ranges.
- Ease of use: Measurements with these biosensors are simple and require no reagent or pretreatment. The tip of the biosensor is simply placed in the sample to be measured, and the analysis time is on the order of minutes.
- Ability to measure continuously, in place and online: These biosensors can be placed in a process vessel or in a process flow and can provide continuous, real-time measurements of the analyte concentration. Such information can then be used for process control or quality assurance/control.
- Low detection limits: Detection limits in the biosensors developed to date range from µg/L to sub-ng/L.
- Small size: The biosensors are based on plastic optical fiber that is about one millimeter in diameter, and can thus easily be placed in small wells.
- Multiplexing: Our optical-electronic hardware unit can monitor up to eight biosensors simultaneously, meaning that several contaminants can be measured.

To date, we have developed biosensors for benzene and toluene (the most water soluble components of petroleum fuels), organic solvents such as 1,2-dichloroethane and trichloroethene, pesticides (atrazine, lindane, paraoxon), and others. With funding from the Department of Defense, we conducted a field demonstration of this biosensor technology that included placing biosensors in groundwater wells (Figure 3) to measure the concentration of 1,2-dichloroethane at different depths, information that was extremely difficult to obtain using traditional methods.

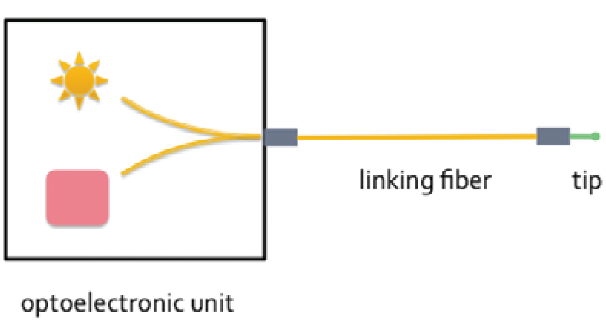


Figure 1. *A schematic of the OptiEnz biosensor system shows the optoelectronic hardware, optical fiber connector, and replaceable biosensor tip. Up to eight biosensors can be used simultaneously.*

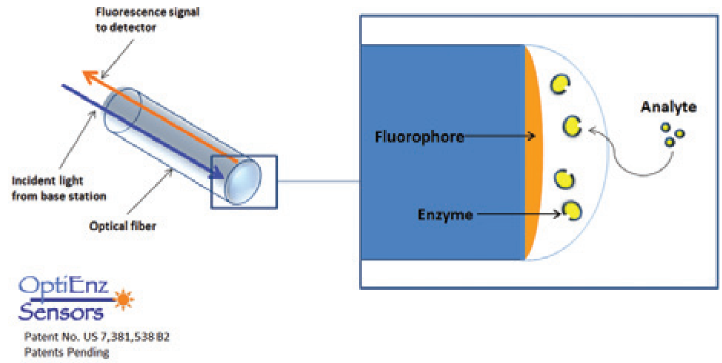


Figure 2. *Schematic of the OptiEnz biosensing concept. Enzymes on the biosensor tip catalyze a reaction of the analyte (the chemical of interest), and the change in the levels of reaction products and reactants alters the fluorescence of a chemical layered on the tip.*

How can these biosensors be used? We started the development of this technology with a focus on the characterization and remediation of contaminated sites, including rapid, on-site measurement of contaminants during the characterization phase (saving time and money over the traditional approach of sending samples to an analytical laboratory); rapid, on-site quarterly monitoring; and online monitoring of pump-and-treat remediation treatment processes to enable them to be operated more efficiently. Recently, we've become aware of many other application scenarios, including monitoring wastewater and drinking water treatment plants, monitoring in sentry wells or at indicator points in a watershed to provide early warning to the presence of contamination, and the measurement of contaminant fluxes in the subsurface. OptiEnz is currently performing product development work at CSU and plans field demonstrations at three sites in the U.S. With more hard work and some luck, this CSU technology truly can provide a new way to measure water quality.

Figure 3. *This device was developed to enable the biosensors to be used in groundwater monitoring wells. The plastic housing protects the sensor tip and weights in the bottom, allowing the assembly to be lowered. This apparatus has been used to measure contaminant concentrations at different depths, revealing unexpected stratifications of contamination in an aquifer.*

Courtesy of Ken Reardon

Flavors of the Drinking Water

Dr. Pinar Omur-Ozbek, Civil and Environmental Engineering, Colorado State University

Humans have been using their sensory perceptions to find food and water and to protect themselves from dangers since they first started walking the earth. This is still the case today as we judge the safety and cleanliness of the water we drink and the food we eat by assessing its aesthetic qualities. Most of the time, our judgment is right on the spot and prevents us from consuming unhealthy food products.

If we look at it from the drinking water perspective, we have to understand the perception of taste and odor and its relation to water quality. When we take a sip, the water immediately makes contact with our taste buds that send signals to our brain to process the taste perception(s). Our brain can indicate whether the water has a sweet, salty, sour, or bitter taste. These taste perceptions are produced by the dissolved compounds in the water that could be harmful or as innocent as table sugar or table salt. If there are volatile (aromatic) compounds present in the water we sip, they will travel to the back of our nasal passage (known as the retronasal passage) and reach our olfactory bulbs, creating an odor sensation.

When we add lemon slices to our pitcher of water, the volatile compounds are released into the water and create the lemony "odor" in our mouth. The combined perception of taste and smell form the *flavor* perception we get when we consume almost any food and beverage. Separation of the taste and smell perceptions may be achieved by tightly closing the nose when consuming a piece of fruit or candy. If you try this, you will notice that you can only perceive the four basic tastes and almost no flavor.

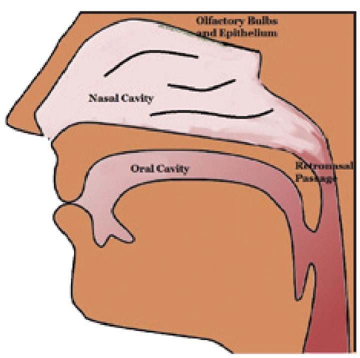


Figure 1. *Flavor perception is a combination of taste and smell.*
Adapted from figure by Dr. Andrea M. Dietrich, Blacksburg, VA

Most of the water contaminants have off-flavors that warn the consumers of their presence. Some of them only cause aesthetic issues by imparting earthy, dirty, musty notes to the drinking water. These compounds, including geosmin (that come from the Greek words ge: earth, osmi: smell) and 2-methylisoborneol (2-MIB) are produced in the surface waters such as lakes, reservoirs, and rivers by the blue-green algae and are detected by humans at 5 ng/L levels (1 ng/L refer to about a one gallon milk jug emptied in the Horsetooth Reservoir). Although geosmin and 2-MIB are very unpleasant when present in drinking water and will cause consumer complaints, they are the major aroma compounds for some the foods we love. Geosmin is found in sugar beets, giving them the distinct earthy note, and 2-MIB is found in coffee. U.S. Environmental Protection Agency (EPA) does not have any guidelines for geosmin and 2-MIB; however, Japan and South Korea set 10 ng/L as a goal to ensure consumer satisfaction.

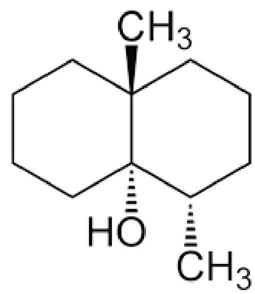
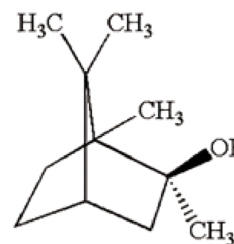


Figure 2. *Chemical structures of geosmin (left) and 2-MIB (right)*



Common water contaminants that are removed by the conventional water treatment operations are at mg/L levels, which is a million times more than the detection limits of geosmin and 2-MIB. Hence, more advanced treatment methods are required for the proper removal of these odorants. Another issue with geosmin and 2-MIB is their periodically high production, which requires an on demand treatment system. During late summer months and early fall, algae blooms reach their peak and start releasing these compounds, and the problem gets worse when the algae die and decompose. Water treatment utilities that have surface waters as their source need to monitor the presence of algae and such odorants throughout the summer to control the blooms and hence the odorant production. Monitoring efforts can include the identification of the algae that produce the odorants and instrumental and/or sensory analysis of geosmin and 2-MIB. The instrumental analysis of odorants is time consuming and costly and hence, water utilities have started to train for and utilize the Flavor Profile Analysis (FPA) method to test their source and finished waters. This method includes trained panelists smelling and/or tasting water samples to identify the flavors and associated intensities. The intensity rating relates to the concentration of the contaminant, and the water utility may adjust their treatment units accordingly.

The most commonly applied treatment method for removal of geosmin and 2-MIB is the use of powdered or granular activated carbon (similar to the material in home filtration systems). Odorant removal efficiency depends on many factors, including the concentration of the odorant, activated carbon (AC) type and dose, and source water quality (other organic compounds may fight for the sites on the AC). Recent research conducted at CSU aimed to identify the effective powdered activated dose (PAC) for removal of geosmin from Horsetooth water. Horsetooth samples were spiked with selected geosmin concentrations and were treated with various PAC doses. The samples were mixed for two hours and the water was analyzed at 15 min intervals to determine the removal over contact time. The results indicated that the AC dose plays a more important role in odorant removal than the contact time between the AC and the odorant. Also, only a small decrease in removal efficiency (8-14 percent) was observed when other natural organic compounds were present in the water samples tested.

Some of the water contaminants may not cause any aesthetic issues but may be a major health concern, and algal toxins belong to this category. However, researchers reported that the algal toxins usually co-occur with geosmin and 2-MIB, and therefore the toxins may be monitored by testing for those odorants. Algal toxins are very potent, and the World Health Organization has guidelines for the most common type: microcystins at 1 μg/L. Microcystins may attack the nervous system, kidney or liver, or just may cause skin irritations. Microcystins can also be removed by activated carbon and other advanced treatments, such as ozone and hydrogen peroxide, and research is underway at CSU to determine the effective doses and conditions for effective treatment.

Metals that may be present in source and treated drinking waters, such as iron and copper, produce an unpleasant metallic taste. Iron is responsible for the beautiful red color of the mountains in Colorado (which also named the state, "color rojo") and may end up in the groundwater as the water percolates through the earth's crust. Copper, on the other hand, is mainly introduced to tap water by the corroding infrastructure.

EPA has secondary maximum contaminant levels for iron and copper in drinking water at 0.3 mg/L and 1 mg/L, respectively, to prevent aesthetical issues. If consumed at higher concentrations, iron and copper cause nausea and abdominal cramps and in severe cases may lead to liver and kidney damage. To prevent the aesthetical issues (including discolored water) and consumer complaints, water utilities precipitate out the dissolved iron and copper from the drinking water by the conventional water treatment units. Utilities may try to achieve the

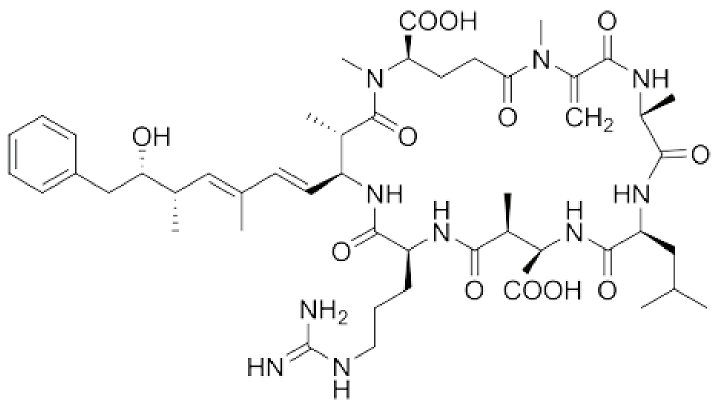


Figure 3. *Chemical structure of microcystin-LR*

levels set by the EPA; however, recent research indicated that the humans are more sensitive to iron and copper than suggested. The sensitivity of the humans to iron and copper was determined by the one-of-five sensory test. Participants tasted the samples in five cups where four contained taste free water and one was spiked with iron or copper. The concentration of the tested metal was decreased, and the lowest concentration that a participant could detect was noted as their threshold (detection) concentration. Results showed that the average threshold concentrations for 27 participants were 0.031 mg/L for iron and 0.61 mg/L for copper. The findings clearly indicate that

Figure 4. *Iron gives the mountains and rocks in Colorado their beautiful red color.*
Photo by Pinar Omur-Ozbek

Figure 5a, b. Participant tasting an iron solution at 10 mg/L with her nose closed (left) and open (right).
Photo by Pinar Omur-Ozbek

if the utilities want to serve the best quality water to their customers, they need to understand the detection levels of the contaminants and may need to treat them further than the aesthetic guidelines. The perception of metallic taste was also investigated during threshold studies with participants tasting the water samples spiked with iron and copper once with their noses closed and once open. Results showed that the metallic perception of iron and copper have a significant odor component. Participants only reported bitter and salty tastes for the metal solutions even at 10 mg/L and as soon as they removed the clips, they couldn't stand the strong metallic flavor. This agrees well with the common knowledge that the humans can detect odors at much lower concentrations compared to tastes, and the metallic odor component means iron and copper are detected at lower concentrations than expected.

Even though the drinking water utilities do their best to provide the best quality drinking water to their customers, presence of low levels of contaminants may affect the perception of drinking water. Utilities need to understand the sensitivity of the population to contaminants of interest and should apply instrumental and sensory analyses to monitor the presence of such compounds in their source and treated water to adopt the best treatment and mitigation techniques. Next time you take a sip of your tap water, pay attention to the crisp taste and please remember that we are very lucky to have great source waters in Colorado and very involved water treatment utilities.

Nutrient loads to the Cache la Poudre Watersheds

Ji-Hee Son, PhD Candidate, Kenneth Carlson, Associate Professor,
and Stephen Goodwin, PhD Candidate, Civil and Environmental Engineering, Colorado State University

Nutrients (nitrogen and phosphorus) are necessary for the growth of aquatic organisms, but when excess amounts are discharged into surface water, the biomass of phytoplankton starts to increase and shifts to bloom-forming species that may be toxic. As the biomass of algae increases, water transparency decreases and taste, odor, and water treatment problems become possible. Microorganisms decompose algae when they die, resulting in dissolved oxygen depletion and thus death of living organisms, fish kills, and deterioration of the aesthetic value of water bodies. This event, "eutrophication," is one of the top five causes of water quality impairment of rivers and streams in the United States along with pathogens, habitat alteration, organic enrichment, and unknown-impaired biota.

Nutrients can enter the watersheds from either point or nonpoint sources. Point source nutrients come from well-identified sources such as wastewater treatment plants (WWTPs), but nonpoint source nutrients come from diffuse and difficult to indentify sources such as storm water from urban areas and agricultural runoff from concentrated animal feeding operations (CAFOs), pasture lands, and cultivated crop lands.

U.S. Environmental Protection Agency (EPA) encourages states and tribes to develop numeric nutrient criteria for their watersheds, and the Colorado Department of Public Health and Environment (CDPHE) has been making an effort to establish nutrient criteria of the state. The proposed limits are 0.16 and 2mg/L for TP and TN, respectively, in the warm river waters. The Cache la Poudre (CLP) River Basin is located in Front Range of Colorado and is a unique place to study occurrence and transport of nutrients, since pristine river water comes from the Rocky Mountains and flows through urban and agricultural area before it converges into the South Platte River (Figure 1).

Five WWTPs are located in the study area, and the Mulberry Water Reclamation Facility (MWRF) is located most upstream and discharges effluent before sampling point 6. However, the facility was offline during events 1-10 in the study due to renovation work. MWRF sent water to the Drake Water Reclamation Facility (DWRF) during that time, and restarted operation in July 2011 (study event 11). For events 1-10, WWTPs discharge effluents were clustered between sampling point 8 and 9 except the Windsor Wastewater Treatment Plant (WiWWTP). Effluent from WiWWTP flows into the river before sampling point 11. During the study period, DWRF had the largest capacity at 23 million gallons per day (mgd), with an annual average flow of 12 mgd. The capacities of the Boxelder Sanitary District (BSD), South Fort Collins Sanitary District (SFCSD), and WiWWTP were in the range of 2.8-4.5 mgd, and average annual flows were in the range of 1.1-2.5 mgd.

River water and riverbed sediments were collected from thirteen sampling locations selected from the pristine area upstream of the agricultural area and downstream along the CLP River to study nutrient load inputs to the

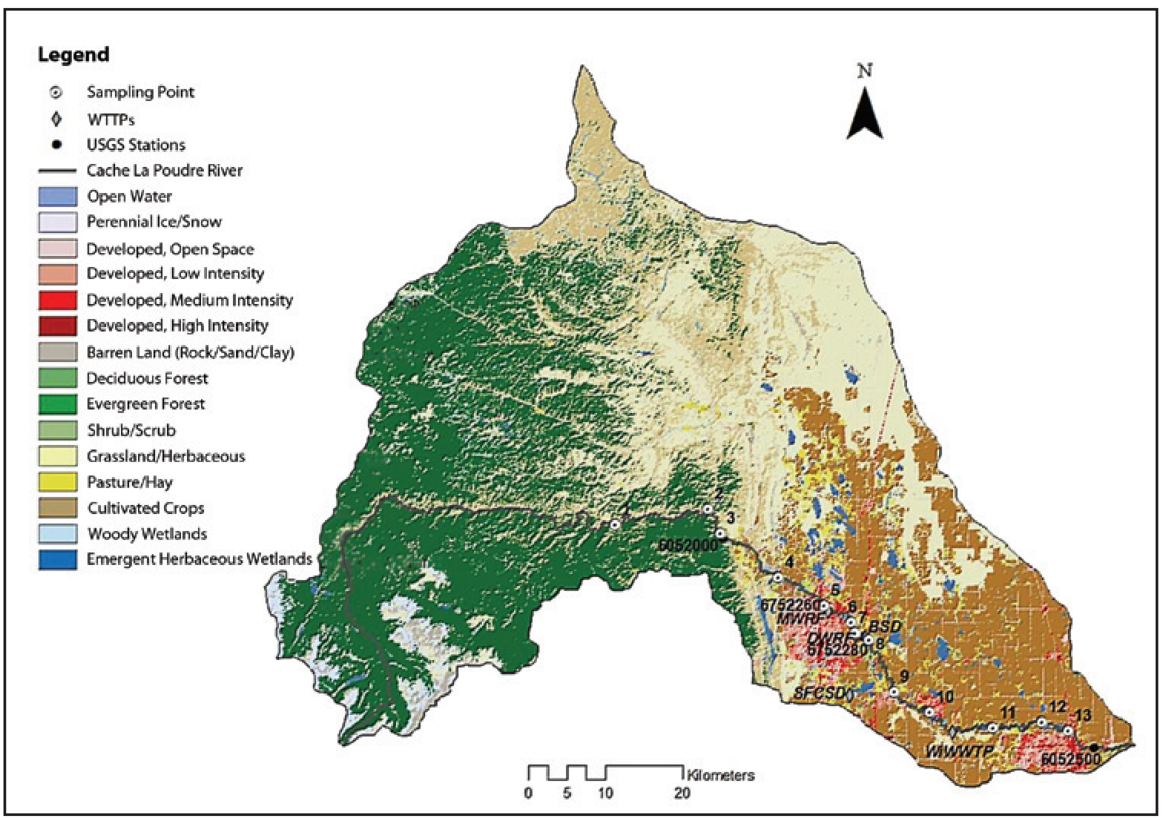


Figure 1. *Map of USGS stations, WWTPs, and sampling points along the Cache la Poudre River and land use of the Cache La Poudre River Basin.*

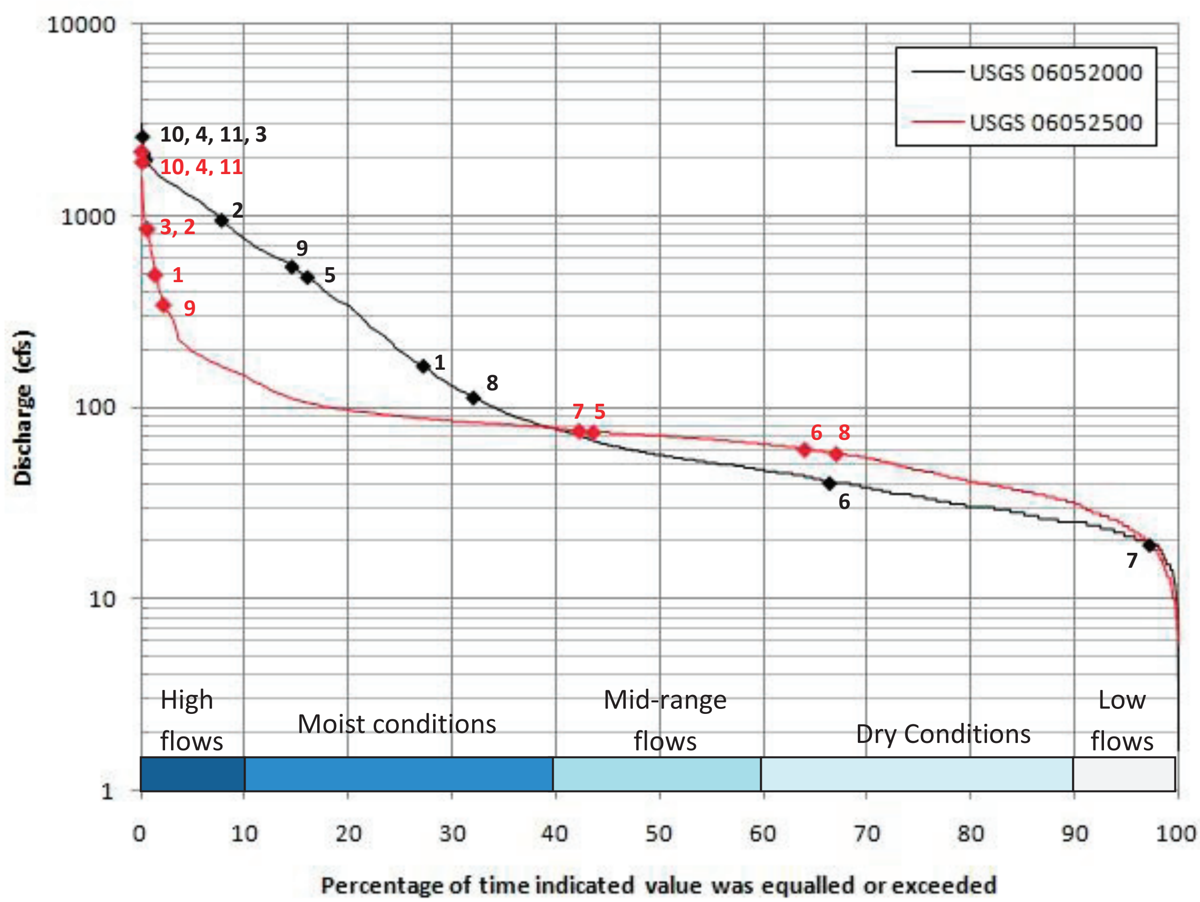
watersheds from March 2010 to July 2011. Sampling dates were chosen to capture all five classes of hydrologic conditions: high flows, moist conditions, mid-range flows, dry conditions, and low flows (Figure 2). The flow duration curve was created using the 100-year flow data collected from the nearest USGS stations upstream (06052000) and downstream (06052500) of the study area. As seen in Figure 2, flows upstream and downstream are not matching because of water transfer from upstream and return flows to downstream.

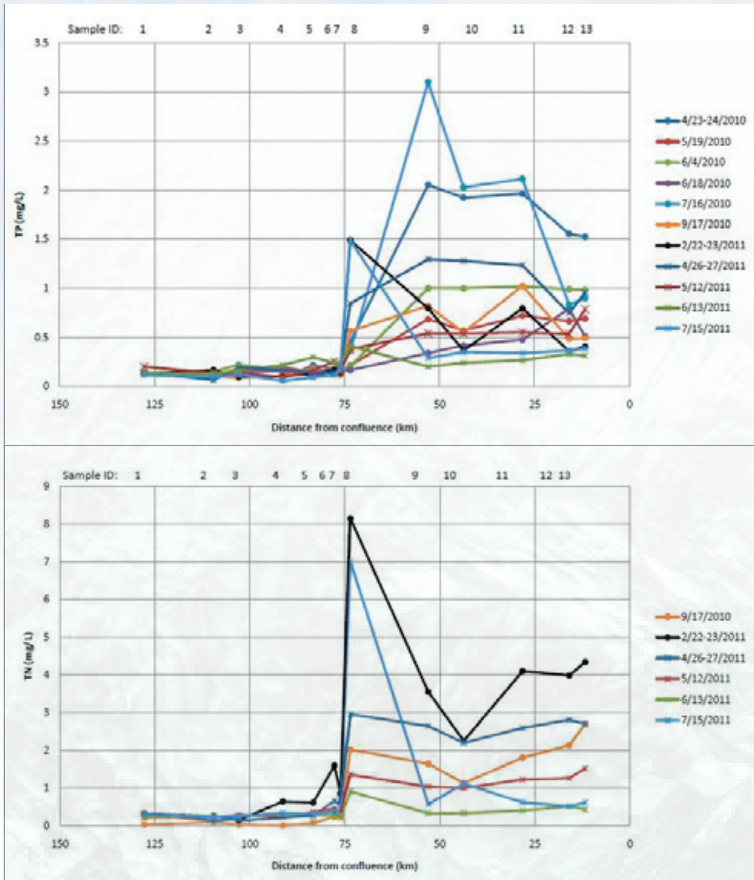
Total phosphorus (TP) and total nitrogen (TN) concentrations (mg/L) were measured using a Hach TP reagent set and Shimadzu TN analyzer in the laboratory, and the daily load (kg/d) was estimated using the flow data on each event date from the closest USGS stations to the sampling sites. Nutrient loading limits for the corresponding flow rate in the river were calculated using the proposed nutrient concentration limits for the warm river water. Total nutrient loads from WWTPs were estimated using average total annual effluent flow and nutrient concentrations from the WWTPs.

Phosphorus concentrations upstream of WWTPs (sample ID 1-7 for events 1-10; ID 1-5 for event 11) were relatively constant, falling in the range of 0.06-0.30 mg/L with 0.044 standard deviation (Figure 3). However, downstream of the major WWTP inputs (sample ID 8-9) where there are significant urban and agricultural influences (sample ID 8-13 for event 1-10; ID 6-13 for event 11), the TP concentrations increase significantly. The first peak was observed at a maximum of 1.49 mg/L downstream of BSD (sample ID 8) except for high flows when dilution is more influential. The second peak was downstream of Fossil Creek Reservoir (sample ID 9) where MWRF, DWRF and SFCSD discharge their effluents for events 1-9 into the river. This peak's TP concentration ranged from 0.20 to 3.1 mg/L. Downstream concentrations were in the range of 0.12-3.1 mg/L with 0.554 standard deviation.

The profile of nitrogen concentration was less dynamic than TP. It constantly had peaks at sample site 8 for all events, and the concentrations were attenuated through sample site 9 and increased downstream except at the highest flow event, event 11. Upstream TN concentrations

Figure 2. *Percentage of flow exceedance curve and flow rates and hydrologic conditions on the sampling event dates. Discharge of event 11 at USGS station 06052000 was replaced by a record at USGS station 06752260 due to an ice effect.*



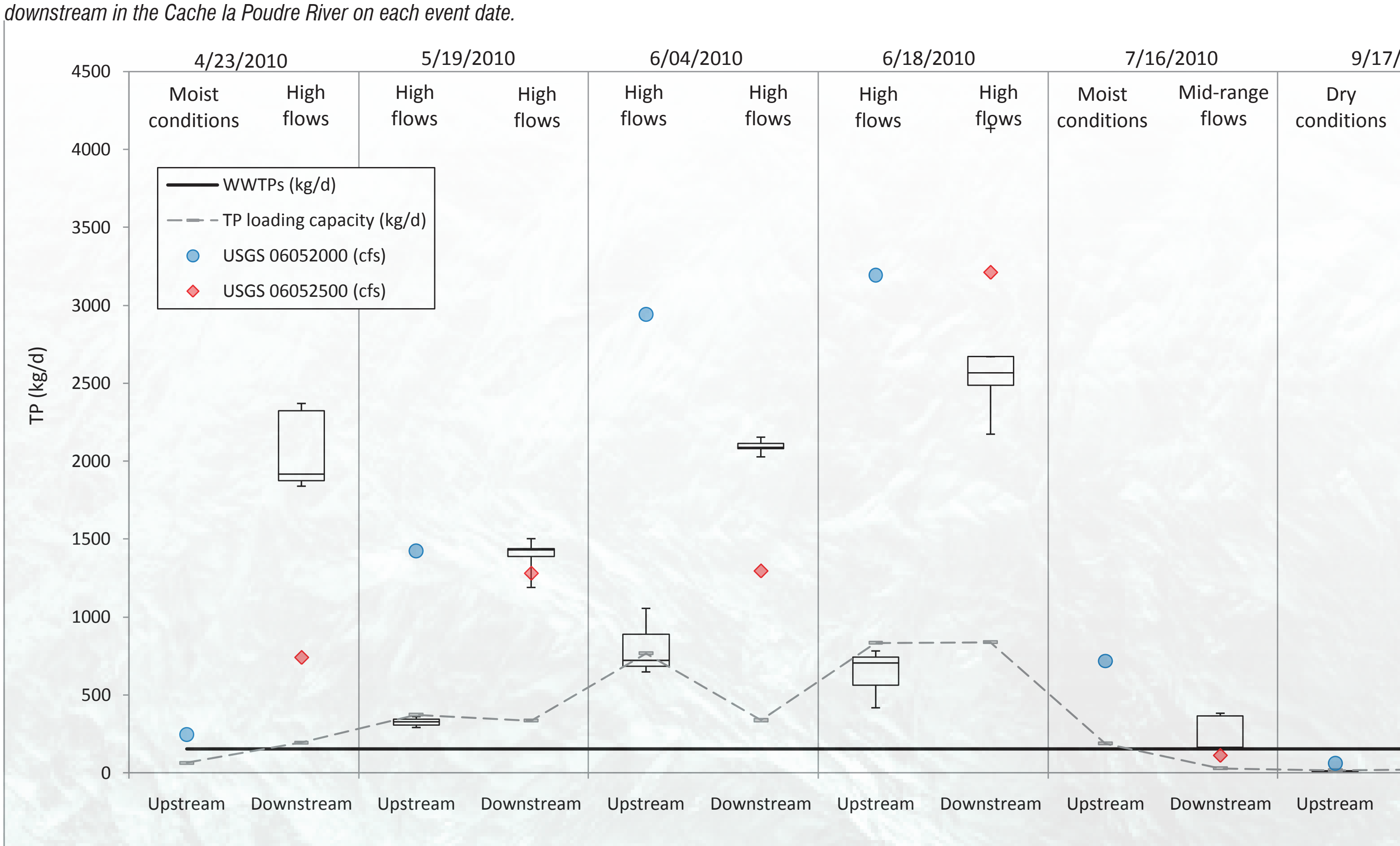


were in the range of 0.01-1.6mg/L with 0.297 standard deviation, and downstream concentrations were ranged from 0.336 to 8.144mg/L with 1.892 standard deviation. Concentrations were proportional to the flow rates on each event date except event 11 (July 2011), in which large amount of TN entered at sample point 8.

Nutrient loading from WWTPs is relatively constant annually due to the treatment process and flows. The estimated average annual TP load from WWTPs is 152.4 kg/d. As seen in Figure 4, significant amount of nutrients entered to the river in addition to loads from WWTPs during high flows compared to other hydrologic conditions. This indicates that large amount of TP comes from other sources, such as agricultural runoff via water or sediments and irrigation return flows. Downstream TP loads in the river in high flows ranged from 449 to 4136.3 kg/d, and the median was 1752 kg/d. In mid-range flows, median TP load was 147.9kg/d and ranged from 62.1 to 381.9 kg/d. The smallest amount of TP loads came into the river during dry conditions with 107.7 kg/d with a median in the range of 70.3-178.5 kg/d. It was observed that downstream, TP loads in the river for

Figure 3. *Nutrient concentrations (mg/L) along the Cache la Poudre River on event dates; TP (top), TN (bottom).*

Figure 4. *(Below) Hydrologic conditions, flows (cfs), the proposed TP loading limit (kg/d), TP loads from WWTPs (kg/d), and estimated TP loads (kg/d) upstream and downstream in the Cache la Poudre River on each event date.*

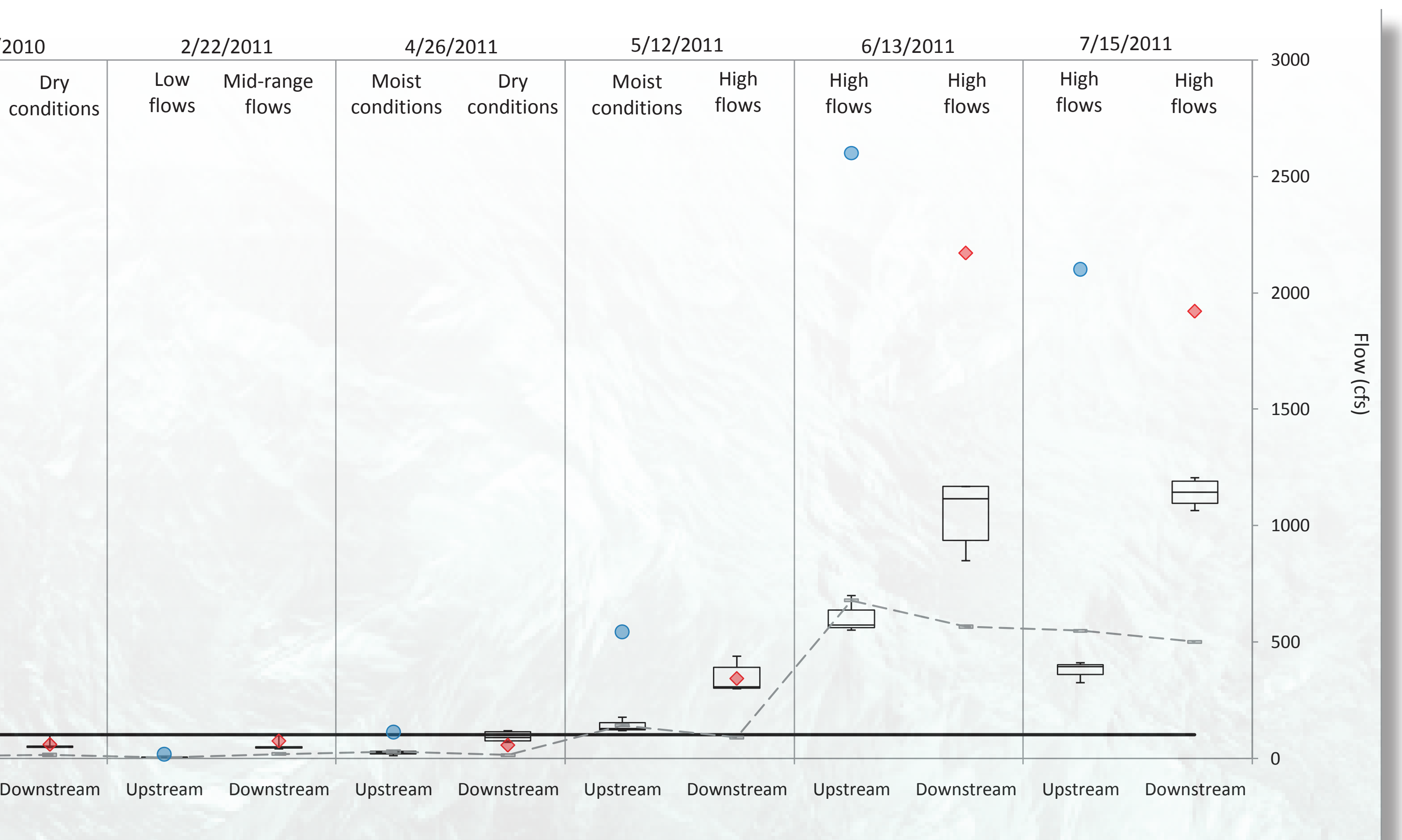


all events exceeded the proposed TP loading limit, and the exceedance was significant during high flows. And it was noted that even some data in upstream have exceeded the loading limit during event 3, 7, 8, 9 and 10.

It was interesting to see TN loads in the river compared to TP. TP load was exceeded for all hydrologic conditions and significantly exceeded the proposed TP loading limit during high flows, but TN load exceeded the proposed loading limit during dry conditions and mid-range flows but not high flows (Figure 5). The estimated annual average TN load from WWTPs is 1031.8 kg/d however 78-95% of TN loads from WWTPs except the WiWWTP were retained through sampling site 9 during dry conditions and mid-range flows in which downstream TN loads have exceeded the proposed loading limit in the river. The DWRF and the SFCSD discharge effluents into Fossil Creek Reservoir and the water flows into the river before sampling point 9. The large reservoir acts as buffer for TN and significant load reduction occurs through denitrification in the reservoir.

From the nutrient load analysis based on mass balance for 11 events, it was observed that TP loads from effluents of WWTPs were dominant (55.1-62.2%) in the CLP River during dry conditions (events 6, 8) followed by that from other (34.6-40.2%) and background sources (3.1-4.8%). During mid-range flows (event 5, 7), TP contribution from other sources (41.5-64.3%) was in the similar range with that from WWTPs (35.7-56.4%) but it was significantly increased (58.3-91.3%) for high flows (event 1-4, 9-11) while TP from WWTPs were remained as low as 2.6-22.3% (Figure 6). For dry conditions, TN loads from WWTPs and other sources were similarly in the range of 45.5-49.7% and 41.9-52.5%, respectively; however, TP loads from other sources were dominant during mid-range flows (76.9%) and high flows (68.7-95.6%) while TP loads from WWTPs were 21.9% for mid-range flows and ranged from 1.1 to 13.3% for high flows.

According to this research, WWTPs are the major nutrient source in dry conditions, but other nonpoint sources, and irrigation return flows, and others are significant not only for high flows, but also mid-range flows and dry conditions in the CLP River. Although WWTPs reduce a significant amount of nutrient loads with high costs, the effect on the total load to the river may be small, and WWTPs alone will not achieve the proposed stream standards without control of other sources.



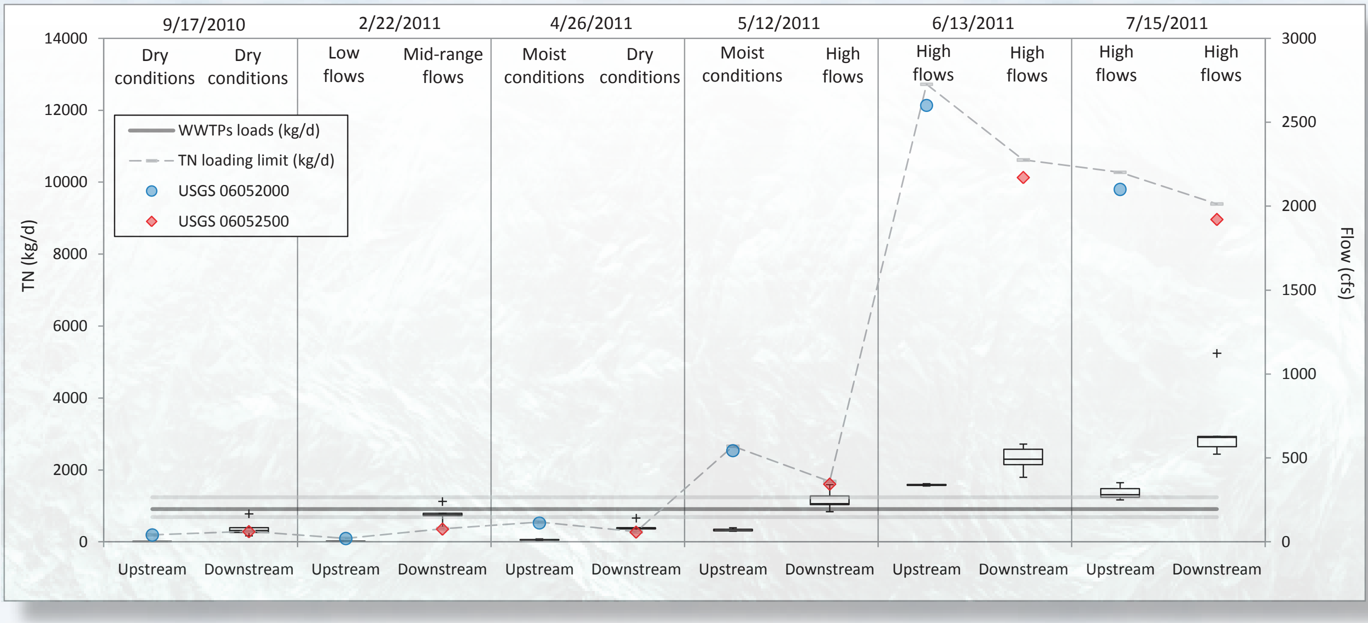
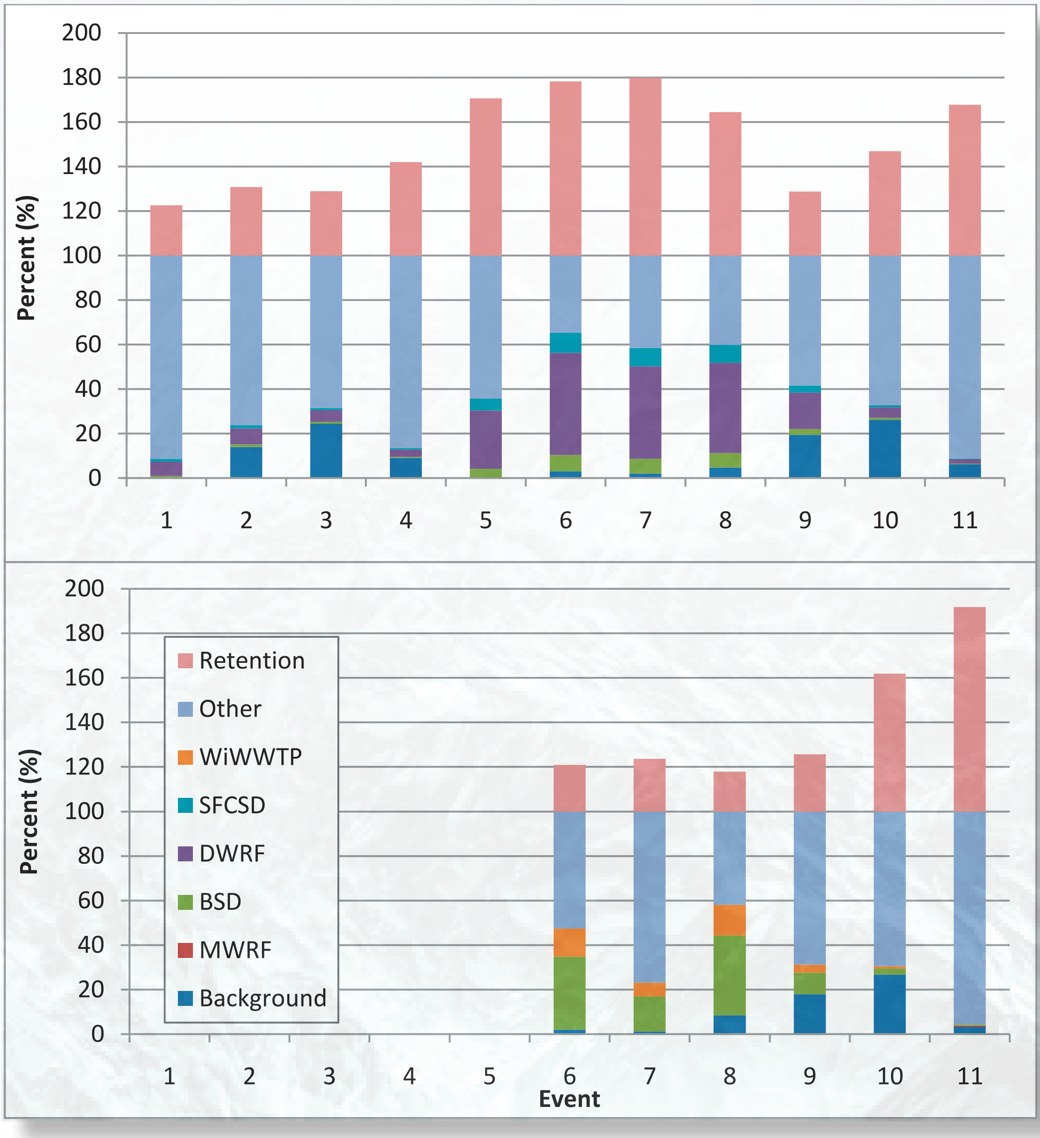
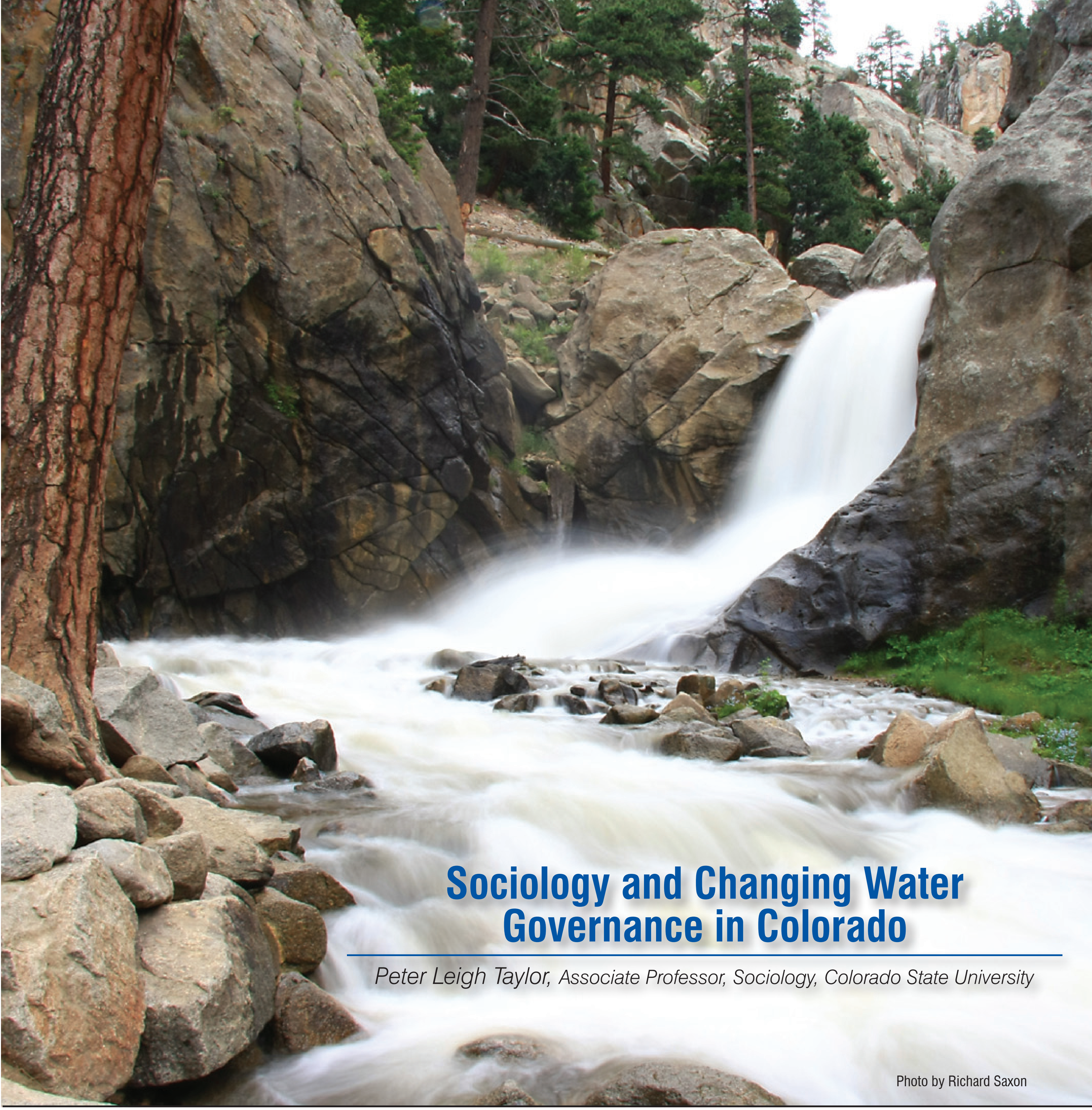


Figure 5. *Hydrologic conditions, flows (cfs), the proposed TN loading limit (kg/d), TN loads from WWTPs (kg/d), and estimated TN loads (kg/d) upstream and downstream in the Cache la Poudre River on each event date.*

Figure 6. *Percentages of nutrient sources in the Cache la Poudre River on each event date; TP (above), TN (below).*





Sociology and Changing Water Governance in Colorado

Peter Leigh Taylor, Associate Professor, Sociology, Colorado State University

Photo by Richard Saxon

I've been asked to reflect on my participation as a sociologist in the 2011 Colorado Water Workshop in Gunnison, directed by Western State College's Jeff Sellin and featuring presentations by some of Colorado's foremost water experts. Though I have long studied community-based forestry in the developing world, I am new to the study of water in the American West. Water governance in our region today faces serious challenges as water managers and users confront the probability of unprecedented future shortages in the face of demographic growth, expected climate change and other diverse pressures. As a sociologist with extensive experience researching environmental governance, my interest has been drawn in particular to how these daunting challenges may be reshaping water governance arrangements in Colorado and the West.

Many of the 2011 Water Workshop's participants spoke of growing tensions emerging among water's increasingly diverse stakeholders, which include traditional users such as farmers and ranchers, urban water utilities, electrical power facilities, protected area managers, and environmentalists, as well as emerging stakeholders such as oil and gas corporations, alternative energy producers, and low income urban ratepayers. The workshop was designed to present interests and perspectives of water's diverse users while exploring possibilities for collaboration. I was impressed by how much discussion there was of experimentation and innovation in Colorado's water governance, as water's increasingly diverse stakeholders seek to organize new coordination and cooperation as an alternative to litigation.

The juxtaposition of conflict and cooperation in changing Colorado water governance is, of course, not new. For example, in 2005, the Colorado Water Institute dedicated an issue of its Colorado Water Newsletter to the intra-basin roundtables and related governance initiatives introduced by the Colorado Legislature's HB 1177. The newsletter's essays highlighted the role that both cooperation and conflict play in generating innovation in water governance. Long time CSU water sociologist David Freeman underscored water's collaborative dimension: "Our communities are made possible by the social organization of water. There is nothing more social than a water molecule." Robert Ward wrote about the promising role the roundtables could play in developing "locally driven collaborative solutions to water supply challenges." Another CSU sociologist, Lou Swanson, wrote of "the contested terrain of water" and predicted that it "will yield new water laws, politics, and markets."

Below, I briefly reflect on some of the governance issues that stood out to me in the workshop, including the complex interactions among water's diverse user groups, recent innovations in water governance, and underlying debates over the organizational principles that might best guide water governance in the future.

Diverse users, interests, perspectives and policy preferences

During the workshop, representatives of water's diverse user groups highlighted the fact that they have distinct historical relationships to the resource, varying interests, and diverse cultural frameworks that shape their perspectives on water management. One Western Slope rancher, for example, spoke of water as crucial to his region's traditional cultural values and expressed concern about the cultural impacts of a rapidly growing recreation industry. Environmentalists spoke of the importance of instream environmental flows for restoration and preservation of natural basin ecologies. One urban water manager suggested that we need to nurture urban spaces as environments rather than see environments as existing only in rural spaces. Patty Limerick of the Center for the American West stated that the "green" movement should rather be called the "tan" movement. Bright green in the Western context, she remarked, is actually "the color of disturbance."

I was struck by how often one user group's representatives spoke directly to the values and interests of another, as when water managers spoke of environmental stewardship, or environmentalists affirmed the need to avoid drying up agriculture. That water's diverse cultural dimensions are capable of bringing together as well as dividing people was underscored by the successful "water poetry slam" organized one evening by Justice Greg Hobbs and Cat Schrier.

Experimentation and innovation in Colorado water governance

Much discussion at the Workshop was devoted to recent experimentation in water governance in search of alternatives to drying up agriculture. Of course, what is new is not necessarily innovative, and what is innovative may have been tried before. Nevertheless, that water users of all kinds are seeking governance alternatives was highlighted by discussions of the strengths and problems associated with water banks, rotational following, temporary water transfers via agricultural water leasing, deficit irrigation, sequestering water in the ground, carbon trading, co-location of alternative energy and cropping, recreational and environmental in-channel diversions, and others. Many participants spoke of the potential of such initiatives to achieve "win-win" responses to Colorado's water problems. Others remarked that these innovations are not neutral, but require careful planning and design to adequately address diverse interests, including those of rural communities.

New water governance arrangements are emerging

New governance arrangements are emerging in Colorado, with new kinds of social and political coordination and negotiation. The three-way keynote panel shared by Patty Limerick, Justice Greg Hobbs and Jim Lochhead of Denver Water highlighted that deeply embedded commitment to the historical framework of the Compact and Water Law exists alongside significant efforts to negotiate "out-of-the-box" solutions. Many of these emerging governance innovations aim to avoid litigation and keep decision-making more local and flexible. Perhaps the most prominent example discussed at length was the recent

Colorado River Cooperative Agreement, jointly negotiated by Denver Water and 37 Western slope organizations.

Emerging debates on organizational principles

Underlying the discussion of innovative water governance arrangements in Colorado were implicit and sometimes explicit debates over the organizational principles that should underlie future resource governance. What, for example, is the most appropriate level at which decision-making should occur: individual water rights holders; public utilities; communities; state or federal government; basin-wide regions; the market?

At the same time, given the reality of multiple, often overlapping governance layers in water governance, what sorts of decisions are best made at which level in which context? For example, should basin-level water governance exercise purely coordinative functions, as one Western Slope nonprofit representative suggested? Or should it exercise more executive functions that can directly link land-use planning to water management, as another presenter argued?

How should one organize for complexity, if water governance must provide for predictability and stability while ensuring sufficient flexibility for adaptation? Patty Limerick put this dilemma succinctly: does complexity bind us together in water or inevitably sow conflict and prevent adaptation?

Who must be included at the negotiation table and who might be left out in order to make negotiation practical and timely? Presenters reporting on the Colorado River Cooperative Agreement remarked on the unprecedented, complex negotiation among Denver Water and Western Slope organizations. At the same time, they admitted that significant affected stakeholders could not be easily included in the process.

What should be the relationship between science and technology on the one hand, and social and political realities shaped by varying user interests and perspectives, on the other? Patty Limerick talked about the need for more effective "engineer-society relations." Another participant, by contrast, expressed concern to me that "people" often make decisions based on ideology, values, and philosophy rather than technical expertise.

How these and related organizational questions are settled will have crucial implications for stakeholders—the "places, peoples and social institutions left in the wake of water's new transformation," as Lou Swanson described them in 2005.

Sociology's contribution to the study and practice of water governance

Sociology is well positioned to contribute to the analysis of and responses to complex environmental governance problems like those encountered in water management, where highly diverse interests and perspectives can either lead people to "talk past one another," or alternatively, serve to drive experimentation and innovation. "Environmental governance," by the way, is defined as "the formal and informal institutions/policies/rules/practices that shape how humans interact with the environment at all levels of social organization."[1]

At the workshop, one speaker suggested that in the context of global climate change, it is difficult to make "rational" economic and technological water-related decisions because of vested interests. By contrast, another speaker discussing the Colorado River Cooperative Agreement remarked that "you cannot find common solutions until you consider and understand the other's position."

Some of the most apparently intractable problems in Western water, to this admittedly new observer's eye, emerge from the fact that diverse users pursue distinct interests in the resource, have varying ways of assigning value to water, and, as a result, often promote conflicting water management policies. Is water's "best use" to produce food, to provide stable and predictable urban supplies, to restore and protect ecological systems, to provide for economically valuable tourism and recreation activities, or other objectives?

Rather than viewing water's diverse stakeholders as impediments to rational resource management, it may be more fruitful to take seriously the diverse relationships of multiple users to the water resource and to each other. As MaryLou Smith suggested in her 2005 Newsletter essay on the possibilities posed by paradox, recognizing that both sides may be "true" in a resource conflict may make it possible to set up a dialogue that brings a creative process out of conflict. From a sociologist's perspective, despite the obvious difficulties they raise for Colorado water governance, the very tensions among water's competing interests and perspectives arguably also drive a rich process of experimentation and innovation worthy of systematic attention.

1. Hendricks, Paul, Michele Betsill, Tony Cheng, and Peter Leigh Taylor. 2009. "The Landscape of Environmental Governance Research." Fort Collins, CO: Colorado State University, Environmental Governance Working Group.

Interview With CDPHE Water Quality Control Division Director, Steve Gunderson

Lindsey A. Knebel, Editor, Colorado Water Institute

Director Gunderson, could you start by describing your role as executive director of the Water Quality Control Division of the Colorado Department of Public Health and the Environment (CDPHE) and tell us about the role of the division in protecting human health in regards to water quality?

My role as director began in 2005, and I've been with the department for over 22 years. For most of that time, I was working in the Hazardous Materials and Waste Management Division. Prior to coming to the Water Quality Control Division as Director, I led the department's oversight on the $6.5 billion cleanup of the former Rocky Flats nuclear plant.

The division is responsible for implementing two water quality laws in the state. One is the Clean Water Act—Colorado has its own version called the Colorado Water Quality Control Act—and the other is the Safe Drinking Water Act. We have a rulemaking body called the Water Quality Control Commission. The Commission promulgates the standards and rules that our division implements. We determine where water bodies are not meeting standards, and we try to determine where the cause of that failure is coming from. We issue permits to facilities that discharge to Colorado surface water and groundwater, inspect both drinking water and wastewater facilities, provide assistance to facilities and if necessary, take enforcement action. The division permits approximately 10,000 discharging entities and oversees more than 2,000 drinking water systems.

What do you consider the greatest challenges in Colorado and the West related to water quality and human health?

The challenges we face are that the Colorado population is growing, has been growing, and will continue to grow. Higher population means more potential to impact water quality in the state. There's also going to be more demand placed on water supply. That will impact water quality in regards to a potential increase in pollution—for example, from nutrients, including nitrogen and phosphorus.

The low-hanging fruits of water quality issues have largely been addressed—the problems we have now are much harder to deal with. These include selenium, which is often leached from bedrock into rivers and streams when people irrigate land that is leached from rocks. Excess levels of selenium in water are detrimental to aquatic life. We have challenges of acid mine drainage from abandoned mines in our mountains. We have increased energy sector development in areas of the state that to date had been largely undeveloped. You superimpose these challenges onto growing state populations and increasing stress on our water supply, and our future can look rather daunting.

Photo by Kyle Thompson

Where do science and research play a role in protecting human health as it relates to water quality? Where does university research miss the mark from a regulator's point of view?

I'm very impressed with the research that universities do in regard to water quality. In a recent tour of CSU research projects, many projects were presented, and I was amazed at how many are likely to result in practical applications that can improve water quality. Some projects included best management practices in agriculture and how changes in land use affect water quality, with, for example, beetle kill. The amount of research of interest to the division is tremendous, and we are able to help fund some of these projects, such as CSU's Tim Gates' work on selenium in the Arkansas River Basin, and others. Science plays a critical role in what we do in so many places.

What are some future challenges in water quality that we need to start working on now?

One challenge that we will be facing is how to deal with what we call emerging contaminants. These contaminants come from all of us—the pharmaceuticals we take, the personal care products that we put on our bodies. They show up in the streams below wastewater treatments plants, and we are starting to find low levels of contaminates in the water we drink. There are so many of them, and they are hard to remove from wastewater. Climate change could be another challenge—we don't fully understand yet if or how it might affect water quality and water supplies.

Replacing aging drinking water and wastewater infrastructure and upgrading infrastructure to improve water quality is another big challenge. Infrastructure can be extremely expensive, and communities are faced with so many financial challenges besides providing safe drinking water and treating wastewater that enters Colorado's waters.

What do think are the most important things for our students and researchers to know about the regulation of water quality for human health?

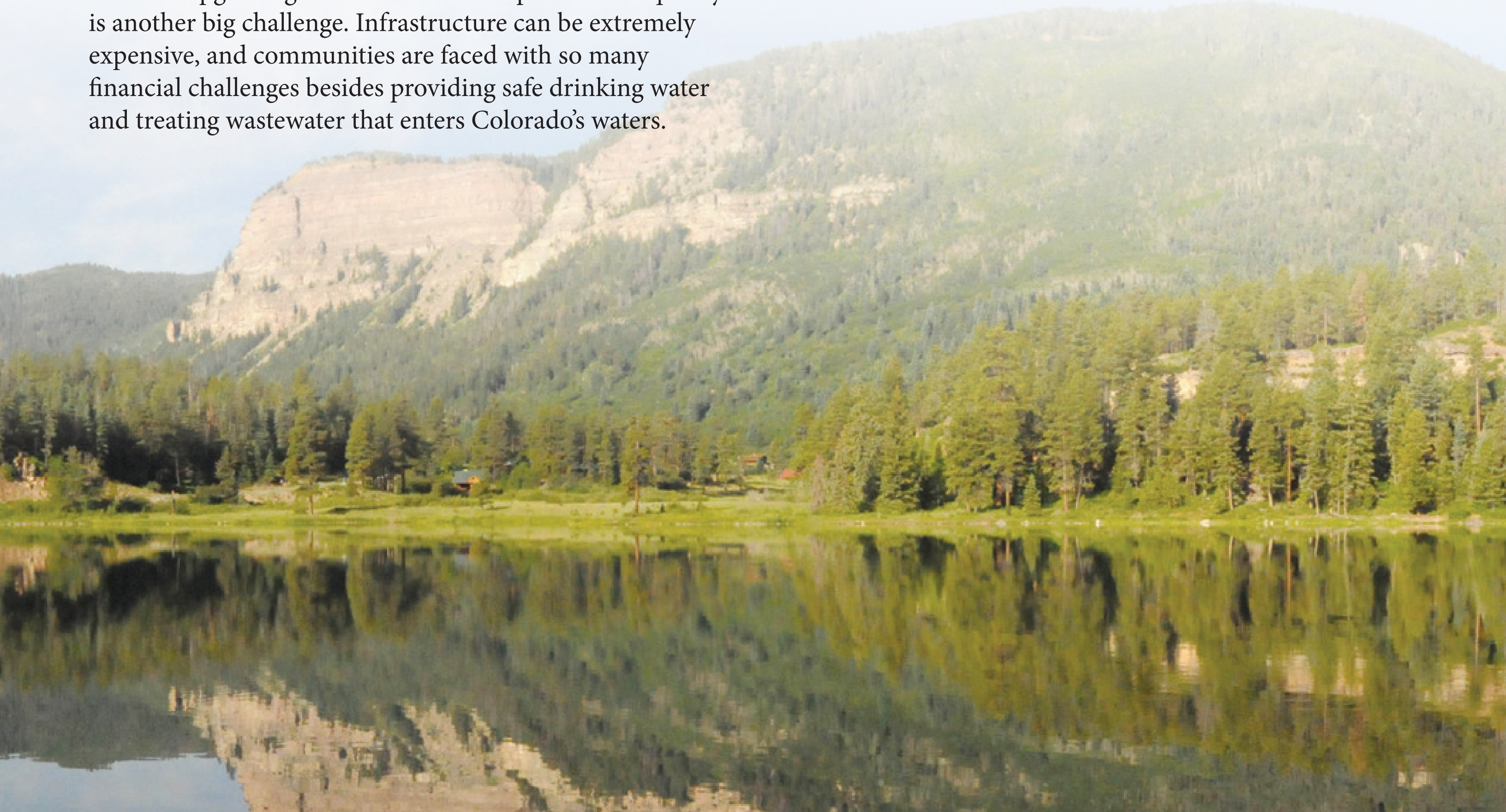
It's important to impress upon people how important water is to both the natural environment and the quality of life. When we use water, it goes into a wastewater plant and people down the stream use it as drinking water. We're lucky in Colorado to be very close to the source. I'm often struck by people not really knowing where their water comes from or what happens to used water that is sent down the kitchen drain or flushed down the toilet.

It's important to take care of this resource and use it wisely. We still have pristine water bodies in our mountains, and we need to protect that beauty. We also live in an arid state—having water is something we need to appreciate and not take for granted.

What do you most enjoy about your job?

This is not an easy job. We cost people money, and that upsets people. We also tend to be the center of opposing ideas—we're either doing too much or not enough.

That being said, there are many things I like about my job. I like a lot of the people I work with, and I feel like I can make a difference here, even though it's not easy. It involves a lot of juggling, multitasking, and that's one of the things that make this job challenging, but also rewarding.



USDA Irrigation Lab Celebrates 100 Years

Tom Trout, Agricultural Engineer and Research Leader, USDA-ARS

The USDA Agricultural Research Service (ARS) Water Management Research Unit in Fort Collins, Colorado celebrated its 100th anniversary Sept 29 and 30, 2011. The Irrigation Investigations Unit in Fort Collins began in 1911 through a cooperative agreement between the USDA Office of Experiment Stations and the Colorado Agricultural Experiment Station, and then became part of Colorado Agricultural College (now Colorado State University). The research effort has continued since and has resulted in 100 years of Innovation in Irrigation Water Management, the theme of the celebration.

Over 100 people attended the celebration, including over half of the Category 1 scientists that have been associated with the unit, representing 67 of the 100 years. The highlights of the celebration were a review of the history in terms of people, places, collaborations, and innovations by retirees Gordon Kruse and Harold Duke, and testimonials from some of the over 300 past students employees and over 200 graduate student advisees of the unit.

While the first day of the Celebration concentrated on history and past accomplishments, the second day highlighted ongoing collaborations and the need for continuing water management research. The current director of the Colorado Agricultural Experiment station, Lee Sommers, described many years of fruitful collaborations between CSU and ARS in water research, and John Stulp, Special Advisor to the Governor of Colorado, gave the keynote address on anticipated water and agricultural challenges over the next 100 years.

The following article is a condensed version of "A Century of USDA Irrigation Research in Colorado" by Harold Duke and Gordon Kruse.

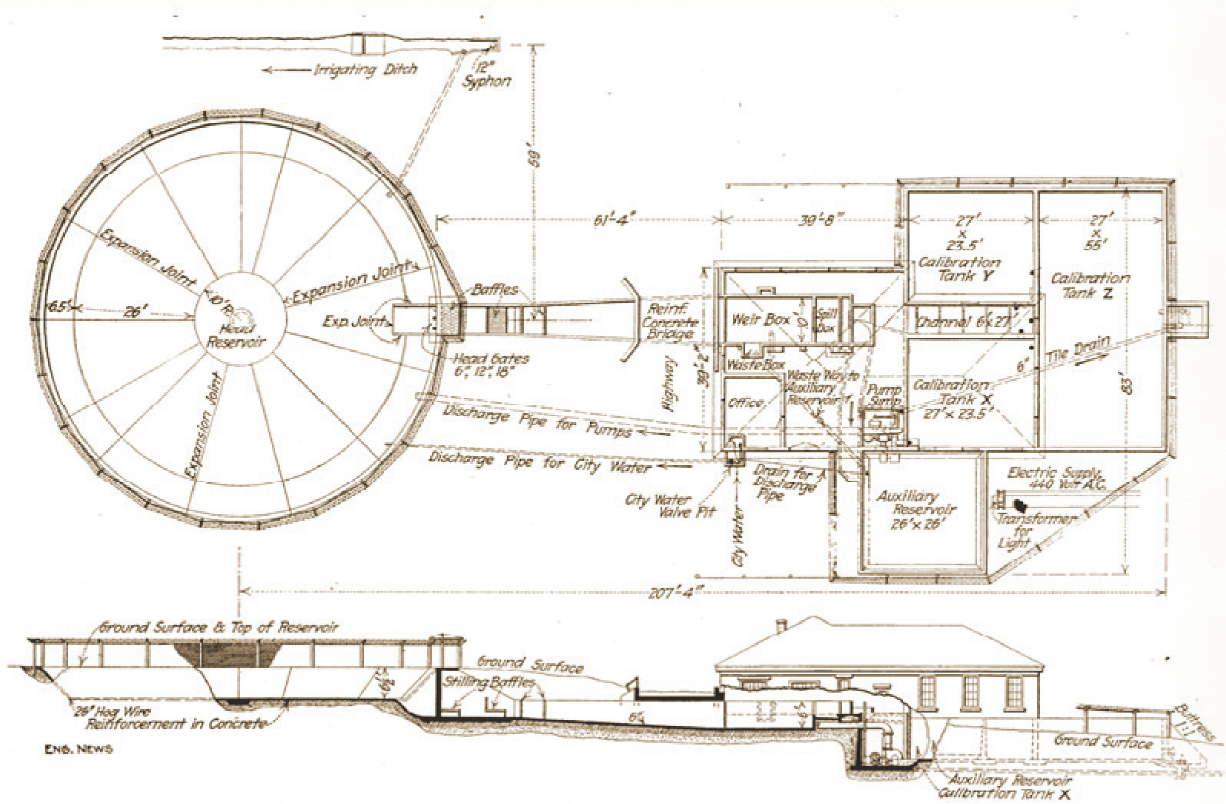
History of the USDA-ARS Water Management Research Unit: 100 years of Innovation and Collaboration

Harold Duke, Gordon Kruse, Retired Agricultural Engineers
Tom Trout, Research Leader, and Mary Brodahl, Soil Scientist, USDA Agricultural Research Service

At the turn of the 20th century, irrigated agriculture was already well established in the South Platte River Basin in Colorado. Elwood Mead began irrigation instruction and research at Colorado Agricultural College (CAC, now CSU) in 1882, and the first irrigation program in the country was established at CAC in 1889. Mead had moved on to the USDA and established the Irrigation Investigations Branch within the Bureau of Agricultural Experiment Stations and began locating USDA researchers at western land grant universities in about 1907. It appears that CAC initially resisted placement of a USDA irrigation research unit in Fort Collins, but a faculty change in 1911 opened the door to USDA, and the Fort Collins Irrigation Investigations Unit began in June 1911 through a Cooperative Agreement between the USDA and the Colorado Agricultural Experiment Station. In that initial agreement, CAC and USDA agreed to do cooperative research on flow and measurement of water, irrigation control structures, water requirements of crops, pump irrigation, and drainage requirements.

The first two appointments to the Unit were both CAC engineering graduates - Victor Cone from Kansas and Ralph Parshall from Golden, Colorado. Carl Rohwer from Nebraska joined the Unit in 1914. Cone left the group during World War I and Parshall and Rohwer formed the core of the USDA irrigation research group in Fort Collins until the 1950s. The scientists were housed in the CAC Irrigation Engineering building located on the southwest side of the Oval (currently the Statistics Dept). One of

Original USDA Hydraulic Lab plans (built on the CAC campus).



THE ORIGINAL HYDRAULICS LAB
1913

their first tasks was to develop a facility where they could conduct the research on water flows, evaporation, and percolation. Parshall and Cone built the USDA Hydraulics Laboratory on campus in 1912. The laboratory was added to several times and used for many purposes. The US Bureau of Reclamation, under the direction of their commissioner, Elwood Mead, used the laboratory in the 1930s to test models of the Hoover and Grand Coulee dams. The laboratory was eventually torn down in the 1950s to make room for the Lory Student Center.

At the beginning of the 20th century, little was known about how much water (irrigation and/or precipitation) was needed to produce a crop and how to equitably distribute irrigation water among ditch companies and farmers. Early research in the unit concentrated on the "duty of water" (how much water is needed to grow a crop), and on the delivery and measurement of irrigation water. Classic studies on evaporation from water surfaces, seepage losses from canals and reservoirs, canal water control structures, sediment control in canals, design of irrigation wells, and measurement of irrigation water were conducted and published by Cone, Parshall, and Rohwer. One of the best known innovations is the Parshall flume, which is still used to measure irrigation water throughout the West and worldwide.

Ralph Parshall poses with a Parshall flume.

Parshall, recognizing that he needed a facility where he could control large flows to test his structures, built a second hydraulics laboratory north of Fort Collins near Bellvue where the Jackson Ditch is diverted from the Poudre River. Parshall and his students continued to use the Bellvue Lab until his death in 1959. Basic laboratory structure still exists today. Parshall, along with CAC President, Charles Lory, recognized that more water would be needed to meet irrigation needs and sustain the inevitable growth along the northern front range. They became early proponents of a plan to transfer water from Grand Lake in the Colorado River Basin to the front range and conducted a full-fledged feasibility study. This plan evolved into the Colorado Big Thompson project that continues to be a major source of water for north-eastern Colorado. Parshall also was one of the first to describe the impact irrigation was having on increasing mid-summer flows in the South Platte and how that flow was the result of a rise in groundwater due to seepage from irrigated fields.

Over the initial 50 years of the Irrigation Investigations Unit, reorganization within USDA resulted in the Unit being part of the Bureau of Public Roads (1918), the Soil Conservation Service (1935, now Natural Resources Conservation Service) and finally, in 1964, the Agricultural Research Service. Throughout its history, it was always been closely allied with the Colorado Land Grant University (CAC, Colorado A&M, and CSU). Most of the researchers were housed in university facilities, collaborated closely with university scientists, and taught university students and it was often difficult to know whether they were part of USDA or the university.

As Parshall and Rohwer were nearing retirement, many GIs were taking advantage of the post WW II GI bill to get their graduate degrees. One of these, A.R. "Robbie" Robinson, finished his graduate degree in 1951 with a joint appointment from the Colorado Agricultural Experiment Station and USDA and led the Fort Collins USDA group from 1956 to 1963. Robinson continued Rohwer's work in seepage studies and interceptor drains and had a long, illustrious career with ARS in Idaho, Mississippi, and Washington D.C. After his retirement in the 1970s, he again worked as a consultant to the CSU Water Management Synthesis Project.

Howard Haise joined the USDA irrigation research team in Fort Collins in 1954. He recognized that the labor requirements of surface irrigation made it difficult to irrigate

A.R. Robinson and seepage study tanks.

Photo of the Bellvue Hydraulics Lab on the Cache La Poudre River.

accurately and scientifically, and spent much of his later career developing and testing devices to automate these systems. Haise retired in 1974, but still lives in Fort Collins and attended the 2011 Centennial Celebration (at age 97).

USDA also sent several of their post-war engineers to CSU in the 1950s to get their PhD degrees. Most notable among these were Marvin Jensen, a student for part of his degree of Art Corey, and Royal Brooks, also a student of Art Corey. These students collaborated with professors to develop two of the landmark relationships still commonly used in irrigation management: The Jensen-Haise ET equation that used solar radiation to improve crop evapotranspiration estimates, and the Brooks-Corey relationships that describe water content and movement in soils. Jensen, after a long and productive career in ARS in Idaho and Washington, D.C., returned to Fort Collins as a National Program Leader for ARS, and after retirement, in an adjunct position at CSU in international programs. Jensen still resides in Fort Collins and continues to present workshops on crop evapotranspiration and reservoir evaporation.

In the 1950s and 60s, a new group of CSU engineering graduate students were hired by what was now the USDA Water Management Unit that would lead the research into the 21st century. Gordon Kruse received his degree and joined USDA in 1957. He worked on surface irrigation automation and led research on water use by irrigated high mountain meadows and on salinity control in the Grand Valley. Harold Duke received his degree under Art Corey and joined USDA in 1967. His work spanned both irrigation methods and water quality issues, with studies of percolation of nitrogen and other potential pollutants below feedlots and farm fields, surface irrigation methods, and control and monitoring of sprinkler systems.

Dale Heermann received his graduate degrees working with Kruse, and joined ARS in 1968. He spent much of his career leading irrigation management into the computer age through mathematical models of water flow in soils, computerized irrigation scheduling, and monitoring and control systems for sprinkler systems. Heermann recognized that center pivot irrigation would dramatically change the way crops are grown in the Central Plains, and helped develop technology that makes center pivot irrigation highly efficient today. Heermann's Center Pivot Evaluation and Design (CPED) Program continues to be used to assess whether systems meet federal guidelines for USDA cost share. In the late 1970s and into the 80s, rural electrical utilities were experiencing peak demands they couldn't meet, and needed to regulate the rapidly increasing center pivot power demands. The Water Management Unit, under Heermann's leadership, developed control systems that allowed farmers and power companies to monitor and control pivots intelligently to reduce electrical load with the least impact on irrigation schedules. These Water and Energy Management Systems (WEMS) evolved into control and monitoring panels that are sold by all center pivot manufacturers today.

Kruse, Duke, and Heermann, besides getting their graduate degrees at CSU, were very active in advising CSU irrigation engineering students. Among them, they advised, and often funded, 47 graduate CSU graduate students, and served on the committees of over 140 students. Many of the current national leaders in irrigation engineering research and education in the U.S. were students of these three USDA engineers.

In the early 1980s, the USDA irrigation group added two engineers to the Unit: Gerald Buchleiter, a CSU graduate and previous student employee of the Unit, and Walter Bausch. Buchleiter worked closely with Heermann on center pivot control systems, irrigation scheduling, and electronic mapping of soils, and worked closely with one of the major pivot manufacturers, Valley, on a pivot-based pesticide application system. Bausch has researched the use of remote sensing to measure soil water conditions and plant water and nutrient stress, using both ground and satellite platforms. His work using satellite data to predict crop coefficients for scheduling irrigation is the basis for world-wide applications of this technology. Both Buchleiter and Bausch continue to work in the Unit.

In the 1980s and 90s, the research in the Unit, which had focused strongly on soil and water engineering, became more interdisciplinary. The desire to better predict global, and specifically USSR, wheat production lead to a project to use remote sensing and crop models to predict wheat yields. Through some reorganization, the Unit inherited and further developed a research program to develop weed management technologies. As GPS and GIS technologies developed, many farmers began exploring the variability in their yields and site specific application of their farm inputs of fertilizer, pesticides, and water, but lacked management information to guide them. The Water Management Research Unit (WMRU) developed an interdisciplinary Precision Agriculture Project in collaboration with several CSU scientists and key farmers. They used their expertise in soil science and mapping, remote sensing, irrigation and weed management, and computer modeling, to explore benefits of site specific management.

By the beginning of the 21st century, a decline in water supplies for irrigation was becoming apparent, but our society was recognizing the need to sustain the rural economies and food production of irrigated agriculture. Tom Trout, an agricultural engineering graduate of CSU in the 1970s, returned to Fort Collins after Heermann's retirement to help the WMRU develop an interdisciplinary program to determine and maximize the water productivity of crops grown in the region, and thus improve the income and sustainability of irrigated agriculture. The emphasis of the current research is on better understanding and measurement of the soil-plant-water-climate relationships that determine crop water use efficiency and plant physiological responses to water stress. This basic knowledge will help farmers manage their crops and water to maximize returns, whether from higher yields per unit water consumed, or through valuing water as a commodity. Thus, although the technologies available to researchers and societal demands have changed over the past 100 years, the basic need and primary research emphasis continues to be to determine crop water requirements (the "duty of water") and improve measurements to assess and meet the requirements.

The close collaboration with CSU has also continued throughout the 100 years in research, education of students, and extension of new technologies. The WMRU has collaborated in many research efforts, trained many CSU students as summer interns (over 300) and graduate advisees (over 250), and participated in innumerable extension meetings, publications (such as this one), and workshops. Most WMRU engineers were educated at CSU. And throughout the 100 years, we have shared resources, knowledge, and facilities. We look forward to another 100 years of collaboration and innovation.

This brief history has only mentioned the highlights and some of the main scientists involved in the irrigation research. For a more complete description of the history, accomplishments, and personnel, see: http://www.ars.usda.gov/Aboutus/docs.htm?docid=8343

Water Management Research Unit

Fort Collins, CO

USDA ars United States Department of Agriculture
Agricultural Research Service

The Crane Trust: From Conflict to Cooperation

Maren Thompson Bzdek, Program Manager, Public Lands History Center

For more than thirty years the Crane Trust has protected and improved habitat for cranes and other migratory birds along Nebraska's Big Bend reach of the Platte River, which lies along the Central Flyway of North America. The non-profit conservation trust has successfully restored thousands of acres of habitat and contributed to the international effort to increase the endangered population of whooping cranes (*Grus americana*).

The Crane Trust originally formed as the Platte River Whooping Crane Habitat Maintenance Trust in 1978 as the result of a settlement between the State of Nebraska, the National Wildlife Federation, and the Missouri Basin Power Project. At the time, Basin Electric, a member of the Missouri Basin Power Project, was in the midst of constructing the Grayrocks Dam and Laramie River Station on a tributary of the North Platte River near Wheatland, Wyoming. Using the considerable powers of the National Environmental Protection Act and the Endangered Species Act, officials from the State of Nebraska cooperated with the National Wildlife Federation to halt construction until they reached a settlement that ensured protection of the designated critical habitat in central Nebraska. The settlement included specific water-release measures and required Basin Electric to provide $7.5 million to fund the trust.

There are less than 300 whooping cranes in the wild and an additional 300 in captivity or in the process of re-introduction.

Photo by szatmar

In their first meeting, the original trustees agreed not to retry the Grayrocks dispute and to focus on their fiduciary duty to facilitate a land acquisition and habitat management plan for migratory birds. They understood that local farmers were worried that the trust's purchasing power might drive up land prices and restrict agricultural activities near the river. Nebraska's birdwatching tourism industry was still in its infancy, and some Nebraskans felt the cranes did not need additional protection and merely served as a legal hook in the regional Platte River water disputes between Wyoming, Nebraska, and Colorado that preceded today's cooperative, adaptive management approach. In the midst of high-stakes water disputes, the Crane Trust was highly unpopular with Nebraska water developers. According to one account describing a water meeting in Lincoln, former Nebraska Governor Robert Crosby got up on the table, stood on one leg, and flapped his arms in imitation of a whooping crane while complaining that the settlement had provided $75,000 per bird for the remaining 100 endangered cranes.

The Crane Trust's lengthy involvement in the Kingsley Dam relicensing process increased the animosity between water development interests and conservationists on the Platte. In 1987, the trust intervened in the *Nebraska v. Wyoming* case in hopes of securing permanent instream flow protection for wildlife. Nebraska Governor Kay Orr was so displeased that she dismissed Richard Spelts, the state's appointee to the trust board, and replaced him with Jack Maddux, a prominent cattleman from western Nebraska. In 1992, U.S. District Judge Warren Urbom confirmed the trust's right to use litigation "to allow the Big Bend Area to continue to function as a life support for migratory birds." The Eighth Circuit Court of Appeals upheld Urbom's decision two years later.

Although whooping cranes and their more numerous cousins, the sandhill cranes, could be a lightning rod for Platte River water disputes, they inspired the admiration and concern of others. Like whales and polar bears, cranes are "charismatic megafauna" with which people readily sympathize. As ecological literacy grew in the 1970s and 1980s, the Crane Trust steadily gained local and far-reaching support from people who recognized that the long-term needs of bird species are intertwined with the needs of human communities.

To that end, the Crane Trust's scientific staff has worked to re-seed, restore, and protect wet meadow along the Big Bend reach with decades of labor-intensive effort. Yet the trust operations are also guided by the principle that their acquired land should be kept in the highest agricultural production that is consistent with their habit-protection goals as a demonstration that agriculture and wildlife can share the same landscape and resources with careful management. The Crane Trust was among the first on the central Platte to experiment with four-pasture rotation, prescribed burning, and mechanical clearing of in-channel vegetation that results from upstream diversions and the interruption of natural flood cycles.

In addition to providing opportunities to experiment with habitat restoration, the Crane Trust has served as a model for how conservation trusts, as a legal instrument, are particularly well-suited to acquire and protect habitat. While the first decades of the trust's operations were mired down in legal battles, the last decade began a new era of regional compromise that Crane Trust officials fully supported. The Platte River Cooperative Agreement, signed by the three states in 1997, and its subsequent implementation plan is now a model of regional watershed management and recovery that governs water development and wildlife protection on the river. The Crane Trust remains an important contributor to that effort and to the scientific study of migratory birds.

Maren Thompson Bzdek is the program manager for the Public Lands History Center at Colorado State University. For more information about the center, visit http://publiclands.colostate.edu. For more information about the Crane Trust, visit www.cranetrust.org. Colorado State University's Water Resources Archives holds the records of the Platte River Whooping Crane Maintenance Trust. For information about that collection, visit http://lib.colostate.edu/archives/water/collections.html.

CSU Student Joseph D. Vassios Receives Award

Colorado State University Ph.D. candidate Joe Vassios was recently honored with the annual Outstanding Graduate Student Award from Aquatic Plant Management Society. Vassios says the graduate work he was recognized for has focused on "examining the absorption and translocation of the aquatic herbicides triclopyr, fluridone, and penoxsulam in two aquatic plant species, hydrilla and Eurasian watermilfoil." In addition to this research, Vassios has been active in CSU Professor Scott Nissen's aquatic plant management research program. He's also been "evaluating current and new methods for control of sago pondweed in irrigation canals and new control methods for Eurasian watermilfoil in lakes, ponds, and irrigation canals."

Vassios plans to graduate in fall 2011, and says he hopes to pursue an industry career in the aquatic plant management field. He holds a Bachelor of Science in Soil and Crop Sciences and a Master of Science in Bioagricultural Sciences and Pest Management, both from CSU.

Drought—Never Too Far Away

Nolan Doesken, State Climatologist, Colorado Climate Center

Colorado's northern and central mountains experienced an incredible snow year in 2011. Streamflow from mountain snowpack was exceptional this year for much of the state – especially the Yampa and Colorado River. Large snow fields persisted through the entire summer above tree line in northern Colorado. For the first time in ten years, there was a sense of, "Finally, we don't have to be so concerned about drought."

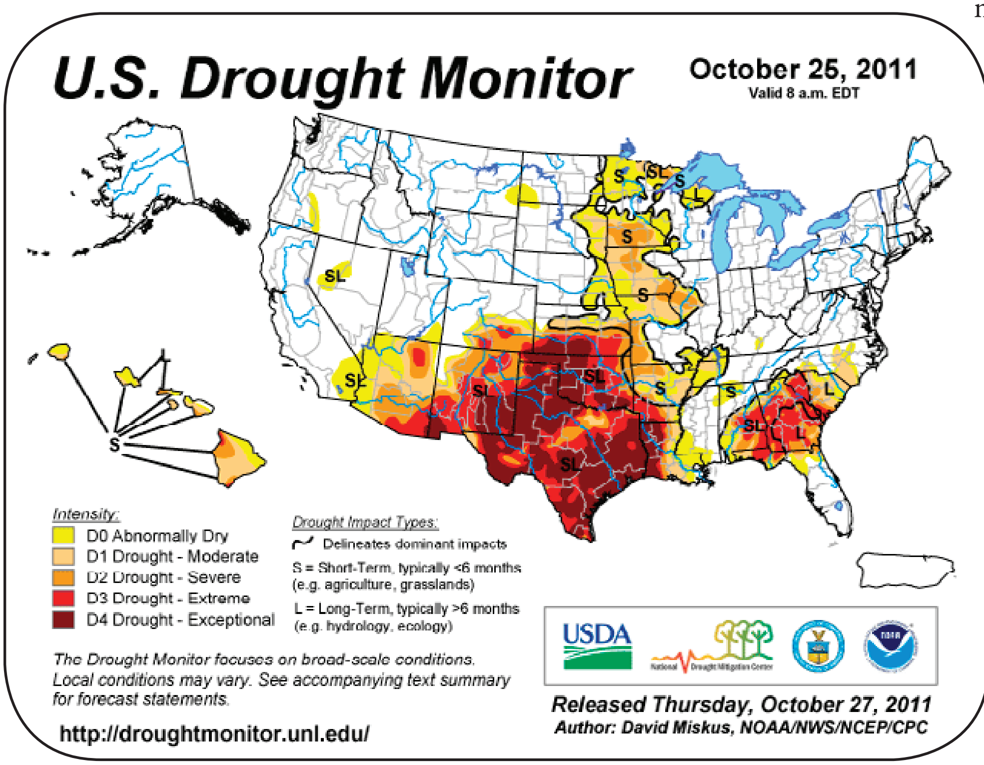
Meanwhile, we saw and heard the stories this year of exceptional drought and extreme impacts not that far from Colorado – record-breaking wild fires in Arizona, New Mexico and Texas; extreme water shortages developed in Oklahoma and Texas and other areas of the South. These states have seen drought before, but drought conditions in Texas in 2011 were unprecedented in terms of the combination of extreme summer heat along with long periods of essentially no precipitation.

While northern and western Colorado enjoyed a green and water-abundant year, southern Colorado was not so lucky. Beginning in the fall of 2010 and continuing throughout the winter, spring and much of the summer, the Rio Grande Basin and most of the Arkansas River Basin downstream from Salida were missed by each of the many passing storms. Much above average temperatures also prevailed. Evapotranspiration (ET) rates this past growing season, as measured by CSU's CoAgMet weather station network (ccc.atmos.colostate.edu/~coagmet) showed extremely high ET rates over southern Colorado approaching or exceeding those observed during the 2002 drought. There was finally some relief very late in the growing season as some late summer monsoonal rains reached southern Colorado and a large storm system brought huge downpours to El Paso County in mid-September

As the 2011 water year and growing season came to an end, southern Colorado continues to struggle with persisting dry conditions. The prediction of continued warm and dry conditions across the southern U.S. associated with a second consecutive year with cooler than average sea surface temperatures in the eastern and central tropical Pacific Ocean (referred to as "La Nina" conditions – http://www.cpc.ncep.noaa.gov/products/predictions/90day/), it looks like dry conditions could prevail for another several months. Fortunately, most of Colorado surface water supplies (stream flows and reservoir storage) are in excellent shape going into the 2012 water year. Most of Colorado can continue to "breathe easy" as we watch and wait to see what the new winter will bring.

As much as we all dislike drought and the stresses and water shortages that come with it, drought is and will continue to be a part of life in Colorado. Our research has shown that since Colorado climate monitoring began nearly 125 years ago, there are drought conditions present somewhere in Colorado almost 90% of the time. (In a future issue, we will describe how drought is defined and how we track drought conditions over time.)

If you would like to receive weekly climate and water supply summaries for Colorado, they are updated every Wednesday at: http://ccc.atmos.colostate.edu/drought_webinar.php If you would like to receive these update reports as an e-mail, please contact Nolan Doesken at Nolan.Doesken@Colostate.edu



Deep Nitrogen Removal with Sunflowers

Extension Joel P. Schneekloth, Regional Water Resource Specialist, Colorado State University Extension and Colorado Water Institute

With irrigated production, many times nitrogen will leach below the root zone of irrigated crops such as corn. Subsequent years of the crop may increase the amount of nitrogen present in soil. This nitrogen buildup can make regions with shallow groundwater susceptible to groundwater contamination, a threat to water quality in the connected water supply.

What crop can effectively remove that nitrogen from deeper in the soil profile? Sunflowers have a deep rooting system and have extracted water from depths greater than six feet. Previous work with dryland sunflowers has also shown nitrogen extraction to depths of six feet. Additionally, irrigated sunflowers have shown promise for irrigated crop production when irrigation water is limited because of sunflowers' ability to root deeply and utilize water sources.

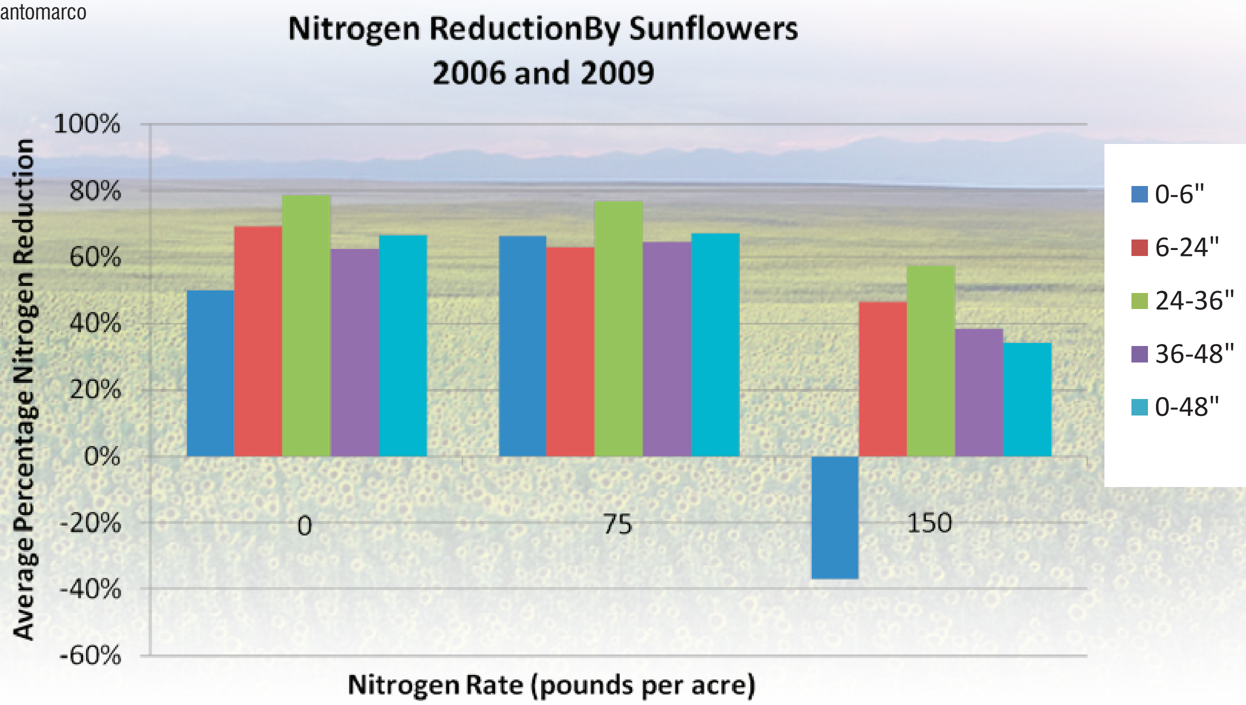
In 2006, 2009, and 2010, a nitrogen rate study was conducted looking at the optimal nitrogen management as well as the deep nitrogen removal of fully irrigated sunflowers. Nitrogen rates of 0, 75, and 150 pounds per acre were applied to sunflowers pre-planting to simulate typical producer management for nitrogen applications. Nitrogen rates above 150 pounds per acre decreased yields, so they will not be discussed. Soil samples prior to planting and after harvest were taken to a depth of three feet in 2006 and to four feet in 2009 and 2010 to look at removal of nitrogen by irrigated sunflowers.

Residual soil nitrogen at the beginning of the growing season was similar in 2006 and 2009. In 2010, residual soil nitrogen was greater, with average residual nitrogen levels greater than 250 lbs per acre. Removal of residual nitrogen was similar in 2006 and 2009. The removal of nitrogen varied by the amount of nitrogen applied prior to planting. However, both the 0 and 75 lbs N removed similar amounts with approximately 67 percent of the beginning nitrogen removed by the crop during the growing season. The average reduction in residual nitrogen ranged from 60 to 80 percent from six to 48 inches. When 150 lbs per acre nitrogen was applied, the nitrogen removal was reduced. The average reduction in residual nitrogen was 34 percent compared to 67 percent for 0 or 75 lbs N. Grain yields did increase from 0 to 75 lbs nitrogen applied. However, the yield increase was less from 75 to 150 lbs nitrogen.

In 2010, beginning residual nitrogen was greater than 250 lbs per acre to a depth of 48 inches. This was three times greater than 2006 or 2009. When no nitrogen was applied,

Figure 1. *Average reduction of residual nitrogen by depth and sample zone for 0, 75, and 150 lbs nitrogen applied for 2006 and 2009. A negative number indicates an increase in residual nitrogen.*

Photo by Matt Santomarco



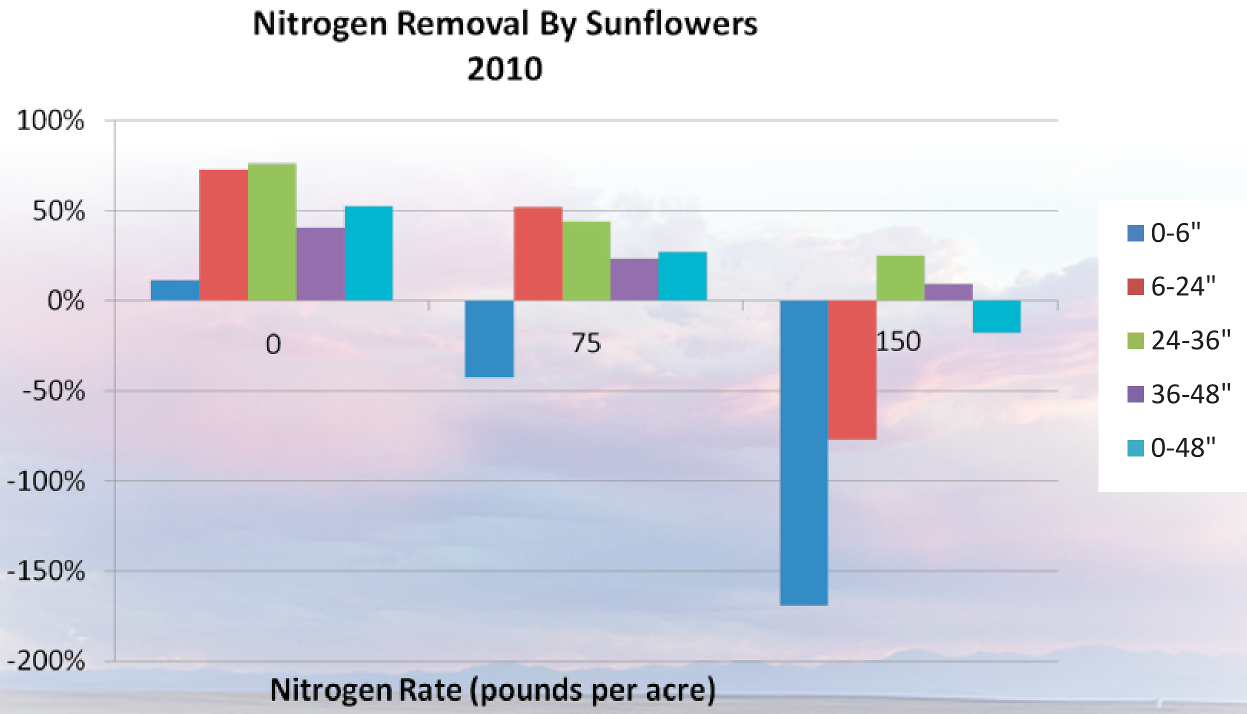


Figure 2. *Average reduction of residual nitrogen by depth and sample zone for 0, 75, and 150 lbs nitrogen applied for 2010. A negative number indicates an increase in residual nitrogen.*

Photo by Matt Santomarco

sunflowers removed approximately 50 percent of the residual nitrogen. Sunflowers removed approximately 70 percent of the residual to a depth of 36 inches and nearly 40 percent of the residual nitrogen from 36 to 48 inches. When nitrogen was applied, the removal was reduced with less than 50 percent removal at all depths for 75 and 150 lbs nitrogen applied. With applications of nitrogen, the surface and six to 24 inch residual nitrogen did increase. Grain yields decreased with additional nitrogen applied with high residual nitrogen as compared to the increase in yield in 2006 and 2009.

Irrigated sunflowers have shown that they can effectively remove residual nitrogen from depths greater than 24 inches. In some instances, this was a substantial amount of nitrogen. Soil sampling to a depth of four feet can reduce applications of nitrogen for producers and reduce the potential for leaching of nitrogen into the aquifer. When residual nitrogen is high, applications of nitrogen can reduce grain yields while increasing soil residual levels.

Current work on fertility management of irrigated sunflowers is looking at nitrogen amounts as well as timing of applications. These timings would mimic fertigation management and looking at the possible reduction in amounts of nitrogen as compared to a complete pre-plant program. Funding for this work was provided by the National Sunflower Association and Colorado Sunflower Association.

Colorado and Arizona Water Institutes Plant Seeds for Agricultural/Environmental Collaboration

MaryLou Smith, Policy and Collaboration Specialist, Colorado Water Institute

Agriculture and the environment both stand to lose in the battle for water in the Colorado River Basin. Urban growth, climate change, and energy development are all poised to grab the water. Can agricultural producers and environmentalists join forces to protect their common interests?

Successful agriculturalists have always had to carefully steward the environment to make it produce for them. Environmentalists value the open space and wildlife habitat that agriculture provides. But ideological differences keep the two groups at odds:

- Do environmentalists value fish more than crops for people?
- Do farmers divert too much of the water away from the rivers?

Western water law gives priority for use of the water to those who first put it to beneficial use. But in the late 1800s, when most senior water rights were claimed for agriculture, no one envisioned a need for the environment to hold water rights. Today, we are trying a number of ways to find water for the environment, including "instream flow rights." But the highest bidder for these senior water rights is most often the urban sector. If both agricultural producers and environmentalists want to keep this water on the land and in the rivers and streams, how can they work together to accomplish this?

Among both groups, die-hard purists form polar ends of the continuum. But in between are pragmatic farmers, ranchers, and environmentalists who seek common ground. There are examples of this throughout the West.

In order for agricultural and environmental stakeholders to recognize the great potential for common gain by working together, traditional barriers must be overcome. Trust building has been difficult in the settings the two groups typically find themselves, such as in endangered species conflicts or litigation—the groups usually fight instead of cooperate.

Stakeholders visited a new headgate at the Three Sisters Wychus Creek diversion in Oregon.

Courtesy of Kendrick Neubecker

Partnering with the University of Arizona and funded by a Walton Family Foundation grant, the Colorado Water Institute at CSU staged field trips to show environmental and agricultural stakeholders in the Colorado River Basin how their counterparts in the Pacific Northwest are successfully working together to keep water in agriculture as well as in the streams.

Two separate trips were staged—one for 23 Arizona stakeholders in August and a second for 25 Colorado stakeholders in September. Both trips featured visits to agricultural sites in central Oregon. The relationship building gained from agricultural and environmental stakeholders spending a full week together was as important a benefit as learning how Oregonians put together their creative multiple-gain agreements.

The goal: to set the stage for Ag producers and environmentalists in the Colorado River Basin to jointly identify and implement agricultural water conserving/water sharing strategies that result in freeing up water for the environment within the context of water scarcity and competition for water resources, while preserving agricultural productivity and rural economies.

Both trips took travelers to areas in Oregon, where irrigation efficiency improvements and other strategies have freed up water for the environment. Both trips included visits to the Upper Klamath Basin and the Deschutes Basin. In addition, the Arizona group toured projects on the Middle Fork of the John Day River.

The Colorado Trip

Colorado Water Institute's Reagan Waskom (director) and MaryLou Smith hosted the Colorado contingent. Participants included West Slope IBCC and Roundtable members, a student from the Yampa Valley studying water law, farmers from the Montezuma and Dolores Valleys, San Miguel and Mesa County ranchers, watershed groups, and those representing groups such as Colorado Water Trust, Trout Unlimited, The Nature Conservancy, and the Southern Ute and Ute Mountain Tribes.

Here are excerpts from their post-trip reflections:

- Both the Deschutes and Klamath Wood river basins face several drivers for flow restoration. These include the adjudication of tribal water claims, listed fish already within the basin or to be introduced, and state Wild and Scenic designations or other caps on new consumptive water development. Instead of continually resisting these drivers, these basins have turned them into cash registers for concurrently improving irrigation systems and restoring river flows.
- The cooperative flow restoration projects we saw in Oregon were built from the ground up by breaking them into manageable steps and not attempting to develop and implement comprehensive plans from the outset. They first entered into temporary water deals, including forbearance and non-diversion agreements and full and split season instream leases, before making permanent transfers and allocations of conserved ditch losses or consumptive use to bolster instream flows.
- Oregon's leasing laws have created a dynamic and widely used system that allows for water to be leased on an annual basis. This short-term approach seems to allow farmers, ranchers, and irrigation companies the ability to move their water freely between irrigated lands and the market as they see fit. While concerns persist with leasing agricultural water in Colorado, it would be helpful to see Colorado follow Oregon's dynamic and progressive example of fully developing and conserving their water resources to achieve maximum public and environmental benefit while benefitting agricultural production.
- Oregon showed us the value and necessity of working within multi-stakeholder groups to achieve shared benefits. Whether it was the Upper Klamath Basin where ranchers were devising water conservation strategies in order to preserve adequate flows for fish and the tribes, or in the Upper Deschutes Basin where irrigation districts were working hand-in-hand with state and local conservation organizations on line and pipe ditches and developing hydropower, the collaborations involving a large number of partners were impressive.
- Area farmers and ranchers were losing water through their open ditches to evaporation and leakage. The cooperating agencies put a plan together to pipe the ditch and, in return for having the costs covered, the irrigation company gave a portion of the saved water for instream flow to improve the river ecosystem and fish habitat. This collaboration avoided costly and divisive litigation as well as created more water for agricultural production.
- We could better manage our water resources by allowing greater flexibility in rules specific to an individual river basin rather than just statewide rules.
- The Conserved Water statute in Oregon would not work in the same manner here, but I do think there is potential for some kind of rule that would encourage and reward water users for conserving water and decreasing historic consumptive use. Using agricultural water more efficiently often has the added benefit of improving water quality and can reduce labor requirements, so anyone who helps make infrastructure improvements needed for such conservation financially possible can incur significant benefits to both his operation and the river system.
- Building hydroelectric plants on irrigation canals in Oregon is something that could be done here in Colorado. Since many of our systems have greater elevation head than exists Oregon, the potential may be even greater. If interests in our state could work together to improve the regulatory environment to allow such projects, it could help provide financing for needed water infrastructure improvements while decreasing our dependence on non-renewable energy.
- I was struck by the point made by Marc Thalacker of Three Sisters Irrigation District. He said in all their negotiation sessions with the environmental community, they focused on things the parties could agree on instead of those things they could not agree on. That gave them a very strong start at collaboration.
- The trip had characteristics of a retreat; energizing with focused discussions. The diverse Colorado contingent brought up many discussions between those of different basins—points of view that might not have been expressed without the travel and time spent away from daily pursuits.
- The passionate testimonies from the cattle ranchers in the Klamath Basin were remarkably powerful. When water users see a noticeable improvement in stream health by making small changes to their water use, they become more likely to protect the resource because of a sense of ownership in the solution.

A Success?

Participants from both states have already begun strategizing ways in which they might apply what they learned. Here is a statement from one of the participants that sums up the trips' success: "I look forward to using the knowledge gained from this trip to help me recognize and think 'bigger' about the opportunities that exist in my own state."

Photo courtesy of Kendrick Neubecker

Fighting Invasive Plants in the Arkansas River Basin: It's All About Partnerships

From the upper to lower reaches of the Arkansas River Basin in Colorado, partners are successfully winning battles against invasive plants. This article highlights some of the projects that have taken a targeted, watershed-scale approach.

Partnerships Along the Fourmile Watershed: An Upstream Battle

Jana Gregg and J.R. Phillips, Upper Arkansas Cooperative Weed Management Area

Weed management often feels like an upstream battle. And, often times, it is!

The Upper Arkansas Cooperative Weed Management Area (UACWMA) believes that operating within the framework of extensive partnerships allows for successful weed management on a watershed basis. UACWMA is the largest weed management area in the state and involves multiple weed management

Fremont County Weed Control, including Jana Gregg, Tom Grette, and J.R. Phillips, works closely with Natural Resources Conservation Service (NRCS) representatives Rick Romano and Melanie Scavarda and Fremont Conservation District Manager Janet Barnhart to develop plans and funding scenarios. Sangre de Cristo Resource Conservation and Development is essential to project planning; Mike Stiehl, president, who also serves as Fremont County Commissioner, and Jane Wustrow, coordinator, have been instrumental in providing administration and coordination for this watershed project. Colorado State University (CSU) graduate students have conducted a number of research plots in the area that involve various herbicide treatments, aerial applications, and mechanical methods, as described in Colorado Water's June/July 2011 issue. Most importantly, landowners have collaborated by contributing funds and labor and hosting weed tours and events on their properties.

Historically, the project involved field operations to control tamarisk and Russian-olive species. The second and third years included management strategies by local qualified supervisors to address secondary species. Integrated pest management methods include mechanical removal, herbicide applications, aerial applications, and biological controls. Some sites include the incorporation of research plots to test the various management strategies. The third year of the project will include reclamation and reseeding of previously treated areas. Natural restoration of native species is already apparent on project sites. In the final stages of the project, agency involvement will decrease and management will transition back to the primary care of the landowners. The outcome is an entire watershed area under noxious weed management and on its way to restoration.

Fourmile Creek showing natural restoration of native species.
Courtesy of Upper Arkansas Cooperative Weed Management Area

Apishapa, Chico Creek, and Huerfano River Watershed Projects

Patty Knupp, Private Lands Biologist, NRCS/CDOW/RMBO

The tamarisk control efforts in the Apishapa River Watershed began in 2005 with one interested landowner. To date, project partners have worked with 10 private and two public landowners and have controlled approximately 1,100 acres of tamarisk along approximately 50 river miles, including side drainages.

In 2008, work began in the Chico Creek Watershed. Four private and two public landowners participate and have controlled approximately 450 acres of tamarisk and Russian-olive.

Last year, tamarisk and Russian olive control began in the Huerfano River Watershed with 10 landowners controlling 1,245 acres.

Due to the linear nature of the tamarisk infestations in the three watersheds, which follow the zigzag, hard to reach drainages, the primary mode of control has been chemical application by helicopter. An integrated approach is necessary, and other techniques such as mechanical and hand treatment, along with biological control, have also been used. Landowners are committed to following up on this approach, a key part of the project's success. Project partners hope the tamarisk leaf beetle will establish itself and play a role in long-term control.

NRCS, one of the primary funding sources, has led these efforts. Another important funder has been the Colorado Division of Wildlife Wetlands Program. Many other partners also are involved in these projects.

Tackling Tamarisk on the Purgatoire

Colorado State Forest Service La Junta District

A main goal of Tackling Tamarisk on the Purgatoire (TTP) is to provide financial and technical assistance to private agricultural producers and other landowners to restore their lands through tamarisk and Russian olive removal. The purpose of TTP is to improve and restore riparian and associated areas of the Purgatoire River Watershed through removal and control of tamarisk and Russian-olive. Desired outcomes include improved water resources and native riparian plant and wildlife communities, protection of communities from wildfire and flooding, enhanced agricultural production, and improved hunting and recreational access and opportunities.

Project partners include private landowners, Branson-Trinchera Conservation District, City of Trinidad, Colorado Division of Wildlife, Colorado State Forest Service, Colorado State Land Board, Colorado State Parks, Colorado Water Conservation Board, Las Animas County, NRCS, Purgatoire River Water Conservancy District, Southeastern Colorado Water Conservancy District, Spanish Peaks-Purgatoire River Conservation District, The Nature Conservancy, Trinidad Community Foundation, U.S. Fish and Wildlife Service, and others.

The upper Purgatoire River and its tributaries, including the mainstem just below Trinidad Dam and the Chacuaco Creek drainage, exhibit intact native riparian vegetation and extraordinary biological diversity. However, tamarisk and Russian olive have been encroaching on this watershed for the past 50 years. Currently, the infestation is manageable in most of the upper watershed. Thus, removal will cost substantially less now than in the future, and the watershed will not require extensive revegetation efforts.

The Tamarisk Coalition began the project planning in 2006 by mapping infestations of tamarisk and Russian-olive. The next step was development of a strategic plan that was completed and approved by the Colorado Department of Agriculture (CDA) in 2008.

Since 2005, approximately 750 acres have been treated within the Purgatoire River Watershed on the upper end of the watershed, Trinidad State Park and reservoir; Purgatoire Mainstem, NRCS EQIP Invasives Program; Chacuaco drainage (largest tributary to the Purgatoire); and Purgatoire Mainstem, Trinidad River Walk.

Project partners also are working with the CDA to establish the tamarisk leaf beetles within the watershed as part of an integrated management approach. Tamarisk leaf beetles initially were released in the Purgatoire River Watershed in 2009, with an additional release in 2010.

Currently, TTP project partners are developing more intensive monitoring protocols for all projects implemented within the Purgatoire River Watershed. These protocols will include effectiveness of control, water quality/quantity, soil quality and vegetation response. Intensive monitoring began in the fall of 2010, conducted by a Denver University team led by Dr. Anna Sher. By 2013, user-friendly monitoring protocols will be developed for use by private landowners and land managers. Funding for this research is provided by the Colorado Water Conservation Board, The Nature Conservancy and the U.S. Fish and Wildlife Service. TTP also was recently awarded additional funding

Trinidad River Walk before and after Russian-olive removal.

Photos by Dick Louden, TTP field coordinator

through the NRCS Conservation Innovation Grant (CIG) program.

The Bioagricultural Sciences and Pest Management Department in the College of Agriculture at CSU also is conducting research on the mainstem of the Purgatoire, focusing on using fire as part of an integrated approach to controlling tamarisk. This research is being led by graduate student Cameron Douglass with oversite from Dr. Scott Nissen. Funding for the research also is provided by the NRCS CIG program.

Tamarisk Biocontrol in the Arkansas River Basin

Dr. Dan Bean, Colorado Department of Agriculture Palisade Insectary

Classical biological weed control utilizes natural enemies from a weed's location of origin to suppress invasive weed populations in the introduced range. Successful weed biocontrol is safe, economical, and self-sustaining, and can play a long-term role in tamarisk and other weed management.

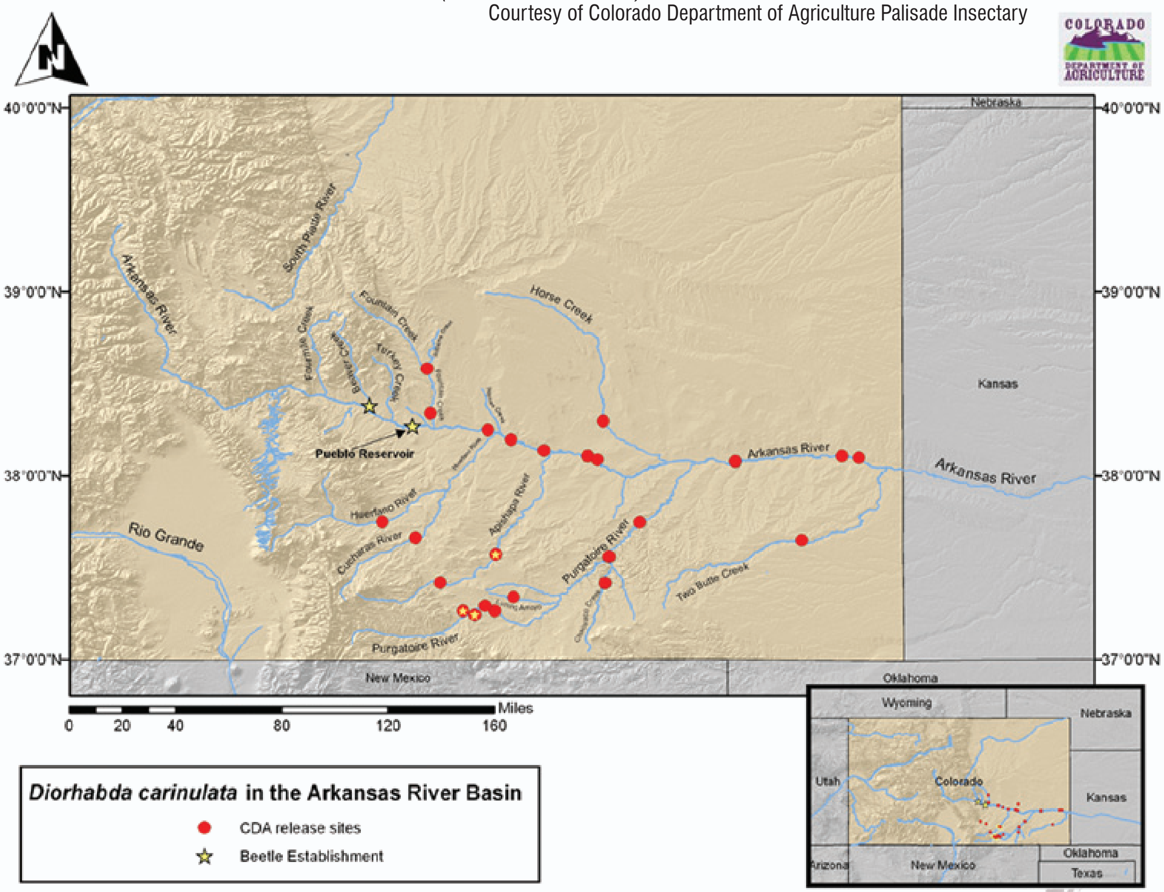
The tamarisk biocontrol program started in the late 1960s, gaining momentum about 20 years later as the magnitude of the tamarisk problem became more evident. By 1998, after extensive safety tests, the first tamarisk biocontrol agent was ready for testing. The agent was the northern tamarisk beetle (Diorhabda carinulata), a small black and yellow striped insect about the size of a lady beetle. The larvae are voracious tamarisk feeders well known to occasionally defoliate tamarisk plants in central Asia, where both tamarisk and beetle are native. In North America, the first trial releases of the tamarisk beetle were made in cages along the Arkansas River, below Pueblo Reservoir. The beetles thrived, defoliating tamarisk locally within and outside of cages. These encouraging results helped launch the program across the western U.S.

In western Colorado, tamarisk beetles have defoliated long stretches of tamarisk along the Colorado, Dolores, Green, Gunnison, Mancos, and Yampa rivers since 2007. In some locations, tamarisk mortality is nearly 50 percent of the monitored trees. A significant decline in green foliage occurred and the tamarisk canopy opened up, even when the shrubs weren't completely dead. By opening the canopy, the beetles help boost native plant growth. In addition, mechanical and chemical control measures are more effective in preventing regrowth of tamarisk plants weakened by the beetles.

Beetles are collected and packaged in western Colorado for shipment farther east. About 10,000 beetles are released at a time, usually in June or July. Twenty-four release sites are established in the Arkansas Basin. In 2008, 175,000 beetles were released, mostly along or near Fountain Creek; in 2009, another 290,000 beetles were released throughout the Arkansas Basin; and in 2010, 225,000 beetles were released. Monitored trees were examined for adults, eggs, and larvae. Beetles are not considered established until verified that they have overwintered and have emerged the next spring/summer. Beetle releases in 2008-2009 resulted in some establishment, but few beetles survived at most of the release sites.

One reason beetles do not survive is because predators like spiders and birds feed on them. However, the most voracious predators are ground-dwelling ants that eat beetles when they go down into the leaf litter to pupate or to overwinter as adults. High numbers of carnivorous ants were found at many of our field sites, and in 2010, some sites were treated with ant bait to reduce the impact of predation.

Arkansas River Basin Tamarisk Beetle (Diorhabda carinulata) Release Sites and Establishment Areas.
Courtesy of Colorado Department of Agriculture Palisade Insectary



Thanks to GayLene Rossiter, Colorado State Forest Service,
for her work compiling and editing
this collection of articles.

A Decade Later: Celebrating Student Assistants

Celebrating 10 Years • 2001 - 2011 Water Resources Archive

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

For most of the decade of its existence, the Water Resources Archive has operated with just one full-time employee. Able assistance in managing the growing physical and digital collections has been provided by nearly 20 students over that same time period. Many of them have been history undergraduate or graduate students, and, no matter what academic discipline, most have had an interest in history or library-related careers.

Student assistants contribute a great deal to the Water Resources Archive, from organizing collections and creating exhibits to managing digitization projects and assisting patrons. Working for the Archive impacts the students as well. They not only receive training in the basics of archival work, but they also encounter a multitude of learning opportunities. Perspectives from three current student assistants illuminate this impact.

Student archive assistants Clarissa Trapp, Jordan Deignan, and Alan Barkley (front) make significant contributions to preserving and accessing historical water documents.

Courtesy of Patricia J. Rettig

Alan Barkley, Graduate Student in History

Living in Boulder County near Baseline Reservoir and the Anderson Ditch for most of my life showed me that water use in Colorado was a complicated subject. However, I did not grasp the full extent of its complexities until I had worked at the Water Resources Archive for several months. Now, after a year of processing and exploring the collections, I know only a small fraction of the history, conflict, and influence of water throughout the western United States. Beyond the practical applications of archival work, that is perhaps the most important lesson the Archive has taught me: there is always more to learn about any topic, especially one as integral to our lives as is water.

My favorite part of working in the Archive has been developing and installing exhibits in the reading room. Though we only have a small exhibit space, we can still tell informative and important stories using archival documents and artifacts. I relish the chance to display and interpret historic items in a public setting; the challenge of presenting history through artifacts and documents is rewarding. The Archive has nearly unlimited stories to tell throughout its collections. Uncovering and interpreting them is a fascinating process.

Working at the Archive has provided me with opportunities to interact with and care for documents and artifacts that have intensified my desire to pursue a career in a similar vein of public history. The professional experience I have gained in my time at the Archive will help prepare me for work in a museum or archive once I complete my studies at CSU.

Jordan Deignan, Senior History Major with Social Studies Teaching Concentration

The Water Resources Archive gives me an opportunity to work with genuine historical information pertaining specifically to Colorado water. While dealing with the collections in the Water Resources Archive, I have learned that a lot of our collections are not only connected to each other, but also to broader historical concepts.

My favorite part about the Water Resources Archive is knowing that the work I do will benefit the research and intellectual desires of many water enthusiasts. Working on the collection of papers from Arthur Littleworth (Special Master for *Kansas v. Colorado*), I gained incredible insight into the world of water litigation, and the collection may be used someday in making new water law!

Working in the Water Resources Archive will benefit my future career as a history teacher greatly. I recently worked on a project that helped tell the story of the 1976 Big Thompson flood to elementary school kids. Working on these types of projects not only enhances my knowledge of water, but also gives me tools to be a successful teacher in the future.

Clarissa Janssen Trapp, Graduate Student in History

As an Iowa farm girl growing up on a farm my dad referred to as "the lowest spot in the county," I thought of water as something to be drained away rather than something to be contested and collected. Then I moved to Fort Collins to pursue a Master of Arts in History, and I landed a job as a Water Resources Archive digitization assistant on a CWCB (Colorado Water Conservation Board)-funded project focused on groundwater in Colorado. While selecting materials for digitization, I began to see how complicated and contentious water was and is in the state. I decided Coloradoans were crazy. I could not, however, deny that water issues in Colorado and the rest of the American West were also compelling and fascinating. In fact, during the year I have worked at the Archive, my interest has grown into a desire to continue researching and working on water-related topics.

Beyond my interest in the content of the Water Resources Archive, the best part about working here is that it presents daily opportunities for professional growth as a historian and archivist. In the last year, I discovered a great deal about the history and development of my adopted state, and I became a better researcher by helping patrons investigate a variety of topics. I learned the steps and skills necessary to digitize archival materials, from creating metadata to loading digital files into online databases. I am currently learning to process new collections that arrive in the archive almost weekly. Perhaps most importantly, I found that I had misconceived archiving as boring and lonely work. Instead, working in the Water Resources Archive has allowed me to pursue interesting topics and meet a plethora of fascinating people, and it has opened the doors to previously unconsidered careers working with history and the public.

The Future

The future of history looks bright in such capable hands. These students, as have those before them, will go on to perhaps be curators, teachers, or researchers. They will be able to share what they have learned working for the Archive with the next generation. One thing is certain: their contributions to preserving historical documents and bringing them to the public will live on in the Water Resources Archive.

Photo By Kyle Thompson

Faculty Profile

Greg Perry

Lindsey A. Knebel, Editor, Colorado Water Institute

Greg Perry started his position as Head of the Department of Agriculture and Resource Economics at CSU on July 15, 2011. Perry joined CSU from Oregon State University-Corvalis (OSU), where he was on the faculty for 25 years. He brings significant administrative experience to the job, including a stint as interim department head, a year working as a special assistant in the dean's office, and serving as co-chair of the university's Curriculum Council, which approves and reviews course curriculums.

In addition to carrying out his leadership and administrative responsibilities, Perry expects to conduct research in the water area. Although still in the learning phase, Perry says he's becoming aware of complex issues like selenium loading, state-to-state compact issues, and water rights.

Perry compares Colorado's water issues to Oregon's, saying that eastern Oregon is much like the drier slope of western Colorado. "But," he says," "Colorado has many more water problems than Oregon. The entire state faces water shortages."

"A good economic analysis can help inform a lot of these decisions," he says.

Despite his short time in Colorado, Perry says that agricultural water usage will continue to be a major research area for his department. In meetings with stakeholders, he's learned that "water is the number one priority among major stakeholders for the College of Agricultural Sciences. They don't see scarcity issues going away." This is important, he says, because agriculture accounts for such a large percentage of water usage in the state.

Perry says that many faculty members in the department are currently working on important water, agriculture, and economics research and outreach. He notes James Pritchett and Chris Goemans for their active field work, as well as Marshall Frasier, who he says is a resource for knowledge on water topics.

Perry is himself already in the beginning stages of a project in the San Luis Valley. The project will use land sales prices to identify the underlying value of water rights on these properties.

Perry says his involvement in water knowledge and research began as early as his academic career—his master's thesis at Utah State University was on cloud seeding, he says, and he also completed a minor in water hydrology as part of his master's program. He then spent a year working on water issues for rice farms in Texas.

In addition to academics, Perry says he gained "a lot of practical irrigation experience" from his father-in-law, a farmer, and he says that most of his career has involved water issues. "I understand water issues from the perspective of farmers, canal companies, environmentalists, and municipalities," he says.

Perry is preparing to teach classes in the spring—AREC 305, Agricultural and Resource Enterprise Analysis, a class that applies financial analysis to real-world, small business situations.

Perry says that his future research might include working with land use—reducing the amount of water used by proposing more efficient use of space. He gives, for example, the idea that building up is better than building out—less property per household limits water consumption for things like lawn care.

He also foresees his department working on more water policy analysis. "As I've listened to shareholders from the state and administrators on campus," he says, "I think there's a need for input from our department on water-related policy."

Good policy, says Perry, can "cause water to move in ways that are beneficial to society." Bad policy, he says, can cause many problems. "We want to play a bigger role in policy both on campus and statewide."

Perry notes that he has received "great feedback" from the state as to the quality of CSU's water outreach programs. Perry says that his career at CSU will encompass all these areas. "I expect I'll be doing more water research and outreach in the future," he says.

Greg Perry
Department Head

Colorado State University

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Recent Publications

Hydrogeology and simulation of groundwater flow in the Arbuckle-Simpson aquifer, south-central Oklahoma; 2011; SIR; 2011-5029; Christenson, Scott; Osborn, Noel I.; Neel, Christopher R.; Faith, Jason R.; Blome, Charles D.; Puckette, James; Pantea, Michael P.

Active Metal and Industrial Mineral Underground Mines in the United States in 2009; 2011; USGS Unnumbered Series;

Assessment of undiscovered oil and gas resources of the Devonian Marcellus Shale of the Appalachian Basin Province; 2011; FS; 2011-3092; Coleman, James L.; Milici, Robert C.; Cook, Troy A.; Charpentier, Ronald R.; Kirshbaum, Mark; Klett, Timothy R.; Pollastro, Richard M.; Schenk, Christopher J.

Assessment of coal geology, resources, and reserves in the Southwestern Powder River Basin, Wyoming; 2011; OFR; 2011-1134; Osmonson, Lee M.; Scott, David C.; Haacke, Jon E.; Luppens, James A.; Pierce, Paul E.

Approaches to highly parameterized inversion: A guide to using PEST for model-parameter and predictive-uncertainty analysis; 2010; SIR; 2010-5211; Doherty, John E.; Hunt, Randall J.; Tonkin, Matthew J.

Site-specific seismic-hazard maps and deaggregation in the western United States using the NGA models for ground-motion prediction; 2011; OFR; 2011-1218; Harmsen, Stephen

Abbreviated bibliography on energy development—A focus on the Rocky Mountain Region; 2011; OFR; 2011-1206; Montag, Jessica M.; Willis, Carolyn J.; Glavin, Levi W.

Trace elements and radon in groundwater across the United States, 1992-2003; 2011; SIR; 2011-5059; Ayotte, Joseph D.; Gronberg, Jo Ann M.; Apodaca, Lori E.

Climate Change and Sea-Level Rise in Florida - An Update of the Effects of Climate Change on Florida's Ocean and Coastal Resources; 2010; Other Government Series;

Land-cover change research at the U.S. Geological Survey-assessing our nation's dynamic land surface; 2011; FS; 2011-3080; Wilson, Tamara S.

Accuracy of flowmeters measuring horizontal groundwater flow in an unconsolidated aquifer simulator.; 2011; Article; Journal; Ground Water Monitoring & Remediation; Bayless, E. R.; Mandell, Wayne A.; Ursic, James R.

Radium content of oil- and gas-field produced waters in the northern Appalachian Basin (USA)—Summary and discussion of data; 2011; SIR; 2011-5135; Rowan, E. L.; Engle, M. A.; Kirby, C. S.; Kraemer, T. F.

Conceptual model of the Great Basin carbonate and alluvial aquifer system; 2011; SIR; 2010-5193; Editors: Heilweil, Victor M.; Brooks, Lynette E.

An inventory and monitoring plan for a Sonoran Desert ecosystem; Barry M. Goldwater Range-West; 2011; OFR; 2011-1232; Villarreal, Miguel L.; van Riper, Charles, III; Lovich, Robert E.; Palmer, Robert L.; Nauman, Travis; Studd, Sarah E.; Drake, Sam; Rosenberg, Abigail S.; Malusa, Jim; Pearce, Ronald L.

U.S. Geological Survey Science for the Wyoming Landscape Conservation Initiative-2010 Annual Report; 2011; OFR; 2011-1219; Edit Bowen, Zachary H.; Aldridge, Cameron L.; Anderson, Patrick J.; Assal, Timothy J.; Biewick, Laura R.H.; Blecker, Steven W.; Boughton, Gregory K.; Bristol, Sky; Carr, Natasha B.; Chalfoun, Anna D.; Chong, Geneva W.; Clark, Melanie L.; Diffendorfer, Jay E.; Fedy, Bradley C.; Foster, Katharine; Garman, Steven L.; Germaine, Stephen; Holloway, JoAnn; Homer, Collin; Kauffman, Matthew J.; Keinath, Douglas; Latysh, Natalie; Manier, Daniel; McDougal, Robert R.; Melcher, Cynthia P.; Miller, Kirk A.; Montag, Jessica; Potter, Christopher J.; Schell, Spencer; Shafer, Sarah L.; Smith, David B.; Stillings, Lisa L.; Tuttle, Michele; Wilson, Anna B.

Stoeckel, D.M., Stelzer, E.A., Stogner, R.W., and Mau, D.P., 1022, Semi-quantitative evaluation of fecal contamination potential by human and ruminant sources using multiple lines of evidence: Water Research, v. 45, p. 3225-3244. http://co.water.usgs.gov/publications/non-usgs/2011_V45_WaterResearch.pdf

Ruddy, B.C., 2011, Probability and volume of potential postwildfire debris flows in the 2011 Horseshoe II burn area, southeastern Arizona: U.S. Geological Survey Open-File Report 2011–1197, 10 p.

Williams, C.A., Moore, J.L., and Richards, R.J., 2011, Assessment of Surface-Water Quantity and Quality, Eagle River Watershed, Colorado, 1947–2007: U.S. Geological Survey Scientific Investigation Report 2011–5075. http://pubs.usgs.gov/sir/2011/5075/

Water Research Awards

Colorado State University (July 16 to September 15, 2011)

Arabi, Mazdak, Civil & Environmental Engineering, USDA-NRCS Natural Resources Consvtn Srv, Assessment of Conservation Practices in Arkansas, Lower St. Francis & Bayou Macon, $90,000

Arabi, Mazdak, Civil & Environmental Engineering, USDA-NRCS-Natural Resources Consvtn Srv, Assessment of Conservation Practices in Arkansas, Cache River Watershed and Bayou Meto Watershed, $60,000

Bestgen, Kevin R, Fish, Wildlife & Conservation Biology, DOI-Bureau of Reclamation, Population Abundance & Dynamics of Introduced Northern Pike, Yampa River, Colorado, $60,000

Clements, William H, Fish, Wildlife & Conservation Biology, DOI-USGS-Geological Survey, Mechanisms of Metal Uptake & Transfer in Stream & Riparian Food Webs, $149,985

Collett, Jeffrey L, Atmospheric Science, DOI-NPS-National Park Service, GrandTRENDS: the Grand Tetons Reactive Nitrogen Deposition Study, $499,972

Cooper, David Jonathan, Forest & Rangeland Stewardship, USDA-USFS-Forest Research, Papoose Meadows Restoration Project, $25,500

Doesken, Nolan J, Atmospheric Science, Canadian Wheat Board, Community Collaborative Rain, Hail and Snow Network (CoCoRaHS) Program, $50,000

Duda, Joseph A, Colorado State Forest Service, USDA-USFS-Forest Research, Western Bark Beetle, $289,000

Garcia, Luis, Civil & Environmental Engineering, DOI-Bureau of Reclamation, Modification and Enhancement of the LCRAS Evapotranspiration Application, $20,264

Hawkins, John A, Fish, Wildlife & Conservation Biology , DOI-Bureau of Reclamation Monitoring of Potential Colorado Pikeminnow Entrainment in the Maybell Canal, Yampa River, Colorado, $2,853

Loftis, Jim C, Civil & Environmental Engineering, DOI-NPS-National Park Service, Tracking, Assessing, and Understanding National Park System Impaired Water Resources, $207,000

Loomis, John B, Agric & Resource Economics, DOI-USGS-Geological Survey, Valuation of Water Resource Benefits from Landsat Imagery, $27,000

Myrick, Christopher A, Fish, Wildlife & Conservation Biology, Colorado Division of Wildlife, Investigation of the Effects of Whitewater Parks on Aquatic Resources in Colorado, $49,800

Myrick, Christopher A, Fish, Wildlife & Conservation Biology, DOI-BLM-Bureau of Land Management, Are Western Sucker Swimming Performances Interchangeable? Comparing the Swimming Performances of Five Sucker..., $60,000

Poff, N LeRoy, Biology, DOI-Bureau of Reclamation, Developing climate analysis tools for the upper Colorado River basin, $104,704

Rathburn, Sara L, Geosciences, DOI-USGS-Geological Survey, Analyze & Map Cottonwood Forest Area-Age Distribution for the Flood-Plain Forest of the Little Missouri Rive..., $18,995

Reich, Denis A, CSU Extension, DOI-Bureau of Reclamation, Quantifying and Promoting Deficit Irrigation in Commercial Peach Orchards of Western Colorado, $24,645

Reich, Denis A, CSU Extension, USDA-NRCS-Natural Resources Consvtn Srv, Irrigation Water Management Training (IWM) for NRCS field office staff in Area 1, $950

Roesner, Larry A, Civil & Environmental Engineering, WateReuse Research Foundation, Treatment, Public Health, and Regulatory Issues Associated with Graywater Reuse, $50,000

Roesner, Larry A, Civil & Environmental Engineering, CSURF-CSU Research Foundation, Determine the Biological Efficacy of Graywater Reuse, $54,056

Rondeau, Renee, Colorado Natural Heritage Program, The Nature Conservancy, USFWS Climate Change Resilience Model in Gunnison Basin, $10,500

Swift, David M, Natural Resource Ecology Lab, DOI-NPS-National Park Service, Investigation of Nitrogen Deposition into Loch Vale, $20,000

Thornton, Christopher I, Civil & Environmental Engineering, OEA, Inc., Bonner Bridge Scour Test Program, $211,700

Thornton, Christopher I, Civil & Environmental Engineering, DOD-ARMY-Corps of Engineers, Full Scale Wave Overtopping Testing, $1,919,463

Waskom, Reagan M, Colorado Water Institute, DOI-USGS-Geological Survey, MOWS - Modeling of Watershed Systems NIWR-USGS Student Internship Program, $20,000

Winkelman, Dana, Cooperative Fish & Wildlife Research, DOI-USGS-Geological Survey, Evaluation of PIT Tag Antennae Array & Analysis of Humpback Chub PIT Tag Antennae Data from Little Colorado River, $50,792

Calendar

November

7 **Colorado College State of the Rockies Project**

14 **WQCC Meeting**
The Commission meets the second Monday (and Tuesday, if necessary) of the month to develop and maintain comprehensive programs for the prevention, control and abatement of water pollution and for the protection of water quality in the state.

30 **IBCC Meeting; Loveland, CO**
The thirty-sixth meeting of the Interbasin Compact Committee formed under the Colorado Water for the 21st Century Act. All meetings are open and the public is encouraged to attend.
http://cwcb.state.co.us/about-us/about-the-ibcc-brts/Pages/main.aspx

CAWA/IBCC Reception

December

1 **Colorado Ag Water Alliance: "Ag Water Summit"; Loveland, CO**
One day meeting to explore agricultural water issues and solutions for keeping water in agriculture
coagwater.colostate.edu/

5 **Colorado College State of the Rockies Project; Colorado Springs, CO**
"The Colorado River Basin and Climate: Perfect Storm for the 21st Century?" Presented by Beth Conover, Stephen Saunders, Jeff Lukas

8-9 **The Essentials of Buying and Selling Water Rights; Denver, CO**
Third annual Water Marketing Conference. Stay up-to-date on the issues surrounding the buying and selling of water rights in Colorado.
www.cle.com/watermarketing

12 **Water Quality Control Commission Meeting; Denver, CO**
There will be a Colorado River Salinity Standards hearing on this date.

January

25-27 **Colorado Water Congress Annual Convention; Denver, CO**
The event draws more than 500 attendees from across Colorado, including legislators, representatives of state and federal agencies, leading water attorneys, water resource managers, engineers, scientists and a broad spectrum of water users.
http://www.cowatercongress.org/AnnualConvention/index.aspx

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Autumn leaves in Silverdale, Colorado.

Photo by Chad K.