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Colorado State University

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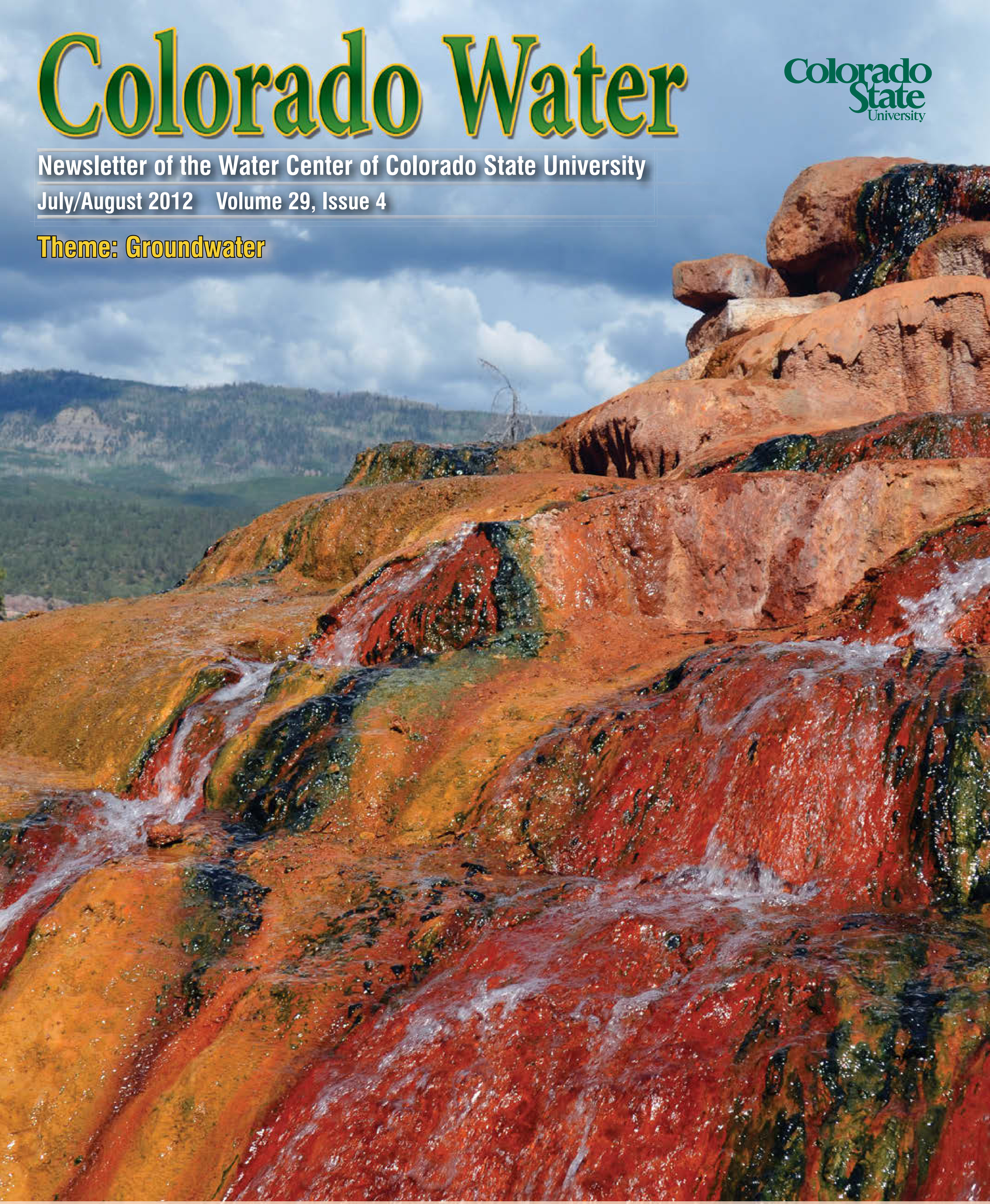

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Highlights

In Every Issue

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Front Cover: Pinkerton Hot Springs, Durango, Colorado. Photo by Kyle Thompson

This Page: Box Canyon Falls, Ouray, Colorado. Photo by Frank Swift

Editorial

by Reagan Waskom, Director, Colorado Water Institute

In January of this year, Colorado Governor John W. Hickenlooper declared 2012 the "Year of Water." Thus far, Colorado's Year of Water has been dominated by a serious deficit of winter snowpack, spring runoff, and summer rain. We've experienced record high temperatures and extreme drought across the state this year, leading to deadly forest fires and withered crops and grazing lands. In years like this, reservoir storage and groundwater aquifers are critical to our economic resilience and social well-being.

The importance of groundwater for Colorado's agricultural and domestic use is evident in the many recent news stories related to groundwater. The media have produced numerous stories this year on hydraulic fracturing for oil and gas development, elected officials calling for well pumping forbearance to mitigate drought impacts, rising groundwater levels in the S. Platte Basin damaging basements and waterlogging crop fields. We witness the recent struggles in the San Luis Valley to arrive at sustainable use of their aquifer system through tightly managed subdistricts, the compact dispute on the Republican River that apparently must be resolved through reductions in groundwater withdrawals, and our communities south of Denver that seek renewable surface water supplies to replace their reliance on Denver Basin groundwater.

Approximately 18 percent of all water used in Colorado is groundwater, either tributary or nontributary. Some 1.2 million acres of Colorado cropland derive all or part of their water from aquifers. States to the east of Colorado have even higher dependence upon groundwater for domestic and public drinking water supplies. Nonetheless, for many of those in Colorado dependent upon groundwater, particularly in the eastern and southern parts of the state, often no other source of water is available locally to meet their needs.

Colorado has implemented an array of management and protection programs over the past five decades to steward this resource, yet we are still working to refine our understanding and administration of groundwater. Part of the challenge is the difficulty of directly observing the impacts of pumping, artificial recharge, and natural recharge. It is hard to see these impacts as they occur, and there are many physical interactions involved, underscoring the utility of well-calibrated models to help us better visualize and understand groundwater systems. Likewise, groundwater contamination can occur undetected and can be very difficult and expensive to clean up, thus the need for proactive programs and regulations to avoid contamination.

How can we better utilize, manage, and protect our groundwater resources? What's needed—better science or better policy? Obviously, both are critical. University scientists and engineers have long been working on groundwater characterization and modeling—at CSU going back to Professor Ralph Parshall's early published groundwater research in the 1920s. This issue of *Colorado Water* newsletter outlines just a few of the many groundwater studies currently underway at CSU. University faculty are currently working to better describe and model the interactions between groundwater, surface water, and human activities on the land surface. Most recently, the Colorado Water Institute has been charged by the state legislature under Representative Fischer's HB12-1278 to undertake a new 18-month study of groundwater management in the S. Platte alluvial aquifer. The role of the university in this study is to bring high-quality unbiased scientific methods to the analysis and interpretation of existing data to understand why groundwater levels are rising in parts of the basin and if there are opportunities for better management. We'll plan to keep our readers informed on the findings and output of this work as it unfolds.

Semi-Analytical Models for Groundwater Management in Alluvial Aquifers Connected to Streams

Domenico Baú and Azzah Hassan, *Civil and Environmental Engineering, Colorado State University*

Introduction

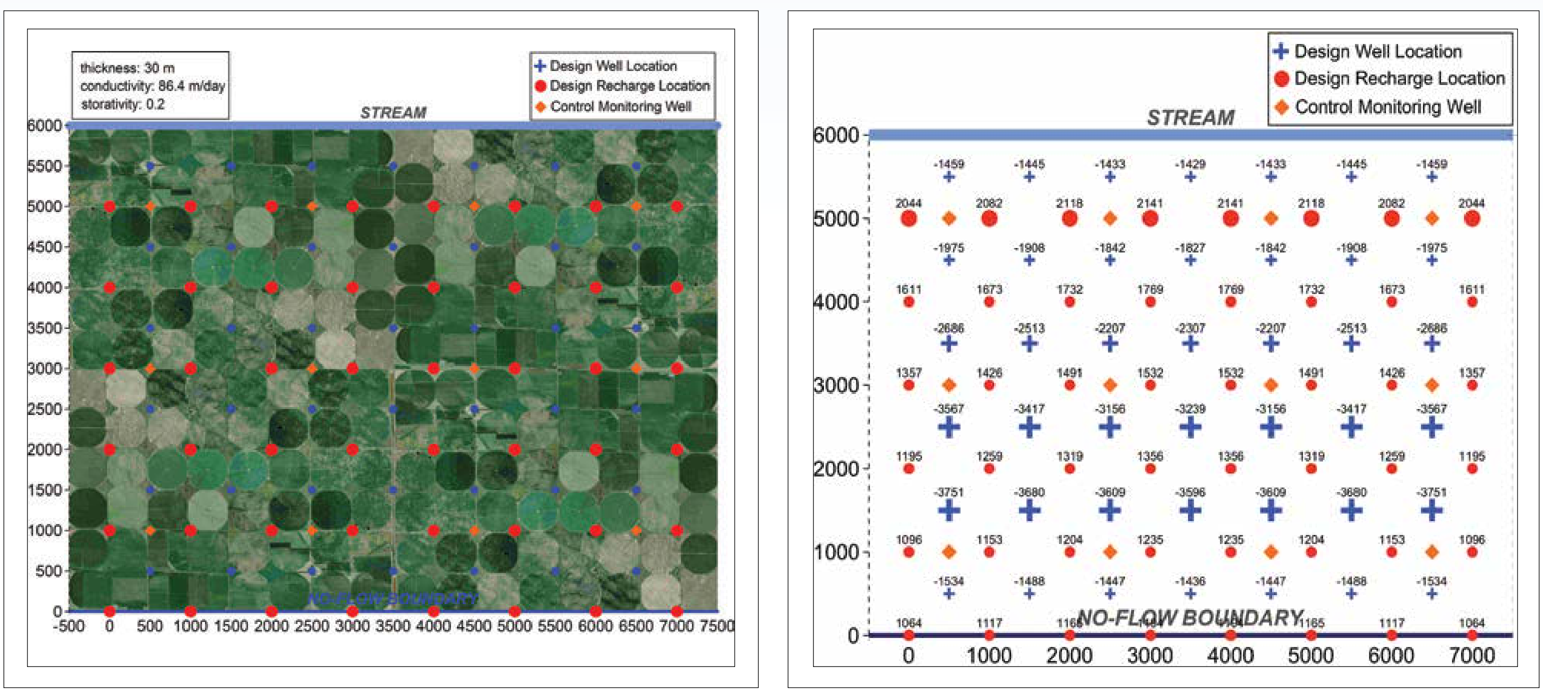
In water management, conjunctive use is defined as the combined use of surface and water resources in order to maximize the global net benefit of users. In Colorado, conjunctive use is of paramount importance for shallow aquifers situated in the South Platte and in the Arkansas River basins. Indeed, these aquifers, which were formed by alluvial deposition processes, are hydraulically connected to the surface network of streams and irrigation ditches, such that consumptive use of subsurface water inevitably affects surface water regimes and vice versa. In the Western U.S., water use is mostly regulated under the Doctrine of Prior Appropriation, which gives senior water rights to users with earlier appropriation dates (first in time, first in right). Each year, senior users have the right to use water according to their full allocation, if available, over "junior" users, who can exert their water rights only if they do not impinge on water rights that are senior to them. Historically, surface water rights (stream direct flow, reservoirs) were fully allocated by the 1920s. Well water rights were adjudicated much later concurrently with the development of high capacity turbine pumps, as it became evident that the use of groundwater had an impact on stream flows. As a result, groundwater users are generally junior to surface users and, in times of drought, might not receive their full allocation.

Since groundwater users can injure senior water rights, it is widely acknowledged that the regulations established by the Doctrine of Prior Appropriation impose limitations to the conjunctive use of water resources. Given these limitations, the management of groundwater resources in Colorado is often thought of as the identification of pumping schemes that meet irrigation demands while minimizing the impact on stream flows.

Semi-Analytical Models

The earliest fundamental analytical solutions for assessing the impact of constant-rate well pumping on water levels and stream flows in aquifers hydraulically connected to streams were obtained by Theis (1935) and Glover and Balmer (1954). These analytical models hypothesize the aquifer as constant-thickness, homogeneous and isotropic, and semi-infinite, i.e. limited by a rectilinear boundary representing the stream. Jenkins (1968) proposed the

Figure 1. *(a) Aquifer Setting and optimal pumping schemes for* *(b) Scenario 1,*



stream depletion factor (SDF) method to extend the Glover model to finite heterogeneous aquifers bounded by meandering streams.

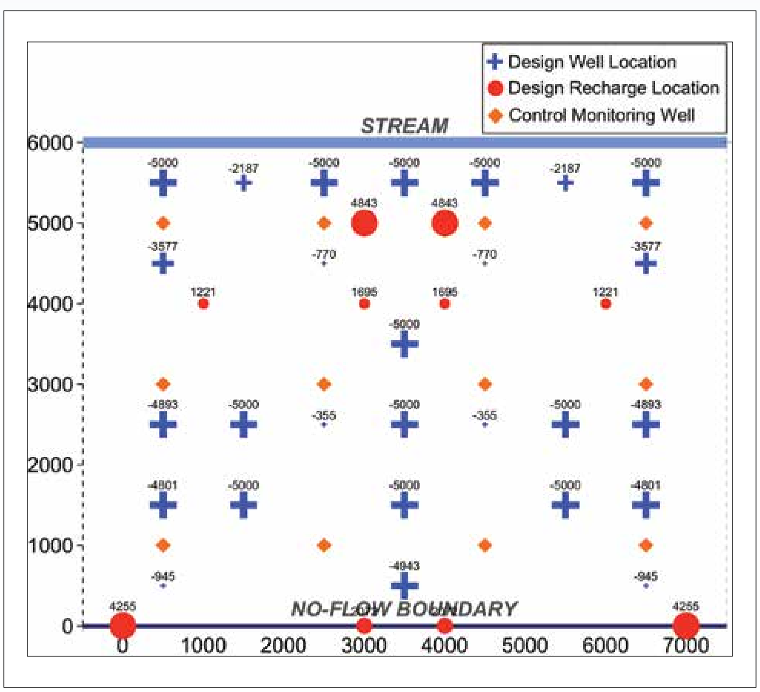
Most often, the applicability of these models to realistic conditions is limited by the simplifying hypotheses on which they rely, which make them valid only under much idealized conditions. For real-world scenarios, the use of numerical models, such as USGS's MODFLOW, is strongly preferable. However, given that these models can be computationally very expensive, the use of close-form analytical solutions remains attractive for analyzing the dynamics of aquifer-stream interaction, screening calculations and overall risk assessment. This explains why models based upon the Glover solution or the SDF method are still broadly used by regulatory agencies to estimate stream depletion due to groundwater pumping and to evaluate plans for stream augmentation by groundwater recharge.

These analytical models were originally developed for semi-infinite aquifers under constant-rate pumping from a single well. In practice, alluvial aquifers have a finite width and are bounded between the stream and another boundary, which can be modeled as impervious, where the alluvium terminates, or as a recharge boundary, where the aquifer is in hydraulic contact, for example, with an irrigation ditch. In addition, every year, irrigation pumping occurs from several wells, which are operated only during the growing season with generally variable pumping rates.

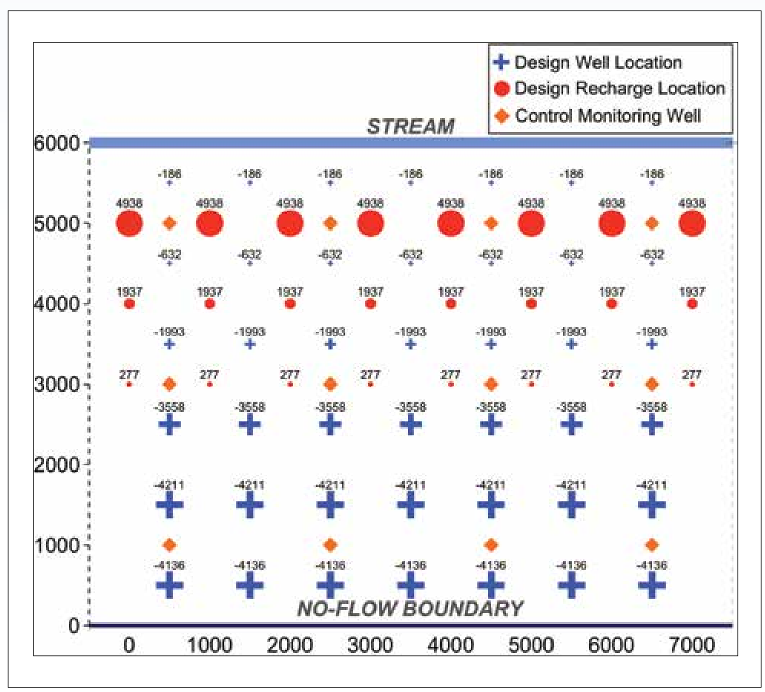
In these situations, both Theis and Glover's models can be extended to account for the effect of boundaries and multiple wells with time-varying pumping rates. Indeed, since these models are linear, there exists a direct time-dependent proportionality between well pumping rate, head drawdown, stream depletion rate, and stream depletion volume. Therefore, superposition of effects and temporal convolution methods can be applied to estimate the impact on water level and stream flow of well fields, no-flow or constant-head boundaries parallel to the stream, and time-varying pumping rates. Based on these ideas, we have developed a suite of semi-analytical models that rely upon Theis and Glover's analytical solutions to simulate and plot the water level spatial-temporal distributions and the time series of stream depletion rate and stream depletion volume due to a well field in which each well operates cyclically over prescribed on-off sequences.

These models are developed for three basic alluvial aquifer conditions: 1) semi-infinite aquifer in hydraulic contact with a stream; 2) finite-width aquifer in hydraulic contact with a stream on one side and delimited by a no-flow physical boundary on another; 3) finite-width aquifer in hydraulic contact with a stream on one side and another stream, or an irrigation ditch, on the other side. These models are implemented in MATLAB and, together with explanation notes and user manuals, are made available upon request to anyone that may be interested in their application.

(c) Scenario 2,



and (d) Scenario 3.



Optimization-Based Groundwater Management

The semi-analytical basis of the developed models makes them computationally very efficient and ideal for simulation-optimization applications to groundwater management problems. Let us consider, for example, the setting depicted in Figure 1a, which represents the 6-km by 8-km stretch of an alluvial aquifer comprised between a stream and a no-flow boundary. The aquifer is used to provide water for irrigation during the four-month growing season (April 1–July 31) in the cumulative amount of 1.2×10^{7} cubic m/year (1000 acre-feet/year). A proposed solution to potential stream over depletion is to acquire an equivalent amount of surface water to recharge the aquifer in a manner that offsets stream depletion rates. Recharge is assumed to occur every year for 180 days, starting October 1.

Given a number of potential or pre-existing well locations and recharge areas (Figure 1a), the groundwater management goal is to identify the spatial distribution of pumping wells and aquifer recharge ponds that minimize the absolute value of the stream depletion volume over an operation period of 10 years. Management constraints are imposed to the maximum pumping capacity of injection wells and the maximum injection rate of each recharge area, which are both set equal to 5000 cubic m/day (about two cubic feet per second). The aquifer has an average saturated thickness *t* of 30 m and, to smooth the variation of water levels, constraints are imposed such that this *t* must be < 29 m and < 31 m at a number of control monitoring wells (Figure 1a). In practice, the water level variations will be significantly larger nearby pumping wells or recharge areas.

Using the semi-analytical models previously described, the groundwater management may be formulated into a linear optimization problem wherein the decision variables are represented by the pumping rate at potential wells and the injection rate at potential recharge locations. Because of the computational efficiency of semi-analytical models, such linear programming (LP) problems may be solved at a relatively low computational cost, which allows for extensive analyses of the systems, thus achieving improved insight into key aspects of groundwater management.

For this hypothetical base case, termed Scenario 1, the optimal solution to the formulated LP problem is presented in Figure 1b. During their respective operation periods, all candidate wells and recharge ponds are "activated" at the rates noted above each marker in Figure 1b. In this scenario, the net volume of stream depletion over 10 years is equal to zero, which indicates that all irrigation demand is truly met by extracting groundwater in equal amounts to the aquifer recharge. In Figure 1b, it is interesting to observe that pumping rates are lower in proximity of the stream in order to minimize stream depletion, and in proximity of the no-flow boundary of the aquifer in order to minimize aquifer depletion. Conversely, recharge rates are progressively decreasing away from the stream, which suggests that a significant portion of recharged water is being used for stream augmentation.

Figure 1c displays the dramatic change in the optimal layout under more stringent water level constraints (29.5 < *t* < 30.5 m) at monitoring wells (Scenario 2). Even though enough recharge capacity is available to satisfy the irrigation groundwater demand, the stream is depleted of

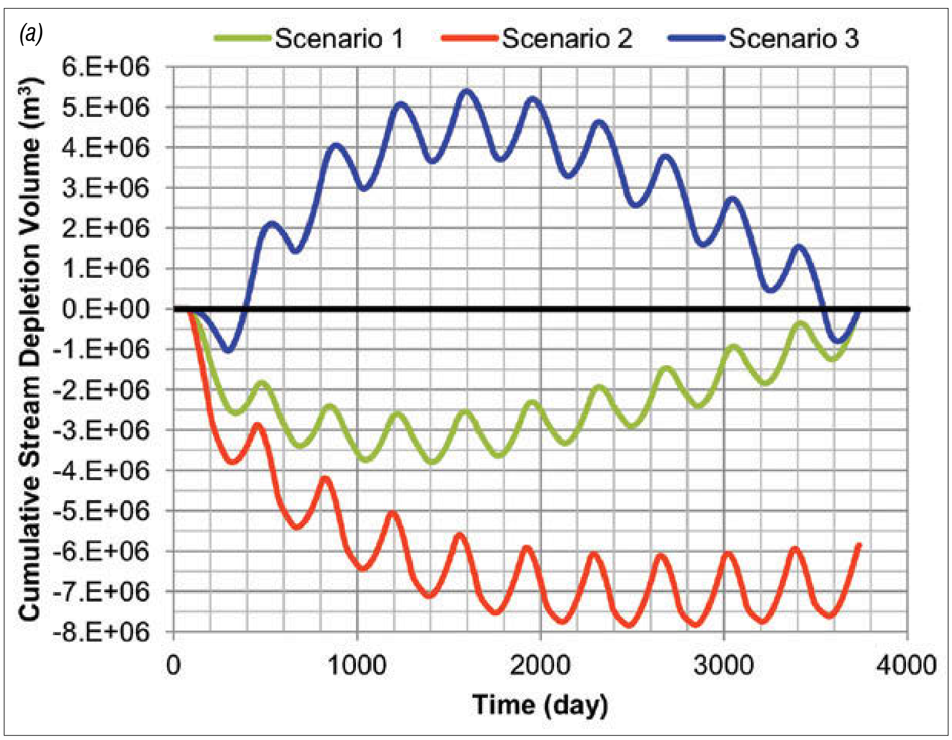
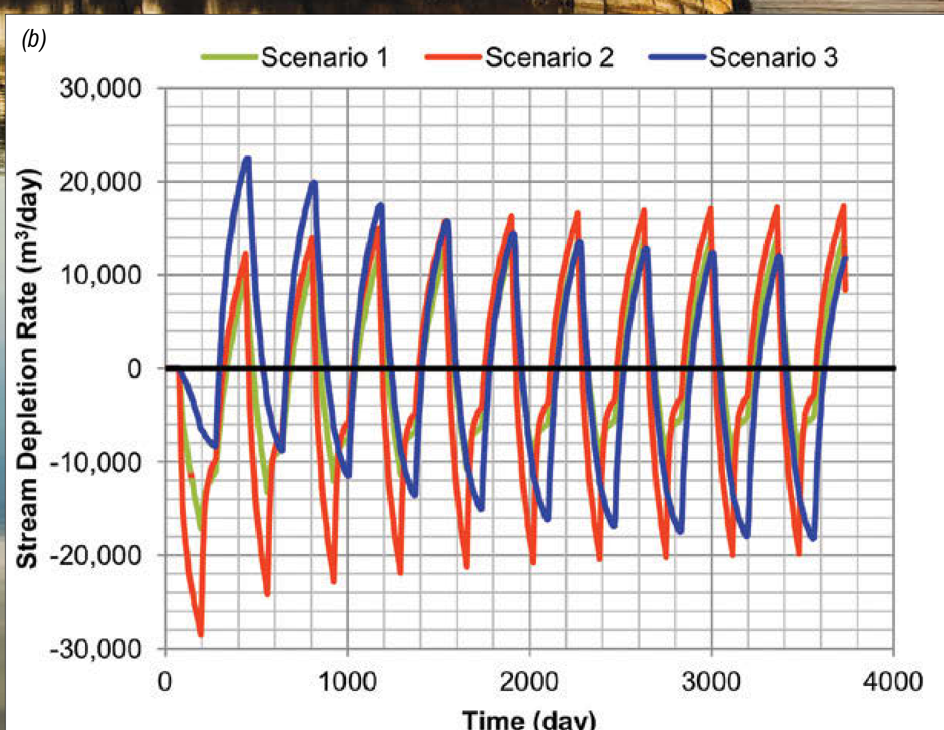


Figure 2. *Time series for (a) total stream depletion rate (m3/day) and (b) total cumulative stream depletion volume (m3) in Scenarios 1, 2, and 3, respectively.*

about 5.9×10^6 m3 (4800 ac-ft) of water over 10 years. Figure 1c reveals that irrigation demand is met using about 20 high capacity pumping wells, some of which are positioned closer to the stream, where water levels are less sensitive to pumping due to the presence of the stream itself. These wells are ultimately "responsible" for stream depletion. Also, a few high capacity recharge ponds are located along the stream to reduce stream impact, and along the physical boundary to reduce aquifer drawdown. Scenario 2 provides a clear example showing that the need to minimize water level variations competes directly with the need to minimize stream depletion volumes.

Figure 1d shows the optimal well/recharge layout for Scenario 3, where the recharge capacity is reduced to 85 percent of the irrigation demand, and the water level lower constraint is relaxed (25 < t < 31 m). Opposite to Scenario 2, the net volume of stream depletion over 10 years is equal to zero even though recharge capacity is less than groundwater demand. This is due to the fact that a significant portion of the irrigation demand can now be supplied directly from the aquifer storage, however at the expense of a decrease of the water levels. Figure 1d shows that pumping is concentrated in the lower half of the aquifer, whereas aquifer recharge occurs mostly in its uppermost portion along the stream.

Finally, Figures 2a and 2b display the time series for the total stream depletion rate and the total cumulative stream depletion volume in Scenarios 1, 2, and 3, respectively. It is worth noting that the spatial distribution of recharge areas with respect to regions where pumping is concentrated has a strong impact on the stream depletion volume profiles. For example, in both Scenarios 1 and 3, the volume of stream depletion at the end of the 10 year time horizon is equal to zero. However, while in Scenario 1 the stream remains depleted for the whole period and recovers only at the very end, this differs in Scenario 3, where stronger recharge occurs in proximity of the stream (Figure 1d). In Scenario 3, the stream is augmented for most of the time period except toward the end, when the impact of groundwater pumping from the lower portion of the aquifer finally reaches the stream.



References

1. Glover, R.E., and C.G. Balmer. 1954. River depletion resulting from pumping a well near a river. AGU Transactions 35, no. 3: 468–470.

2. Jenkins, C.T. 1968a. Techniques for computing rate and volume of stream depletion by wells. Ground Water 6, no. 2: 37–46.

3. Theis, C.V. 1935. The relation between the lowering of the piezometric surface and the rate and duration of discharge of a well using groundwater storage. AGU Transactions 16, no. 2: 519–524.

Riverbend Ponds, Fort Collins, Colorado.
Photo by David Kingham

Groundwater Recharge in Eastern Libya

William Sanford, Associate Professor, Department of Geosciences, Colorado State University

The country of Libya, in northern Africa, has a tremendous amount of groundwater resources in six large basins. The Great Man-Made River Authority (GMRA) has undertaken the development and operation of large scale pumping projects to extract water from the aquifers beneath the Sahara and transport the groundwater to the north through 4 m diameter pipelines that are up to 1,000 km in length (Figure 1). The Libyan government has already spent nearly $20 billion on this project. Ninety percent of the population lives along the northern coast near the Mediterranean Sea in population centers such as Tripoli and Benghazi. Rainfall in the southern portions of the country is less than 25 mm/year, with amounts in the southernmost basins around one mm/year. The research summarized herein is focused on three aquifer systems located in two groundwater basins in the eastern part of Libya: the Sirte and Kufra basins.

GMRA has developed two pumping centers, Sarir and Tazerbo, located 600 and 880 km south of Benghazi, respectively, each with the capacity to extract one million cubic meters of water per day. A third pumping center is in the planning stages for Kufra in the far south (1300 km south of Benghazi) that will have the capacity to extract approximately 1.6 million cubic meters per day. The three aquifers are part of the Nubian Sandstone Aquifer System (NSAS), which covers an area of two million square km underneath Libya, Egypt, Chad, and Sudan. The NSAS is the largest aquifer system in the world, containing around 150,000 cubic km of water. Once all the well fields and agricultural systems come on line, Libya will be pumping several cubic kilometers of water per year from the NSAS. Because the aquifer system lies beneath several countries and is located in a hyper-arid climate, concerns are raised on what the effects of large-scale water extraction will be both locally and internationally.

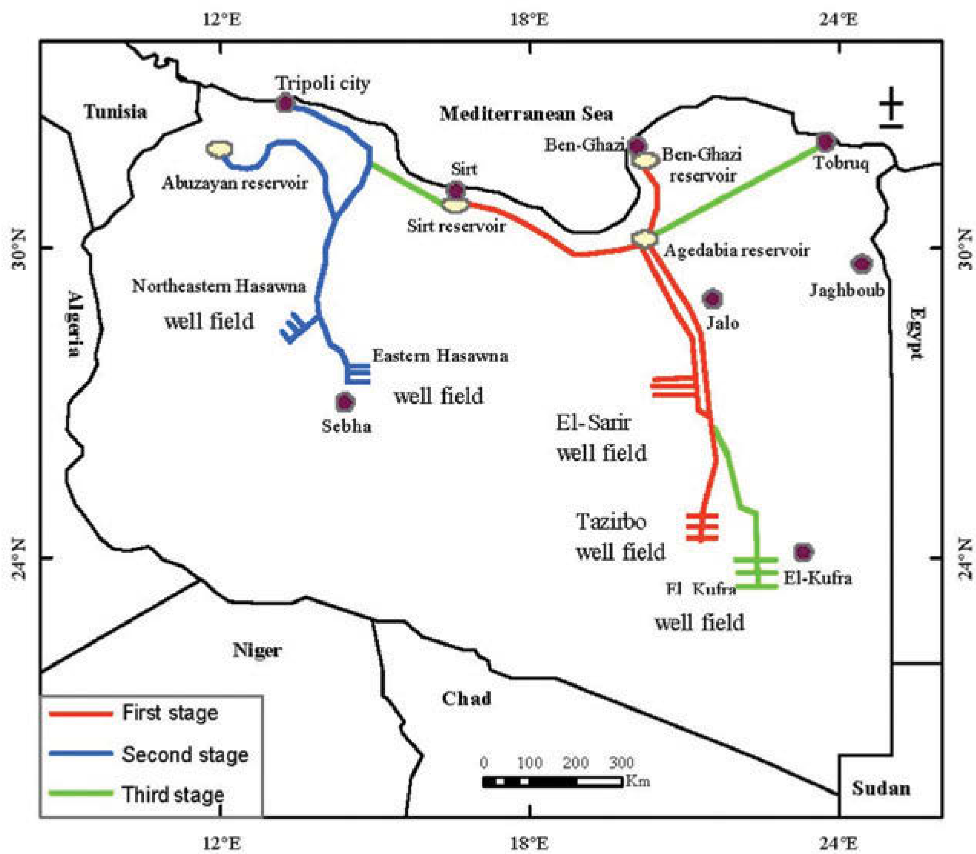


Figure 1. *Current and proposed projects of the Great Man-Made River Authority, Libya.*

Due to such low precipitation, present-day recharge is little or nil, and groundwater is considered fossil (trapped in ancient sediment with little to no replenishment), with water extraction involving mining the aquifers. Our research project is focused on determining the timing of recharge to the aquifers during different climate periods. This information is important because of conflicting ideas as to whether recharge is happening currently or whether the observed flow through the aquifers is related to the re-equilibration and draining of the system, since recharge occurred millennia ago. The development of accurate groundwater models depends upon correctly handling the recharge issue. The models will then be used to predict the effects of large scale water extraction and to develop the optimal management of these aquifers.

Our approach was to collect groundwater samples (Figure 2) from the aquifers at Sarir, Tazerbo, and Kufra to determine their carbon-14 (^{14}C) ages, the compositions of the heavy stable isotopes of hydrogen and oxygen (^{2}H and ^{18}O) that are part of the water molecule, and the concentrations of the noble gases (Ne, Ar, Kr, Xe) and N_2 that were dissolved from

Figure 2. *Bill Sanford and Mohamed Al Faitouri, CSU PhD student, collecting water samples at Sarir.*

the atmosphere during recharge. The ^{14}C ages reveal the time in the past that the water entered the aquifers. The less the ^{14}C in the aquifer, the older the water is. The stable isotope compositions are used to determine the source of the rainfall and the climate at the time of recharge. The stable isotopes are compared to those in modern precipitation, and the amounts of the heavy isotopes are related to the past climate and direction from which precipitation came. The relative concentrations of the gases allow us to estimate the local temperature at the time that the aquifer was recharged.

Results

The majority of the groundwater ages are between 18,000 and 30,000 years, indicating that most of the recharge to the aquifers occurred during a humid period corresponding to the last global glacial period. During this time, the recharge areas to the south potentially received between 600 and 900 mm/year of precipitation. The infiltrated precipitation flowed as groundwater from the recharge areas to the basins through paleo-river channels that were formed millions of years ago. Today, these paleo-river channels are buried by the sands of the Sahara. The lack of younger ages in the aquifers is consistent with the area becoming more arid during the time following the last global glaciation, culminating in hyper-aridity a few thousand years ago.

During the last glacial periods, the precipitation patterns were different than today due to the advance of continental glaciation in Europe. Others have suggested that the precipitation 20,000 plus years ago was the result of increased monsoonal rains from the southwest. Evidence for this is seen in the compositions of the heavy stable isotopes found in the groundwater. The fossil groundwater has less of the heavy isotopes than today, which is a result of both the increased distance that the precipitation needed to travel across the continent from the southwest as compared to today and the effects of precipitation forming in the much higher elevations of the recharge area.

The recharge temperatures calculated from the dissolved gas concentrations range from a few degrees lower to the same temperature as is found in the area (average annual temperature of 23°C, or 73°F). The lower temperatures are consistent with precipitation occurring during a cooler, more humid time. Our noble gas results are consistent with other research in tropical areas around the world for this same time period.

Summary

Our work has shown that the groundwater of the Nubian Sandstone Aquifer System in Libya was recharged around 20,000 years ago, indicating that the water is fossil. In addition, there is little or no evidence of there being any modern recharge. The current and planned large scale pumping will be mining the groundwater. Further modeling should be conducted to optimize pumping rates from the well fields in order to prolong their lifespan and to minimize harm to the surrounding countries that rely on water from the NSAS.

Background Photo: *Bezeema Oasis located 60 km south of the Tazerbo well field.*

Figure 2. *Irrigation practices in the Arkansas River Valley.*
Photo by Bill Cotton

Nutrient Management Practices and Groundwater Protection Assessing Adoption by Colorado Producers

Extension

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Catherine M.H. Keske and Erik Wardle, Department of Soil and Crop Sciences, Colorado State University

According to the U.S. Census Bureau, the Earth's estimated human population has surpassed seven billion. It is certain that each and every one of these people will require food and clean water for survival. Nutrient use in agriculture is closely tied to providing both of these basic needs. Agricultural productivity critically depends upon adequate soil nutrients. Replenishment of soil system nutrients removed by crop production is not only necessary for agricultural productivity, it is also essential for the sustainability of the soil resource. However, these soil nutrients must be appropriately managed in order to protect water quality. This article summarizes recent findings regarding Colorado agriculture soil nutrient management and the costs of adopting nutrient management practices.

Nutrients in Cropping Systems and the Environment

In the context of agricultural production, the nutrients nitrogen (N) and phosphorus (P) are typically referred to as "macronutrients" due to the large amounts necessary for crop production relative to the other 16 essential nutrients for plants. While N is ubiquitous in the environment as a stable gas (N_2), reactive Nitrogen (Nr) forms of N such nitrate and ammonia are most limiting for biological systems. In most systems, Nr can be a potential pollutant in both surface and groundwater. Due to solubility and use as a plant nutrient, the nitrate ion (NO_3-) form of nitrogen has been a primary concern. While critical to increased plant growth, water quality impairments from N and P have been well-documented and researched in many environments and cropping systems.

Colorado Policies and Educational Programs

Groundwater contamination from nitrate is currently a recognized issue related to agricultural nutrients in some areas of Colorado. Beginning in the late 1980s, sampling began to show certain regions of the state where elevated nitrate-nitrogen concentrations above the EPA drinking water standard of 10 mg/L (ppm) of nitrate-nitrogen could limit the use of groundwater resources for drinking water supplies. As concern over these findings increased, in 1990 the Colorado General Assembly passed proactive legislation for addressing nitrate contamination in groundwater. This legislation was written as an amendment to the Water Quality Control Act, and established what would later become the Agricultural Chemicals and Groundwater Protection Program (Groundwater Program). This multi-agency program is led by the Colorado Department of Agriculture (CDA), who partners with Colorado State University Extension and the Colorado Department of Public Health and Environment, to achieve the following program goals: 1) remedy areas of nonpoint source groundwater impairment, 2) prevent new contamination, and 3) understand trends in groundwater vulnerability and quality. The Groundwater Program has used a combination of three approaches to achieve these goals: targeted regulation, education through demonstration and outreach, and groundwater monitoring.

Costs of Adopting Nutrient Management Practices and Current Trends

In an effort to understand current adoption of nutrient best management practices (BMPs) by Colorado agricultural producers, the Groundwater Program conducts periodic assessments of trends and costs of nutrient management practices. As follows is a summary of methodology and results from a 2011 study.

The 2011 assessment consisted of a mail-back survey that queried 2,000 irrigating agricultural producers about BMP adoption rates and costs for the 2010 growing season and calendar year. The survey was pilot tested with 16 producers, extension specialists, agency personnel, and university faculty during development. Survey questions focused on determining which BMPs producers were using to determine their nutrient rate, form, timing and placement. In addition, practices that are generally termed ‘precision agriculture’ were queried to better understand how producers are incorporating this new technology into their nutrient management. Producers were also asked about nutrient management practices that reduce off-field nutrient transport, recordkeeping and cost of BMP implementation.

The survey sample was drawn from farm operators utilizing 100 acres or more of irrigated land for production. The National Agricultural Statistics Service (NASS) stratified the sample of Colorado irrigators by county. Producer identities were anonymous to researchers at all times, as surveys were mailed directly to producers by NASS. In order to ensure a successful response rate, widely recognized survey design methodologies were followed. Surveys were initially mailed in February 2011, and later in March to those who did not respond to the first mailing. Producers who did not complete and return the second mailing were contacted by the NASS call center to increase response rate.

The final overall response rate was 44.8 percent. To control for the diversity of cropping practices in Colorado, survey responses were grouped into six geographic regions based upon county. This regionalization also allows for comparison to regional data presented in previous Colorado surveys conducted in 1997 and 2002. A few highlights of the survey are provided in the following table and figure. A complete report will be published in a CWI bulletin soon.

Among the sampled producers, certain BMPs, such as soil testing in the E. Plains and S. Platte regions showed very high adoption rates (Table 1). Results indicate that this basic BMP is well accepted by irrigating producers in these areas to help determine the correct amount and type of nutrient required to achieve high crop yields. In contrast, plant tissue testing is adopted at a

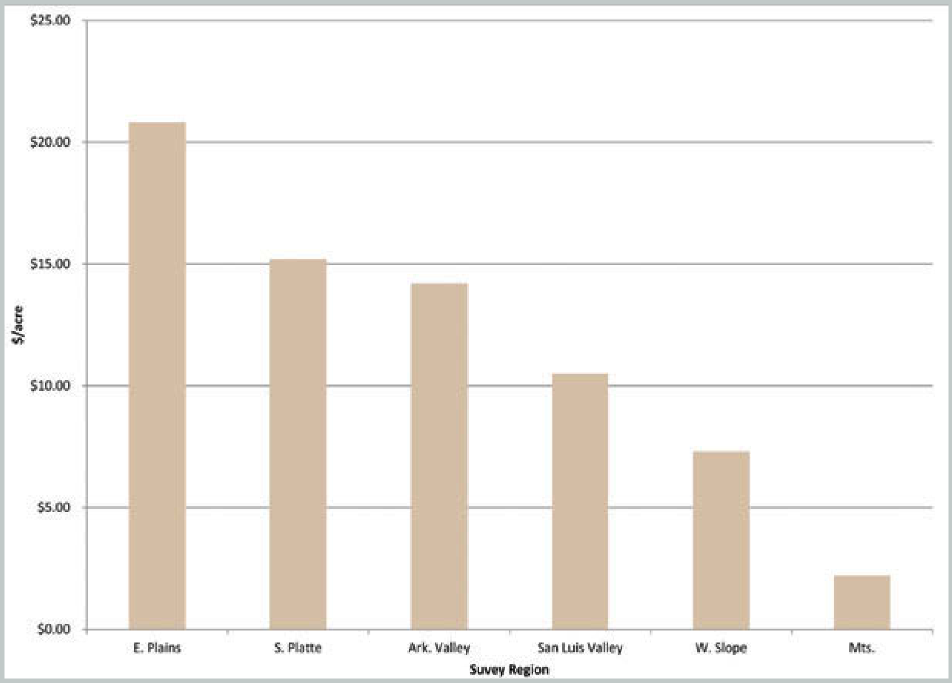

Figure 1. *Average annual expenditures on nutrient management practices*

	Region of Colorado[1]					
	Ark. Valley	E. Plains	Mts.	S. Platte	San Luis Valley	W. Slope
Soil Test Analysis	41.1%	86.2%	21.2%	75.4%	50.0%	44.7%
Split Apply N[2]	46.3%	72.5%	2.5%	43.1%	38.7%	21.8%
Keep Written Records	32.1%	67.0%	26.3%	52.1%	49.1%	30.6%
Establish Yield Goals	30.4%	51.1%	14.1%	41.2%	30.6%	15.9%
Use Paid Crop Consultants for Advice	14.3%	47.9%	1.0%	22.8%	23.2%	1.9%
Deep Soil Test	12.5%	36.2%	0.0%	26.6%	18.6%	5.9%
Plant Tissue Samples	5.4%	22.3%	4.0%	12.3%	20.4%	4.7%
[1]Respondents were asked to indicate multiple management practices incorporated therefore response estimates calculated across region will not sum to 100.						
[2]Refers to applying N fertilizer in two or more doses, typically one of these is during the growing season to maximize efficiency						

Table 1. *Percentage of respondents incorporating selected nutrient management practices*

lower rate across all regions since the practice is typically limited to certain higher value crops. Record keeping, which is required to qualify in some USDA cost sharing programs, has been adopted at a rate of less than 50 percent in four of six regions. However, this is still a higher rate than reported in a previous survey. The percent of producers using paid crop consultants to determine fertilizer rates is highest in areas of higher value crops and where crop consultants are actively seeking clients.

Figure 1 shows expenses the respondents reported for costs to manage nutrients during the 2010 cropping season. These included nutrient management BMPs and other practices, such as conservation tillage, that prevent nutrient losses from fields. These costs varied among regions similar to patterns seen with BMP adoption, with the exception being the Arkansas Valley (figure 2). It is important to point out that many of these costs also have benefits, such as improved yield or reduced fertilizer expenses, but others do not have net return for the producer. In many cases, cost-sharing programs from the USDA Natural Resources Conservation Service and other programs can help producers with these expenses and improve adoption.

A key result from this survey is that nutrient BMP adoption and expenditures on BMPs varies widely by region of the state. These differences are expected, as Colorado's irrigated farming regions are diverse in terms of crop and livestock systems utilized, irrigation systems and water sources, nutrient type and amount applied, input costs, and management styles. Additionally, crop landscapes vary from high altitude mountain hay meadows to intensive vegetable row crops in some river valleys. In general, nutrient BMP adoption is highest within the regions where fertilizer and manure nutrients are utilized more and in areas with higher value crops.

Summary

Supplemental nutrients, particularly N and P, are critical components of highly productive, profitable irrigated agriculture and to meet the food intake requirements of an increasing global population. This study found that most of the Colorado producers who responded to our survey are implementing some level of nutrient management practices to enhance nutrient use efficiency and prevent losses from irrigated fields. The BMPs with higher rates of adoption tend to be those with lower costs or are cost neutral to the producer, whiles others may require incentive programs to achieve higher levels of adoption. Ultimately, the decision on whether to implement a BMP or suite of BMPs can only be made at the local watershed scale, incorporating local knowledge of field conditions and cropping systems.

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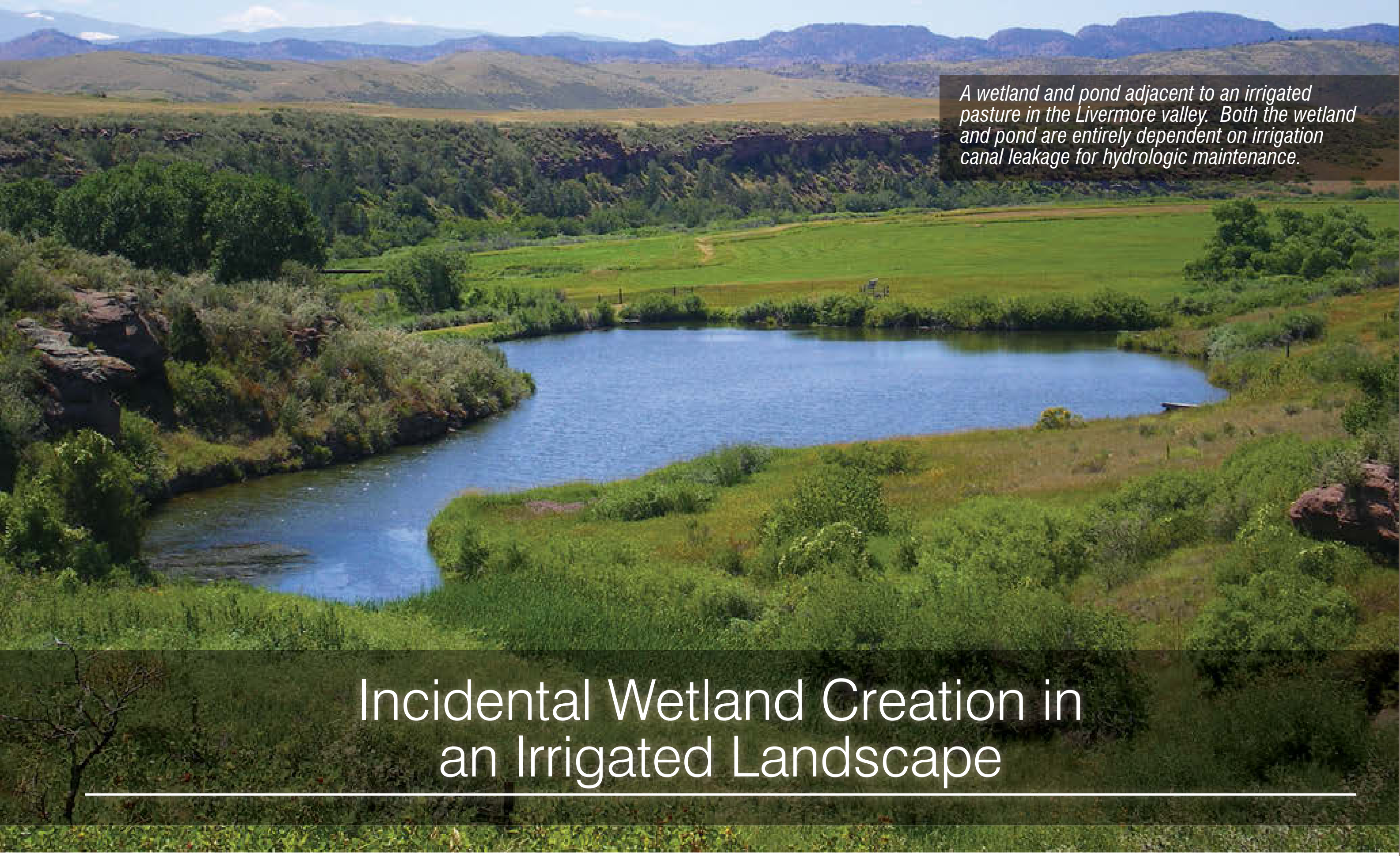


A wetland and pond adjacent to an irrigated pasture in the Livermore valley. Both the wetland and pond are entirely dependent on irrigation canal leakage for hydrologic maintenance.

Incidental Wetland Creation in an Irrigated Landscape

Agricultural Experiment Station

Jeremy Sueltenfuss, MS Candidate, Ecology, Colorado State University
Faculty Advisors: Rick Knight, Reagan Waskom, and David Cooper

Introduction

Agricultural productivity in the semi-arid American West has relied on irrigation for centuries. Early irrigation efforts were often located in floodplains adjacent to rivers and utilized small, hand dug canals to irrigate pastures (Morgan 1993). As larger areas of land were settled, canals became larger and longer, and transported water to uplands far from the original water source. Irrigated land in the West has continued to expand from three million hectares (ha) in 1900 (Pisani 2002) to over 17 million ha of irrigated land today (Gollehon and Quinby 2000).

Irrigation canals across the American West are known to have water losses up to 50 percent due to leakage (Luckey and Cannia 2006). Though the negative impacts of water diversions on rivers are well documented (Strange et al. 1999), the environmental changes created by irrigation canal leakage remain understudied. Although some authors have suggested a direct competition for water between irrigated agriculture and wetland ecosystems (Lemly et al. 2000), others have mentioned the possibility of canal leakage creating and maintaining wetland and riparian habitat (Kendy 2006).

Wetlands are an important part of a landscape, yet estimates of historical wetland loss due to river diversions and land conversion in some western states range between 50 and 90 percent (Yuhas 1996). Because wetlands provide habitat to a disproportionate number of animal species and perform essential ecosystem services related to water quantity and quality (Zedler 2003), understanding the influence of irrigation canals on the hydrologic regime of wetlands is necessary for future water planning and wetland conservation. The present study sought to answer the following questions: (i) Are there hydrologic processes linking canals and reservoirs to wetlands, and (ii) What types of wetlands are supported by irrigation canals?

Study Area

North Poudre Irrigation Company (NPIC) is one of many irrigation water delivery companies in northern Colorado. Located in the South Platte River Basin on the plains and foothills north of Fort Collins, Colorado, NPIC has a total service area of 23,300 ha and delivers water to 9,700 ha of irrigated land utilizing 16 holding reservoirs and approximately 250 km of canals (Figure 1), 89 percent of which are unlined earthen canals that have been in place for over a century. Water diverted from the North Fork and main stem of the Cache la Poudre River is transported through the canal system from April through September to upland areas away from river corridors. In 2010, NPIC diverted approximately 89,400 acre feet, 45 percent of which was lost to evaporation and canal seepage (pers. comm. NPIC manager). Previously measured NPIC canal water losses range from zero percent to 50 percent per canal (Riverside Technology, Inc. 2005).

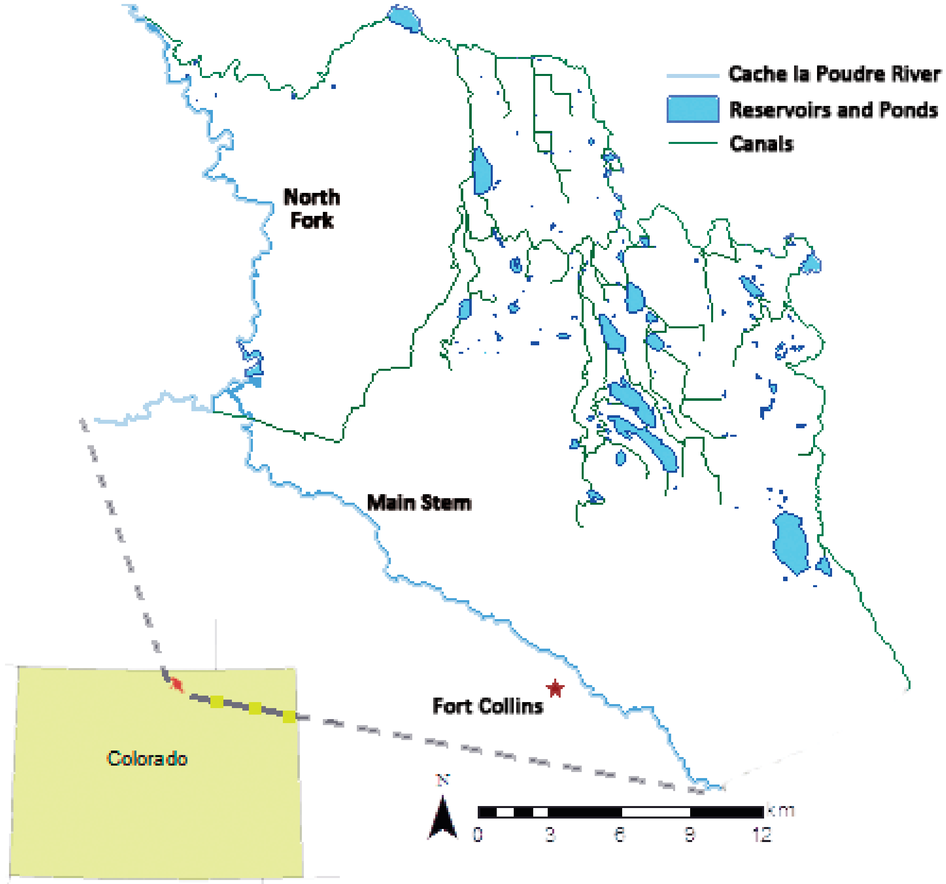


Figure 1. *Study area map of North Poudre Irrigation Company canals and reservoirs adjacent to the Cache la Poudre River in northern Colorado.*

Methods

Wetland Mapping

Wetlands were mapped using National Wetland Inventory maps from 1975 and were refined using aerial images in ArcMap 10. The hydrologic source of each mapped wetland was visually determined with aerial photographs by tracing surface water flow paths or subsurface flow paths as detected by increased primary productivity back to a source.

Vegetation was characterized using aerial images for every wetland in the study area. Because aerial images were not precise enough to identify vegetation to the species level, vegetation was separated into three broader categories: "Marsh" communities visible in the image as tall, dense stands of *Typha latifolia*, "Meadow" communities visible as shorter stands of sedges such as *Carex spp*, and "Salt flats" visible due to the presence of white salt on the land surface with sparse vegetation such as *Atriplex spp*.

Wetland Hydrology

A total of 70 monitoring wells were installed in 20 wetlands throughout the NPIC service area. Wells were dug to approximately one meter depth, cased with 1.5 inches schedule 40 PVC pipe with holes drilled approximately every five centimeters and backfilled with native soil. Water tables were measured approximately every two weeks from May through November 2011. Pressure transducers (In-Situ Rugged Troll 100) were installed in six monitoring wells to record hourly water table depths. Wetland water table fluctuations were compared to both daily canal flow and precipitation. Daily canal flow was estimated from daily irrigation order records from NPIC customers along each canal. Precipitation data were collected from six precipitation stations in the Community Collaborative Rain, Hail & Snow Network (www.cocorahs.org).

Aerial image of an irrigation canal transporting water across a semi-arid landscape. Various points of water leakage in the canal lead to the flow of water down the landscape, converging to create wetland habitat in topographic depressions.

Results

Wetland Mapping

A total of 176 wetlands covering 652.3 ha were mapped within the NPIC boundary. Of these, 56 wetlands covering 173.7 ha were associated with irrigation canal leakage (Table 1). According to previously measured canal water loss data, 50.6 percent of canals had high percent water loss greater than 17 percent, 36.5 percent of canals had moderate water loss between seven percent and 17 percent, and 12.8 percent owf canals had low water loss less than seven percent. The majority of wetlands associated with canals were below high water loss canals with percent water losses greater than 17 percent. Along with canal seepage, seepage from pond and reservoir dams was a major hydrologic source for wetlands, sustaining 52 wetlands totaling 186.7 ha. Within the study area, agricultural water storage, conveyance losses, and application were visually attributable for 89 percent of the number of wetlands, and 92 percent of the total wetland area.

Within the study area, 43 percent (279 ha) of the wetland vegetation was marsh, 40 percent (263 ha) meadow, and 17 percent (111 ha) salt flats.

Wetland Hydrology

Wetland water table depths adjacent to canals with high water loss were heavily influenced by changes in canal flow (Table 2). The highest wetland water table depth change recorded from when a canal was flowing to when it stopped flowing was 131.4 cm. The Buckeye Main canal recorded the highest flows through the irrigation season, and its interaction with an adjacent wetland serves as an example consistent with most instrumented wetlands. Groundwater levels in this wetland immediately adjacent to the Buckeye Main canal increased as canal flow increased throughout the summer. Once the canal stopped transporting water in the fall, the water table in the wetland declined by 60 cm (Figure 2), with very little response to precipitation throughout the year. The trend of decreasing wetland water tables following the drying of irrigation canals was seen in the majority of instrumented wetlands.

Discussion

The functions of agricultural ditches running through areas already saturated and those traveling across arid land are fundamentally different. For already saturated land, ditches are used to lower water tables and manipulate them for the benefit of crops, often leading to a decline in wetland area (Krause et al. 2007). In arid and semi-arid regions, ditches are used to convey water from river corridors, groundwater pumping stations, and reservoirs to uplands where it is applied to arid lands. Although intended to irrigate arid lands to produce livestock forage and crops, not all diverted water is consumptively used by plants (Fernald et al. 2010). As seen in this study, excess water that leaks from canals and dams, as well as the over-application of water to fields, creates a large amount of wetlands on previously arid land.

The transport of water from streams and reservoirs in irrigation canals and ditches, some with seepage rates exceeding 50 percent, and the excessive amount of water applied to some irrigated fields has resulted in the unintentional creation of a wide range of wetland types in this study area, and likely in many parts of the western U.S. as well. Though some authors suggest that competition for water occurs between wetlands and agriculture (Lemly et al. 2000), irrigated agriculture appears to have played an important role in the redistribution of water and the creation and maintenance of a large proportion of the total wetland area in many western landscapes (Peck et al. 2001).

Non-riparian wetlands have groundwater as a primary water source (Mitsch and Gosselink 2000) and are generally independent of precipitation in arid regions (Laubhan

Table 1. *Census of mapped wetland attributes corresponding to their hydrologic source. Canals are separated by percent water loss as previously measured from Riverside, Inc. The number of wetlands, the total wetland area, and average wetland size are reported for each infrastructure category. "Intentional Water Delivery" refers to managed wetlands with water deliveries. The hydrologic source for 18 wetlands located below multiple irrigation canals could not be determined, and are reported as "unknown source, below canal." Only two wetlands were located above irrigation canals. "Tail water" refers to wetlands located at the low point of irrigated fields. "Pond/reservoir outlet" refers to wetlands downhill of ponds or reservoirs. "Reservoir Fringe" refers to wetlands along the banks of NPIC reservoirs.*

Wetland hydrologic source	# Wetlands	Total Wetland Area (ha)	Average Wetland Size (ha)
<7% Loss Canal	3	7.1	2.4
7-17% Loss Canal	17	31.8	1.9
>17% Loss Canal	36	134.8	3.7
Intentional Water Delivery	12	98.5	8.2
Unknown Source, Below Canal	18	51.1	2.8
Above Canal	2	1.1	0.5
Tail Water	7	13.1	1.9
Pond/Reservoir Outlet	52	186.7	3.6
Reservoir Fringe	29	128.1	4.5

2004). Kendy et al. (2004) found that changes in groundwater had large impacts on wetland ecosystems. Canals may therefore act analogously to streams in arid regions, and influence or control water table position through the subsurface movement of water from the canal to surrounding areas (Francis et al. 2010). Because canal seepage can raise local water tables (Harvey and Sibray 2001), the current wetland distribution in many agricultural areas is likely a result of the location and functioning of the irrigation infrastructure (Kendy 2006).

Hydrologic regime is often identified as the key determinant of wetland structure and function (Mitsch and Gosselink 2000). This study has highlighted the importance of canal seepage in influencing the hydrologic regime of wetlands and its control over the types of wetlands in an agricultural landscape. Similar to previous accounts (Crifasi 2005) many wetlands in this study were found on hill slopes directly below irrigation canals and were dominated by wet meadow plant species, including members of the genera Juncus and Carex. Slope wetlands are often the first wetland type to be lost due to land use change (Skalbeck et al. 2008), but are thought to support high biodiversity (Stein et al. 2004), and may be some of the more resistant wetlands to future climate change (Winter 2000). Wetlands that have been created by irrigation water may be indistinguishable in form and floristic composition from wetlands with more natural water sources (Peck and Lovvorn 2001) and may provide greater ecosystem services due to their longer hydroperiods (Kendy 2006), such as biodiversity support (Rumble et al. 2004), flood abatement (Zedler 2003), and water quality improvements (Fennessy and Craft 2011). Lining canals, transferring irrigation water to cities, or altering current irrigation practices in the name of increased efficiency could therefore have detrimental impacts on both wetland functions (Fernald and Guldan 2006) and biodiversity (DiNatale et al. 2008).

Conclusions

Water in the American West is a limited resource, and its use is contentious between agriculture, growing municipalities, and the environment. Though agricultural practices are often viewed as inefficient, large wetland complexes are maintained through seepage from canals, pond and reservoir dams, and tailwater from irrigated fields, as well as through interactions with shallow aquifers. Because water quality and biodiversity support are growing concerns in many landscapes, future work should focus on the functions and services of agricultural wetlands, as well comparisons between the

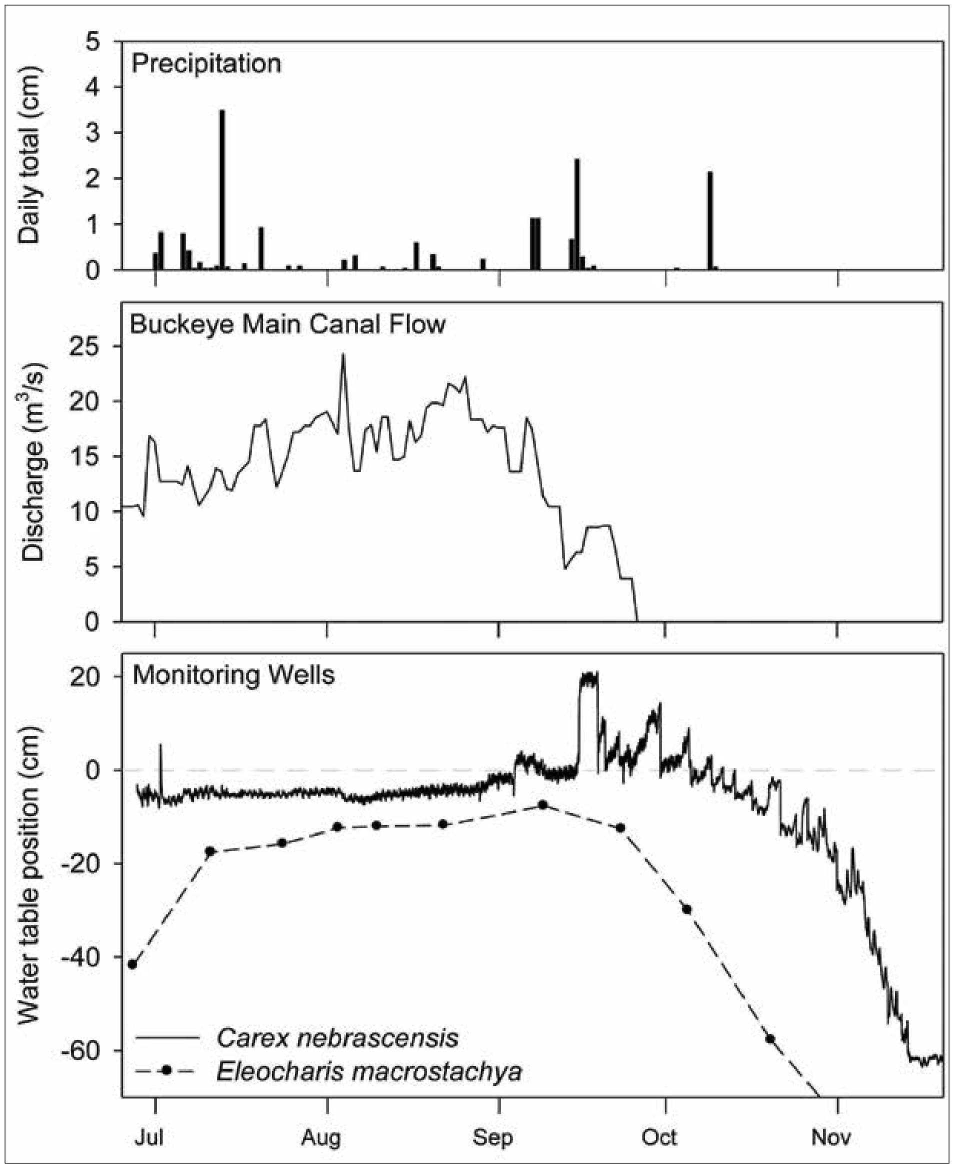


Figure 2. *The effect of daily precipitation and adjacent canal flow on water tables from one wetland. Monitoring wells were located in two vegetation communities in a wetland adjacent to the Buckeye Main canal during the summer of 2011. The dominant plant species occurring at each well is used as that well's name. Water levels represent hourly data within a Carex nebrascensis community (solid line) and bi-weekly data within an Eleocharis macrostachya community (dashed line). Points along the dashed line represent specific measurements. A 50 day lag occurred between the declining flow in the canal and the declining groundwater level for the C. nebrascensis community, with a shorter lag for the E. macrostachya community.*

Infrastructure Category	Category Amount	Intrumented Wetlands	
		Distance to Source (m)	Water Table Change (cm)
< 7% Loss Canal	32.2 km	13.5	83
	13% of total	135	50.6
7-17% Loss Canal	91.5 km	30.2	None
	36% of total	9.8	None
		41.7	None
> 17% Loss Canal	127 km	16.6	103.6
	51% of total	13.2	14.6
		10.3	12.4
		6.8	17.7
		10.7	51.3
		11.7	None
		50	131.4
		58.8	59.3
		23.9	102.7
		70	120.5
		15.7	52.7
Pond/Reservoir	1571.2 ha	16.4	None
	Surface area	20.8	None
		49.4	None

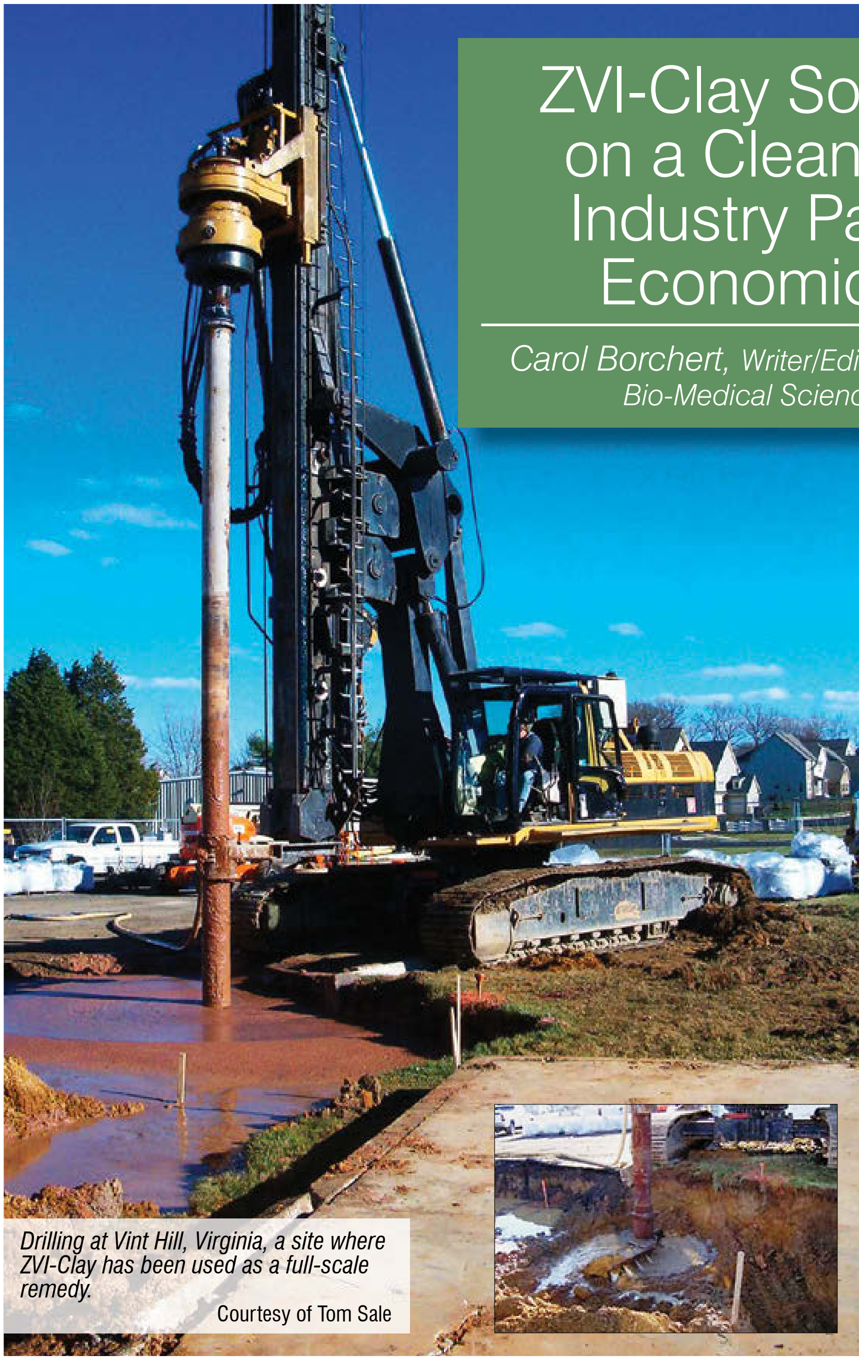
location of historic wetlands and those currently in existence. Water transfers and changing agricultural practices to increase water efficiency put existing wetlands at risk, necessitating an understanding of policy and management implications on agricultural wetland ecosystems. Current wetlands may only be as permanent as the irrigation practices that sustain them.

References avaliable upon request.

Table 2.Characteristics of NPIC canals and reservoirs as well as the instrumented wetlands associated with them. The length of each canal and the percent of total canals are reported for each canal percent loss category as well as the total surface area of ponds and reservoirs. Characteristics of the instrumented wetlands associated with each category include the distance to the associated category as well as the wetland water table response to the stopping of the adjacent canal flow. Note that most wetlands had changes in water table position in response to changes in canal flow.

ZVI-Clay Soil Mixing Delivers on a Cleaner Environment, Industry Partnerships, and Economic Development

Carol Borchert, Writer/Editor, College of Veterinary Medicine and Bio-Medical Sciences, Colorado State University



Drilling at Vint Hill, Virginia, a site where ZVI-Clay has been used as a full-scale remedy.

Courtesy of Tom Sale

One tablespoon of chlorinated solvents—like that used by dry cleaners and industry—can contaminate an Olympic-sized swimming pool full of drinking water beyond drinking water standards. Unfortunately, spills and leaks of chlorinated solvents associated with past industrial practices have caused widespread contamination of groundwater. The result? Complicated dispersal and plume patterns, persistence in the subsurface, and difficult cleanups. Zero Valent Iron (ZVI)-Clay Soil Mixing, a venture of the Center for Contaminant Hydrology based in the Department of Civil and Environmental Engineering, is taking a new approach to decontaminating chlorinated solvent sites and seeing success in the application of its technology.

"Nobody really knows how many sites are out there," says Tom Sale, associate professor in the Department of Civil and Environmental Engineering and director of CCH. "It's easily in the tens of thousands of sites in the United States alone."

Chlorinated solvents include a large family of chlorine-containing organic compounds used for a wide variety of commercial and industrial purposes, feed stock for plastics, degreasers, and dry cleaning. Concerns about chlorinated solvent contamination—which can have significant toxicity to plants and animals, including humans—began to surface in the 1950s. Unfortunately, clean-up efforts have been expensive and often ineffective. Sale states that given high costs and limited progress, chlorinated solvents are not only an environmental challenge; they also pose large economic burdens for government, industry, and society as a whole.

In 2003, DuPont and Colorado State University initiated a collaborative research initiative focused on developing better solutions for chlorinated solvents and other contaminants. Principal investigators on the project at CSU are Sale and Charles Shackelford, a professor in the Department of Civil and Environmental Engineering. The initial focus was development of a promising new technology referred to as ZVI-Clay.

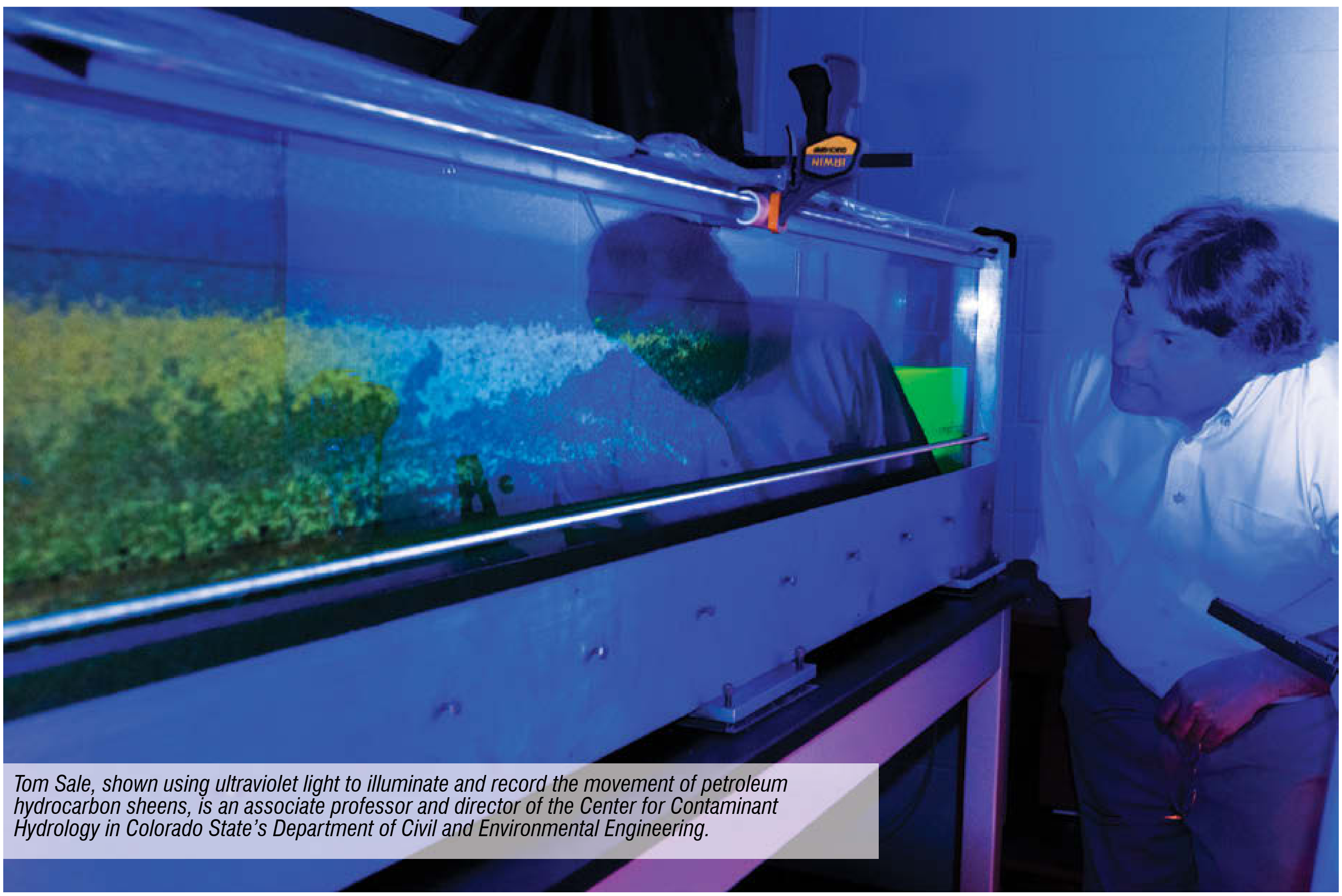
ZVI-Clay involves using heavy construction equipment to mix iron filings and clay with soils containing high concentrations of chlorinated solvents. The iron filings, referred to as ZVI, are a common waste product from automotive and other machining operations. Oxidation of the iron in the ground reduces chlorine in toxic compounds to nontoxic chloride—what we have in table salt, notes Sale. At a typical chlorinated solvent source zone, conventional soil mixing equipment is used to add and mix the iron filings and clay into soil columns that can go down to bedrock. The number and size of the columns depends on the size of the contaminated site. The mixing homogenizes the soil and brings all contaminants into close contact with the iron particles. The clay minimizes the hydraulic conductivity of the mixed soil body, isolating it from groundwater flow. The closed system allows for a reductive dechlorination process to progress, decreasing the amount of contaminant discharged from the treated zone and reducing the inflow of competing oxidants that may consume iron.

DuPont's contribution for ZVI-Clay has included the donation of two related patents to the Colorado State University Research Foundation, nearly $500,000 in research funding, and access to DuPont's technical and commercial resources. CSU contributions have included 20,000 hours of research effort from students, staff, and faculty members.

Working with partners in industry and Colorado State University, ZVI-Clay Soil Mix has been used in 10 field applications including U.S. Department of Defense sites, former dry cleaners, and industrial facilities. Three additional projects are planned for 2011, along with five active laboratory studies. The technology has been used to clean 80 tons of chlorinated solvents (enough to contaminate all potable water in Colorado for 20 years) in 50,000 cubic yards of soil and generated $1.5 million in research revenues for Colorado State University and $250,000 in patent royalties. The initiative has led to $10 million in engineering projects.

"Through ties with industry, we are advancing our academic programs, training the next generation of engineers and scientists, creating a cleaner environment, managing social costs, and driving economic activity at local, state, and national levels," says Sale.

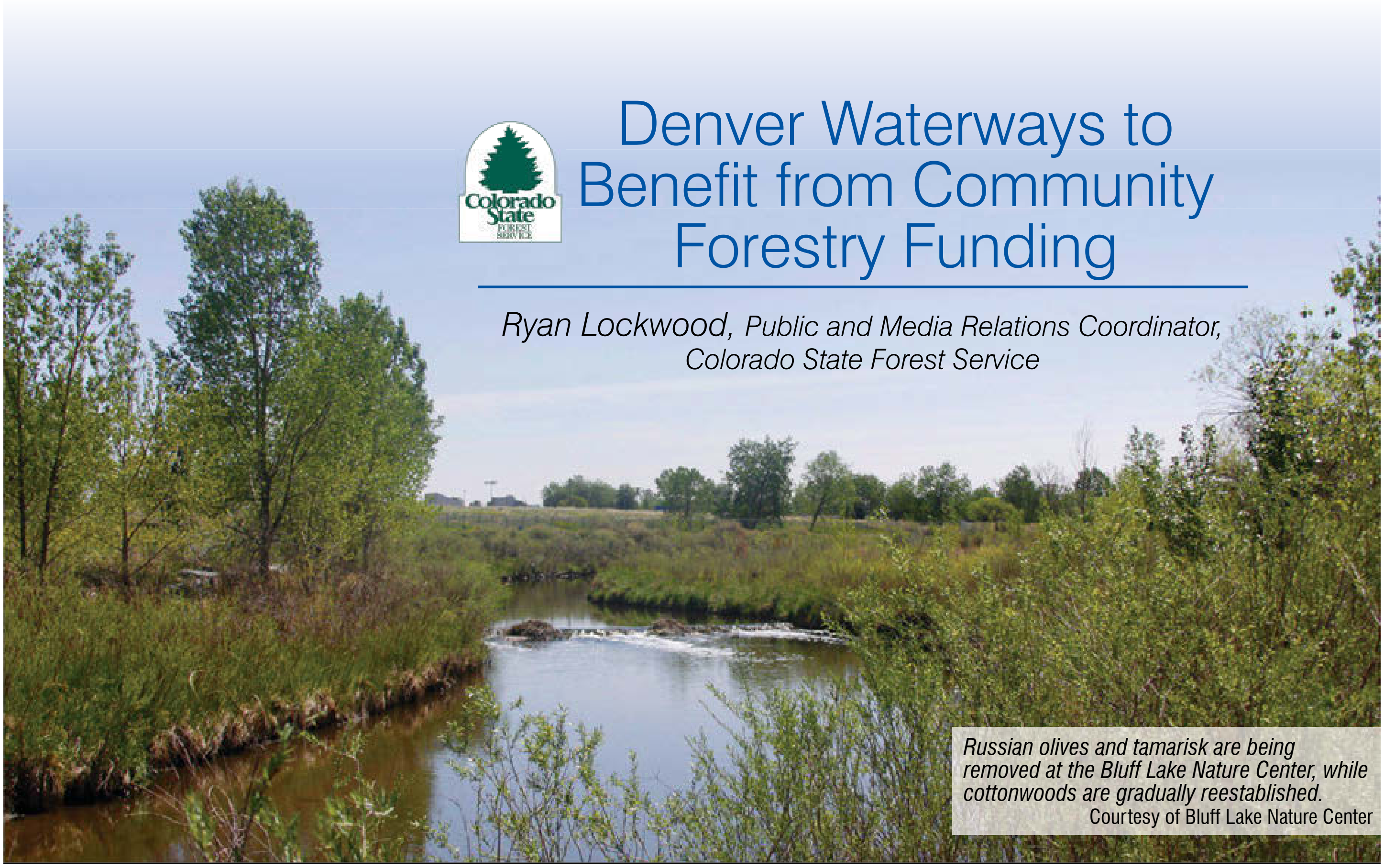
ZVI-Clay Soil Mix, notes Sale, is successful to date because of robust partnerships within Colorado State University and industry. Early adopters of the ZVI-Clay technology include CH2M Hill and ARCADIS. Partners include GeoSolutions, USA Environment, AECOM, Adventus, TetraTech, GSI Environmental, Golder and Associates, and URS.



Tom Sale, shown using ultraviolet light to illuminate and record the movement of petroleum hydrocarbon sheens, is an associate professor and director of the Center for Contaminant Hydrology in Colorado State's Department of Civil and Environmental Engineering.

Denver Waterways to Benefit from Community Forestry Funding

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



Russian olives and tamarisk are being removed at the Bluff Lake Nature Center, while cottonwoods are gradually reestablished.
Courtesy of Bluff Lake Nature Center

Denver's waterways are about to get a little cleaner – and a little greener. This spring, the Colorado State Forest Service awarded a total of $100,000 for four projects to restore and protect Denver-area waterways, while reconnecting local populations with their invaluable water resources. Funding for the projects, which involve the removal of invasive species and planting of native trees in riparian and wetland areas, was awarded under the Denver Metropolitan Urban Waters Forestry Project administered by the CSFS.

"When our waterways become polluted or otherwise degraded, it not only harms the environment, but also prevents the surrounding communities from enjoying related socioeconomic benefits," said Keith Wood, CSFS community forestry program manager. "This program helps improve the quality and accessibility of Denver-area waterways, largely through urban forestry practices."

Project funding was made available to the CSFS Urban and Community Forestry Program through a U.S. Forest Service grant resulting from its involvement in the Urban Waters Federal Partnership. The CSFS and the USFS Rocky Mountain Region sponsored the project to improve and restore crucial Denver-area waterways using urban forestry methods to involve local communities in the stewardship of these areas, and to showcase these projects for replication in other urban areas with degraded waterways.

The purpose of the Urban Waters Federal Partnership is to reconnect urban communities – especially those that are underserved or economically stressed – with their local waterways, and to improve collaboration among agencies striving to improve those waters. Specific program objectives include addressing waterway protection and restoration, ensuring community involvement and education, and working with local officials and community-based organizations to leverage local expertise and funding.

The South Platte River in Denver was one of seven national locations selected to receive assistance from the 2012-2013 Urban Waters Federal Partnership. The four projects in Colorado that received funding in 2012 are:

- City and County of Denver Parks and Recreation ($50,442)
- Institute for Environmental Solutions ($20,000)
- South Suburban Parks and Recreation ($20,000)
- Bluff Lake Nature Center ($9,050)

According to the official request for funding proposals, the South Platte watershed was selected because of the large number of citizens impacted by local waterways and potential economic and social opportunities:

"Urban waters within the South Platte watershed impact large populations in the adjacent, upstream, and downstream Denver metropolitan communities. Urban waters have the potential to be treasured centerpieces of urban revival, and proper tree planting and care along these riparian areas

plays a role in this. Restoring urban riparian ecosystems with tree planting and care will help grow local businesses and enhance educational, recreational, and social opportunities in the communities through which they pass."

"Planting and maintaining the right trees in these areas will restore degraded waterways by offering flood control, absorbing pollutants and providing shade to reduce water loss and stabilize water temperatures for the benefit of aquatic organisms," said Wood, who manages the project for the CSFS.

As required under the scope of the Denver Metropolitan Urban Waters Forestry Project, all of the awarded proposals are located in the South Platte River corridor or along its major tributaries in the Denver Metropolitan area. Each awarded project is required to put forth an equal cash/in-kind match from the applicants, and project work must be completed by Aug. 31, 2013.

The Urban Waters Federal Partnership includes the following national agencies: Department of Agriculture, Department of Health and Human Services, Centers for Disease Control, Department of Commerce, Environmental Protection Agency, Department of Housing and Urban Development, Department of Interior, Department of Transportation and Department of the Army, as well as the Corporation for National and Community Service.

Brief descriptions of the four CSFS-funded projects are as follows:

- **City and County of Denver Parks and Recreation**

  Denver Parks and Recreation (DPR) addresses underserved areas in the South Platte River corridor by restoring, enhancing and protecting local waterways. Through DPR's partnerships with city agencies, nonprofits and neighborhood groups, DPR can extend its reach to residents living near project areas in Grant Frontier, Overland Pond, Ruby Hill and Habitat Parks.

  The funded DPR project advances employment and job training opportunities, environmental education, riparian restoration and community engagement. Under DPR supervision, the Mile High Youth Corps will be utilized for up to four weeks along the project area to remove Siberian elm and Russian-olive trees. The project also involves planting 135 trees and shrubs of diverse species, including American plum, western chokecherry, narrowleaf cottonwood, plains cottonwood, peachleaf willow and Rocky Mountain juniper. Environmental Learning for Kids will assist with outreach and education, and DPR will engage an outside contractor to assist with mulching, pruning, inspection, monitoring and

Left photo: *South Suburban Parks and Recreation volunteer Amy Sposato waters a recently planted tree.* Right Top and Bottom: *Volunteers plant site-appropriate trees along the South Platte River.*

Photos by Scott Grimes

watering of all tree plantings for up to three years.

- **Institute for Environmental Solutions**

  The Institute for Environmental Solutions (IES) is a Denver-based nonprofit dedicated to addressing environmental challenges, advancing science-based solutions to the region's most pressing environmental concerns – including water quality.

  The CSFS-funded IES project uses a multi-phase plan to restore and revitalize the Clear Creek waterway as it passes through the Wheat Ridge Greenbelt Conservation Area. IES will collaborate with the City of Wheat Ridge Parks and Recreation Department and Mile High Youth Corps to remove invasive Russian-olives prior to planting trees to replace canopy gaps. The tree-planting plan is designed to optimize air and water quality, enhance stormwater management and protect the native habitat of the Ute Ladies'-Tresses Orchid species. IES will recruit and train community volunteers on proper tree care and maintenance practices. It also will take steps to increase awareness of the benefits of urban forestry by educating the local community through informative signs posted near planting sites and providing educational materials that focus on the many ecosystem benefits trees provide.

- **South Suburban Parks and Recreation**

  South Suburban Parks and Recreation (SSPR) is planting 200 site-appropriate trees to create a new riverside forest along the South Platte River. An automated, underground drip irrigation system will be installed to ensure tree establishment and vigorous growth. SSPR is engaging student and faculty volunteers from the Earth and Atmospheric Sciences Department at Metropolitan State College, local service clubs, high school students and the South Metro Chamber of Commerce.

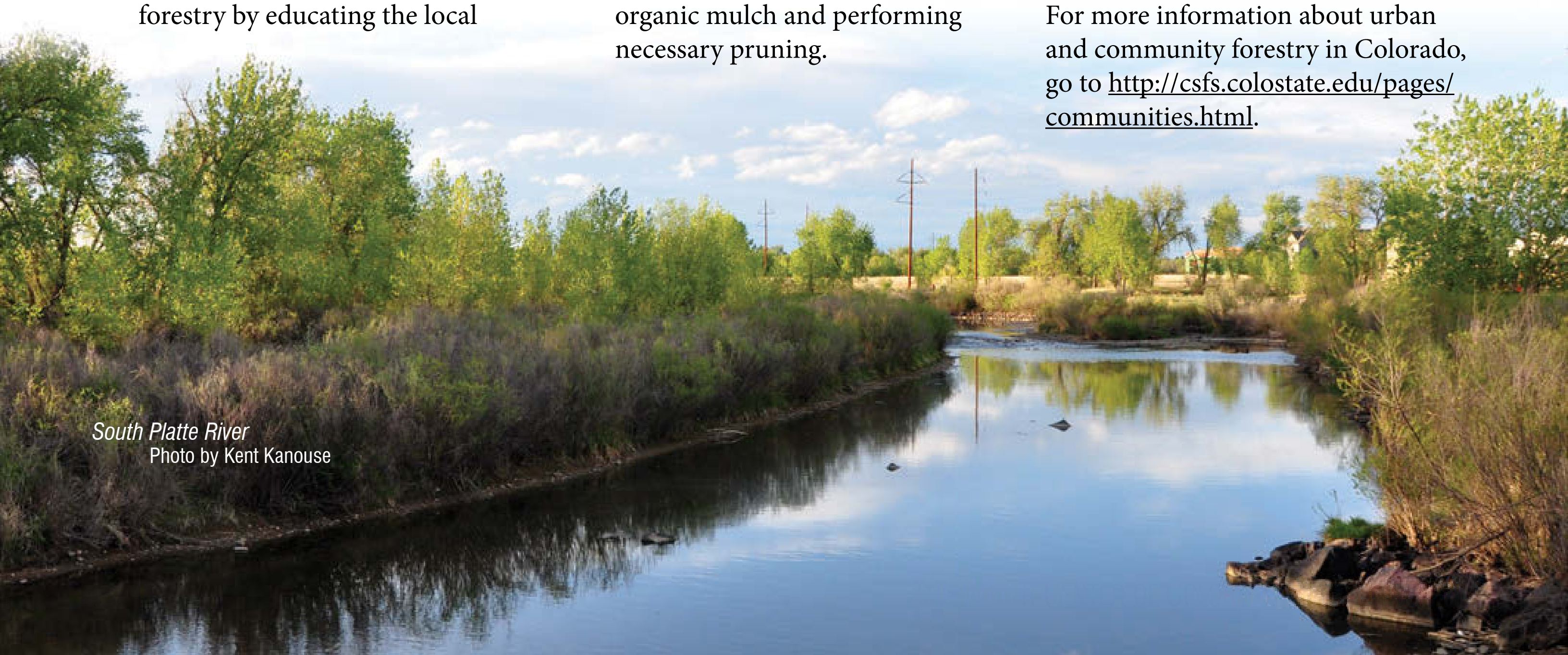
  SSPR will provide community outreach about the newly enhanced area of the South Platte River and distribute educational pamphlets on the values and benefits of community forests. Environmental stewards will assist with tree care, while SSPR forestry crews will lead efforts to establish and care for newly planted trees by maintaining irrigation systems, overseeing regular inspections, providing organic mulch and performing necessary pruning.

- **Bluff Lake Nature Center**

  The Bluff Lake Nature Center (BLNC), located in northeast Denver, is a nonprofit agency that owns and manages an urban wildlife refuge and outdoor classroom. The refuge is home to abundant wetland wildlife and native plants. According to the nonprofit's website, nearly 5,000 elementary students visit Bluff Lake each year as part of its formal education programs.

  The Bluff Lake Nature Center project focuses on maintenance of existing plantings and on making improvements to wetland/ riparian wildlife habitat. Funding will help with the removal of invasive species and planting of native species to attract and support wildlife, which in turn should enhance visitor experiences. The BLNC will use funding to continue its management of woody invasive species and removal of slash piles, which are chipped and used as soil amendments for continued plantings and erosion control. A community of trained volunteers will help coordinate these efforts, as well as efforts to educate the public on the importance of watershed and wildlife habitat.

For more information about urban and community forestry in Colorado, go to http://csfs.colostate.edu/pages/communities.html.



South Platte River
Photo by Kent Kanouse

GRAD592

Interdisciplinary Water Resources Seminar

Fall 2012 Theme: **Addressing Global Water Resource Challenges with Local Expertise**

Mondays at 4:00 PM, Building NATRS 109

Aug 20	John Stednick Erin Donnelly	Environmental Flows; Or Can Groundwater Pumping Grow More Sturgeon?
Aug 27	Susan De Long Jeremy Chignell	Energy Recovery From Wastewater: New Trends and Possibilities
Sept 10	Brian Bledsoe Joel Sholtes	River Management Under Environmental Change: Tools for Planning Under Uncertainty
Sept 17	Larry Roesner Sybil Sharvelle	Integrated Urban Water Management
Sept 24	Steven Fassnacht Niah Venable	Overcoming Hydrologic Data Paucity in Mongolia
Oct 1	Patty Rettig	Using the Water Resources Archive for Research, Teaching and Scholarship
Oct 8	Patrick Byrne	Breeding for Improved Water Productivity for Colorado Wheat
Oct 15	Allan Andales Neil Hansen Kendall DeJonge	Addressing Water Scarcity Through Limited Irrigation Cropping: Field Experiments and Modeling
Oct 22	Susan De Long Maria Renno	Development of Sustainable Water Treatment Technologies
Oct 29	William Bauerle Grace Lloyd	Reconciling Physiological Models of Stomatal Conductance to Soil Drying
Nov 5	Mark Fiege	Using Digital History for Education About Local Water Resources
Nov 12	Melinda Laituri Faith Sternlieb	Building Bridges and Crossing Boundaries: Water Banking in the Colorado River Basin
Nov 26	Jorge Ramirez	Vulnerability of US Water Supply to Hydroeconomic and Climate Variability
Dec 3	LeRoy Poff	Using Environmental Flows to Stem Species Invasion of Western Rivers in a Period of Rapid Climate Change

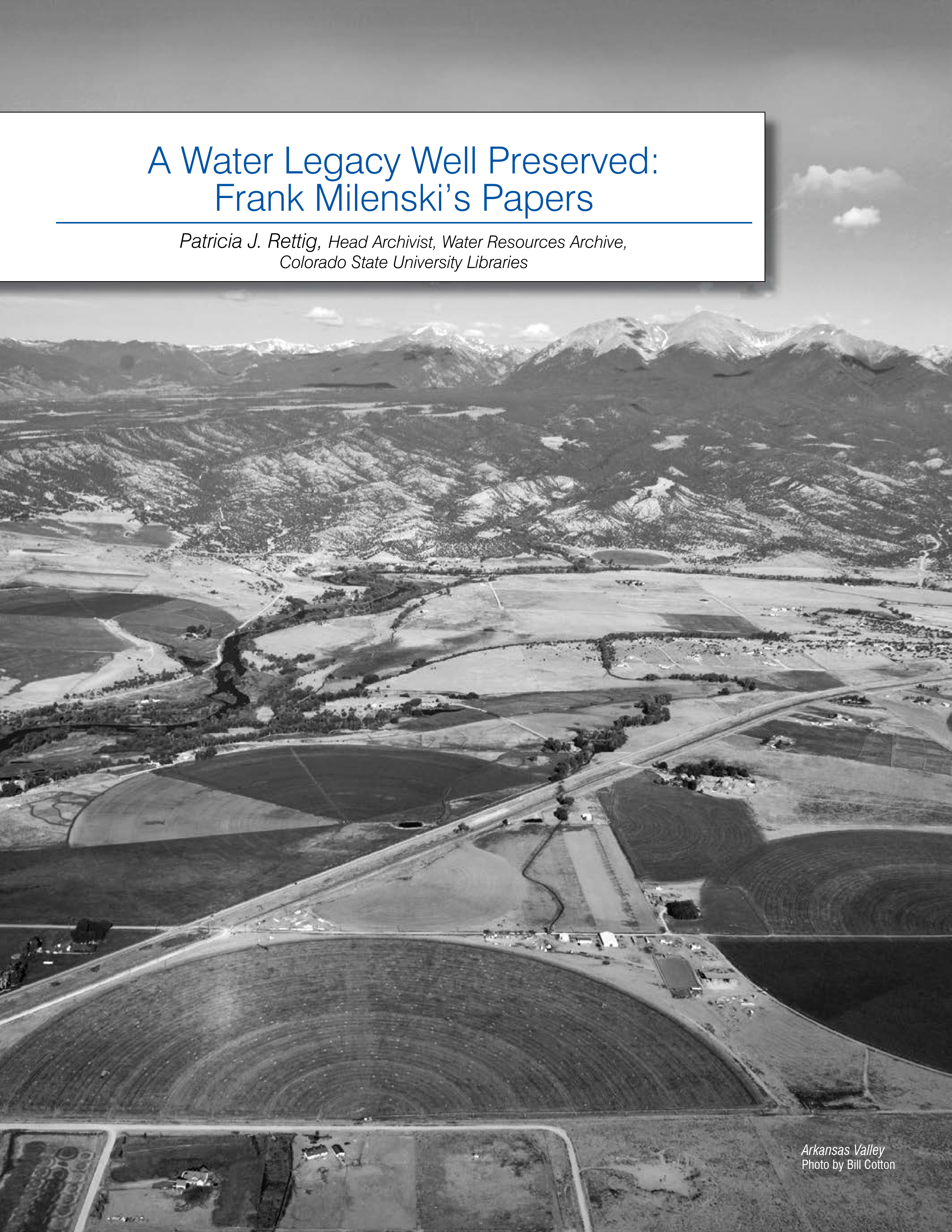
Students wishing to obtain 1 credit for the seminar may sign up for Water Resources Seminar (CRN 67067) GRAD 592 Section 001. The Fall 2012 seminar will be held Monday afternoons at 4-5pm in Natural Resources Room 109.

Faculty and guests are welcome to attend and participate.

For more information, contact Reagan Waskom at reagan.waskom@colostate.edu or visit the CWI website.

A Water Legacy Well Preserved: Frank Milenski's Papers

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



Arkansas Valley
Photo by Bill Cotton

“There isn’t any question in my mind that water is the most valuable asset, and probably the least understood of any of the commodities, in the State of Colorado.”

This first sentence of the book *Water: The Answer to a Desert’s Prayer* reveals the author’s twin aims: to both explain the value of water and educate the state about it. In just over 150 pages, Frank Milenski accomplishes both, all the while not hesitating to tell it like it is.

During his lifetime, Milenski was regarded as one of the most knowledgeable water experts in the state. He recorded that knowledge in not one, but two books about Colorado water history, particularly focused on the Arkansas Valley, the place he called home. Those two books are not his only legacy, though.

When he died in 1998 at the age of 85, Milenski left behind nine filing cabinets, full of his reference files, working papers, and manuscript drafts. With the family not interested in retaining the materials, the filing cabinets were acquired by the Lower Arkansas Valley Water Conservancy District. This spring, the nine cabinets—plus seven boxes—made their way to the Water Resources Archive, to be preserved in perpetuity.

The contents of the cabinets are a rich historical resource, not only about Milenski and his career, but also concerning Arkansas Valley water issues. Particular subject areas covered include groundwater, irrigation, interstate compacts, municipal water usage, and much more. Milenski accumulated five drawers full of local court cases and two on the *Kansas v. Colorado* case. Two other drawers contain information on canals and reservoirs, most especially the Fort Lyon and Catlin canals. Another drawer documents the Southeastern Colorado Water Conservancy District.

Frank Milenski accepting the Headgate Award, 1975.
Courtesy of the Water Resources Archive, Colorado State University Libraries

The majority of the drawers and the folders inside are labeled and well organized, making it easy for archival staff to perform their work of making everything accessible for research. The materials have not yet been thoroughly inspected, but among the reports, meeting minutes, and letters, some photographs, slides, and maps have been seen. One white three-inch binder labeled “Jokes” is full of cartoons, quips, and anecdotes

Just one of 36 drawers of Frank Milenski’s files.
Courtesy of the Water Resources Archive, Colorado State University Libraries

from a variety of sources. This may not tell a great deal about Colorado water history, but it certainly reveals something about Milenski’s sense of humor!

Eventually, archivists will create an inventory of the materials and post it on the Water Resources Archive’s website. Someday, the files themselves may get scanned and uploaded. Until that happens, the collection will be accessible to the public for on-site research in Fort Collins.

Milenski, the youngest of his parents’ six boys, was the only one born in Colorado, west of Rocky Ford. Milenski farmed under the Catlin Canal for most of his life and was president of its board of directors for 29 years. He was on Southeastern’s board for over 30 years and also served on the Colorado Water Conservation Board during the early and middle 1960s. In 1975 he received the Headgate Award from the Four-States Irrigation Council. In 1989 the Colorado Division of Water Resources named him water manager of the year. He was the recipient of the Wayne N. Aspinall Water Leader of the Year Award from the Colorado Water Congress in 1993.

Milenski wrote in his second book *In Quest of Water: A History of the Southeastern Colorado Water Conservancy District and the Fryingpan-Arkansas Project:* “This book is dedicated hopefully to the wise use of water. One of the Earth’s greatest blessings.” Hopefully, the rich historical resources Milenski left behind will be well and wisely used in the best interest of the state’s most valuable asset.

For more information on the Milenski Papers or related collections, see the Water Resources Archive website at lib.colostate.edu/archives/water/ or contact the archivist (970-491-1939; Patricia.Rettig@ColoState.edu) at any time.

High Park Fire
Photo by Kim Hudson

COLORADO CLIMATE CENTER

Drought Stinks!

Nolan Doesken and Wendy Ryan, Colorado Climate Center

As I write this, it is late June 2012—the midpoint of our statewide "Water 2012" water celebration. 2012 was chosen as this special year of honoring the importance of water in our state because of the convenient coincidence of many water organization anniversaries—a 10th, 50th, 75th, 100th and even one 125th anniversary—our Fort Collins weather station here on the Colorado State University campus (http://www.water2012.org/). When the 2012 water celebration year was selected, some of us joked around saying "I bet we'll have a drought." Little did we know 2012 would turn out with a miserably memorable drought season.

As we move through summer, our beautiful Colorado mountain streams are flowing—but with only 1/10 or less of the volume of what they had this same time last year. Farmers are doing their best to be optimistic and productive, but each day, crop conditions are deteriorating. Soils are so dry, evaporative demand is so high, and precipitation has been so rare and localized that even irrigated crops are water stressed. Farmers with irrigation are hoping that late seasons water supplies will hold out.

One can overlook drought here in Colorado—especially since so much of Colorado is already short on rainfall, even in a good year. But when the air is full of dust and smoke, and when the few clouds that do form don't make rain, it gets harder and harder to overlook. That is especially true during the summer, when vegetation is parched, and many wildfires are burning. Each afternoon, we are greeted by a huge column of smoke and clouds formed by the nearest and largest fire to the Colorado State University campus—the High Park Fire. Temperatures are soaring over 100°F in Fort Collins (and over 110°F in some parts of eastern Colorado). Denver just reached 105°F, and I hear that our all-time state record of 114°F from the 1930s and again in 1954 may have just been matched. Many mornings we wake to the smell of stale forest fire smoke. We won't be forgetting this "Year of (not enough) Water" in Colorado for a long, long time.

I sincerely hope that by the time you read this, weather patterns will have changed and a few soaking rains and some cool temperatures may have finally brought some relief. But right now, that's hard to envision. So how did we get in this predicament so soon after the drought we didn't want to repeat—the drought of 2002?

The Route to Drought

Think back to last year. Last year it was Texas, New Mexico and Oklahoma who were parched and roasting with most of the huge state of Texas facing Extreme to Exceptional drought all at the same time based on the U.S. Drought Monitor. Southern Colorado shared some of the misery with very dry conditions in the Rio Grande watershed and across most of the Arkansas River Basin. Baca County drought conditions nearly matched those of the 1930s Dustbowl years. Meanwhile, northern Colorado was bathed in water bounty as a winter of heavy snows followed by a cool wet spring (2011) resulted in a long and lovely spring runoff, with high flows on many rivers lasting well into the summer. There were concerns

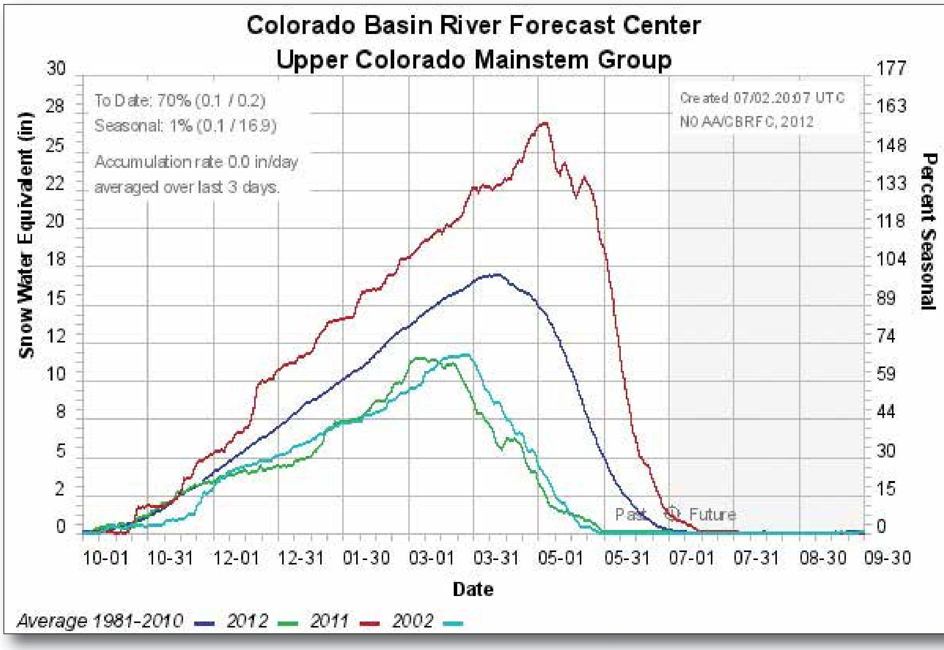


Figure 1. *Evolution of basinwide seasonal snow water content in the Upper Colorado River basin in Colorado based on selected SNOTEL stations (USDA-Natural Resources Conservation Service). The 2012 water year is compared to 2011 (top line), 2002 (severe drought year) and the 1981-2010 average (smooth curve).* *Figure 1. Evolution of basinwide seasonal snow water content in the Upper Colorado River basin in Colorado based on selected SNOTEL stations (USDA-Natural Resources Conservation Service). The 2012 water year is compared to 2011 (top line), 2002 (severe drought year) and the 1981-2010 average (smooth curve).*

over potential snowmelt flooding, but for the most part those were not realized. Instead the snow melted steadily spread out over several weeks. Now that seems so long ago—but that was just last year.

The dry predicament we're in now did not sneak up on us but neither was it obvious. Late summer 2011 was hot and dry, but there were several fall snowstorms, and the mountain snowpack seemed promising. With lingering La Nina conditions (cooler than average sea surface temperatures in the eastern and central tropical Pacific off the coast of South America), it seemed that we may be in for a continuation of the drought over the southern states and southern Colorado and perhaps more generous precipitation over northern Colorado. But as the winter progressed, snow accumulation lagged over much of the mountains but especially in places like the Gore Range, the Eagle River valley, the Yampa and the North Platte watersheds. Some "upslope" storms helped the Colorado Front Range, but month by month, the graphs of accumulated snow water content looked worse and worse. Timely storms did bring beneficial moisture to southern Colorado and greatly helped those same areas that had been the driest during 2011.

What Happened in March (2012)

Those of us who were here to watch the evolution of the 2002 drought all remember clearly the month of April when in a matter of weeks, what we thought was a decent snowpack seemed to simply evaporate, disappearing without producing appreciable runoff. Many of us who attended the tense April meeting of the Colorado Water Availability Task Force that year recall the TV trucks and cameras and the plume of smoke from an April fire southwest of Denver—a precursor of much worse things to come. This year, the onset of drying winds and warm temperatures came to visit just like in 2002—but this time it came a full month earlier.

After one last widespread snow during the first days of March, the weather turned balmy, and snowpack rapidly retreated. At first it felt great—sunshine and warm temperatures had people out hiking, biking, golfing and enjoying the great outdoors. But skier visits declined sharply at our mountain ski areas, and by early April we were already saying, "Whoa, if this keeps up this is going to be just like 2002"—and we all knew that wasn't good (see Figure 1).

Spring—A Bad Time to be Hot and Dry

Spring storms dropping widespread precipitation and keeping Colorado cool and cloudy for days at a time are fairly typical for Colorado in April, May, and sometimes into early June. These storms replenish soil moisture in the foothills and plains and add late season snowpack in the higher mountains. Spring storms are a double bonus—they add water supply while reducing water demand. But this year, such storms were largely absent. There was a good soaker that helped green up the southern Front Range from Trinidad to Colorado City (greatly appreciated after the lasting drought there in 2011), but most of Colorado missed out. Abnormally warm March temperatures were not followed, as we had hoped, by spring storms. Instead it kept getting warmer and warmer, and drier and drier (Figure 2) Almost every week the weekly Climate, Water and Drought webinar participants ended the session by recommending expansion of drought conditions somewhere in Colorado, and now in June, that trend continues.

These webinars are open to the public: http://ccc.atmos.colostate.edu/drought_webinar.php At the end of each webinar, we prepare a written summary of water supply conditions. If you would like to be on the list to have these summaries e-mailed to you each week, contact me at nolan@atmos.colostate.edu.

Dry, warm springs may have been pleasant for Colorado residents and easy on our heating bills, but they are not a good thing for our forests and rangeland. Most Colorado grasses love cool and occasionally damp spring weather and don't grow unless these conditions occur. Thus, range and pasture conditions have deteriorated steadily, and ranchers have few options. I don't have to say much about our forests, with one disastrous fire after another, starting with the lower North Fork Fire (Jefferson County—late March 2012), then the Hewlett Gulch fire (mid-May in Larimer County). With no interruption in the dry spring weather, forests were way too dry way too early—early enough that the spring winds still had all their muster to help fan any fire that started. It was sad then, but almost not surprising when the High Park Fire exploded west of Fort Collins in early June and took only three days to burn over 40,000 acres and many homes. Also not surprising was that as more weeks elapsed without rain and as temperatures climbed to over 100 degrees, the fire could not be extinguished despite valiant efforts by over 2,000 fire fighters, and that many other large fires erupted elsewhere in Colorado. Drought has many expensive impacts that play out over weeks, months, and even years. But the face and the hands of wildfire are what so deeply grab and hold our attention. Even while out of state on a June vacation, we found ourselves drawn to get the latest updates on the High Park fire.

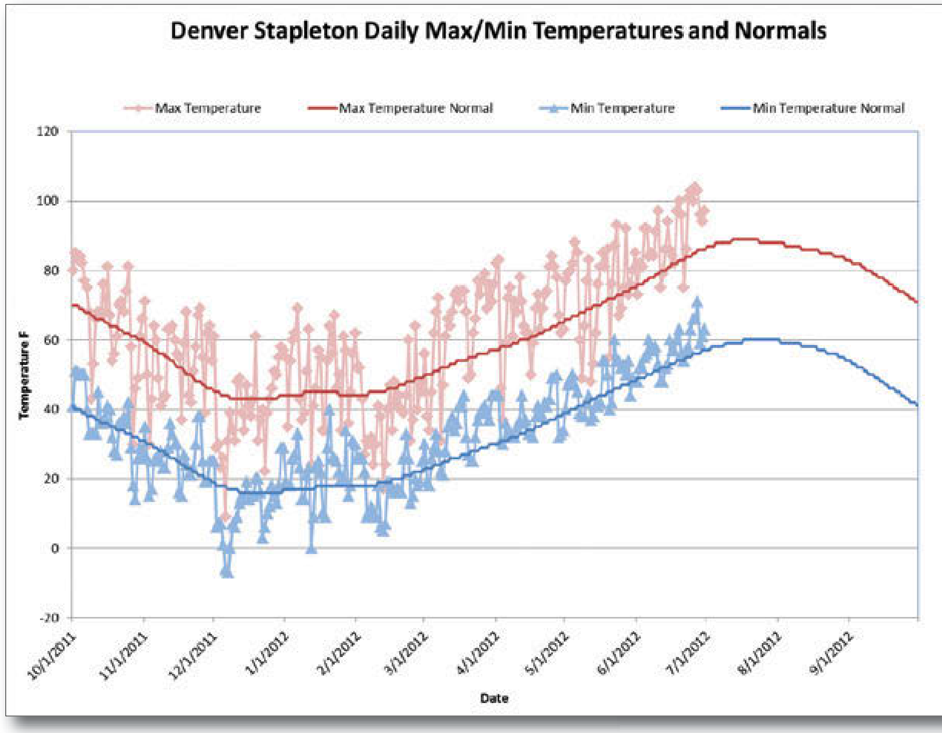


Figure 2. *Daily maximum and minimum temperatures compared to average for Denver Stapleton compared to average (smooth lines). Note the persistent above average temperatures since early March 2012.*

Could it be any worse?

The greatest impacts from drought in Colorado are usually experienced in the summer months—June through August. With summer drought often comes intense heat, wilted crops, dust, and fire. From this late-June vantage point, our current situation seems be just about as bad as it can get. But believe it or not, it could be worse—a lot worse. What 2012 has going for it was nearly full reservoirs and fairly generous baseflows in streams and rivers, all a result of the big snow year and wet spring of 2011 in northern and central Colorado. The real nightmare comes when we string two, three, or four years like this in a row. It could happen and has happened before. 2002 followed on the heels of two already dry years in Colorado. 1902, 1934, 1954 were all extremely dry years (at least for some parts of our state) that were embedded within multi-year dry periods. So yes, it could get worse, and possibly very soon. It seems too soon to happen with 2002 so close behind in our rear view mirror. There are no confident indicators that point to 2013 being another drought year, but neither are the indicators strong saying that it won't be. We'll have some indication already by the time you read this because if the rest of 2012 is as dry as the first half, Colorado's reservoirs will be dropping fast.

Statewide recovery from drought doesn't happen overnight.

A rain, another rain, and then a few more followed by a long, cold, and snowy winter—that's what we need in the coming months. But with the size and climate diversity of Colorado, it is much more likely that one area of the state may see rapid improvement while other parts don't. Remember the March 17-20th snowstorm on the Colorado Front Range back in 2003? In just one week, Denver and surrounding parts of Colorado were rescued from a lasting drought by a remarkable storm. Other parts of the state missed the brunt of that storm and took years to recover from the intense drought of 2002. It wasn't really until 2007 that we could say that the 2002 drought was over for all of Colorado.

The same will likely be true this time. Occasionally, though, recovery takes a different course like back in

1957, where the wettest year in state history successfully brought to a close the "drought of the '50s" for the whole state. Most likely, we'll still be dealing with drought in some parts of the state this time next year.

And can it flood during a drought?

You bet and we'll put that question to the ultimate test this summer. By the time you read this article we'll likely know. Colorado's worst flood of all is arguably the Republican River flood of—you guessed it—1935, smack dab in the middle of a decade long drought (Figure 3). September 1938 flooding was extreme—a short interlude in an otherwise long drought. 1955 floods in southern Colorado were a short interruption in the otherwise relentless drought of 1952-56. Even the widespread extreme flooding of June 1965 was sandwiched between two otherwise very dry years; 1964 and 1966. The Big Thompson flood in 1976 really was the event that marked the beginning of the 1976-77 drought. Basically, flood and drought are both defining characteristics of our semi-arid Colorado climate and they can both occur almost together.

Another flood threat, just to add insult to injury, is post-fire flood potential that is quite real. This threat stems both from the lack of groundcover after wildfire (groundcover helps soften the impact of raindrops and slow the movement of runoff, so that more soaks into the soil) as well as a hydrophobic layer that develops in the soil after plants burn in a hot fire. These two scenarios can cause flash floods with just small amounts of rainfall. With large acreages of burned area in our state, it is important to be keenly aware of the potential for post-fire flooding.

Can we deal with drought?

We've come a long way since the 1930s. The many water institutions that have been founded in our state that we are celebrating together with this year have helped us manage and plan for variations in water supply. As a result, impacts of drought have been greatly mitigated. But we must not be complacent. The drought of 2002 and now again in 2012 seem "as bad as it gets" and most of us are getting along. But history tells us that droughts of the past have sometimes lasted for decades. Life "as usual" would be hard to maintain.

A special Colorado Water Conservation Board conference is scheduled this September 19-20, 2012 to bring many experts together to discuss and plan how we can and are getting even better prepared for living with drought. Perhaps we'll see you there. (http://cwcb.state.co.us/water-management/drought/Pages/2012CWCBStatewideDroughtConference.aspx).

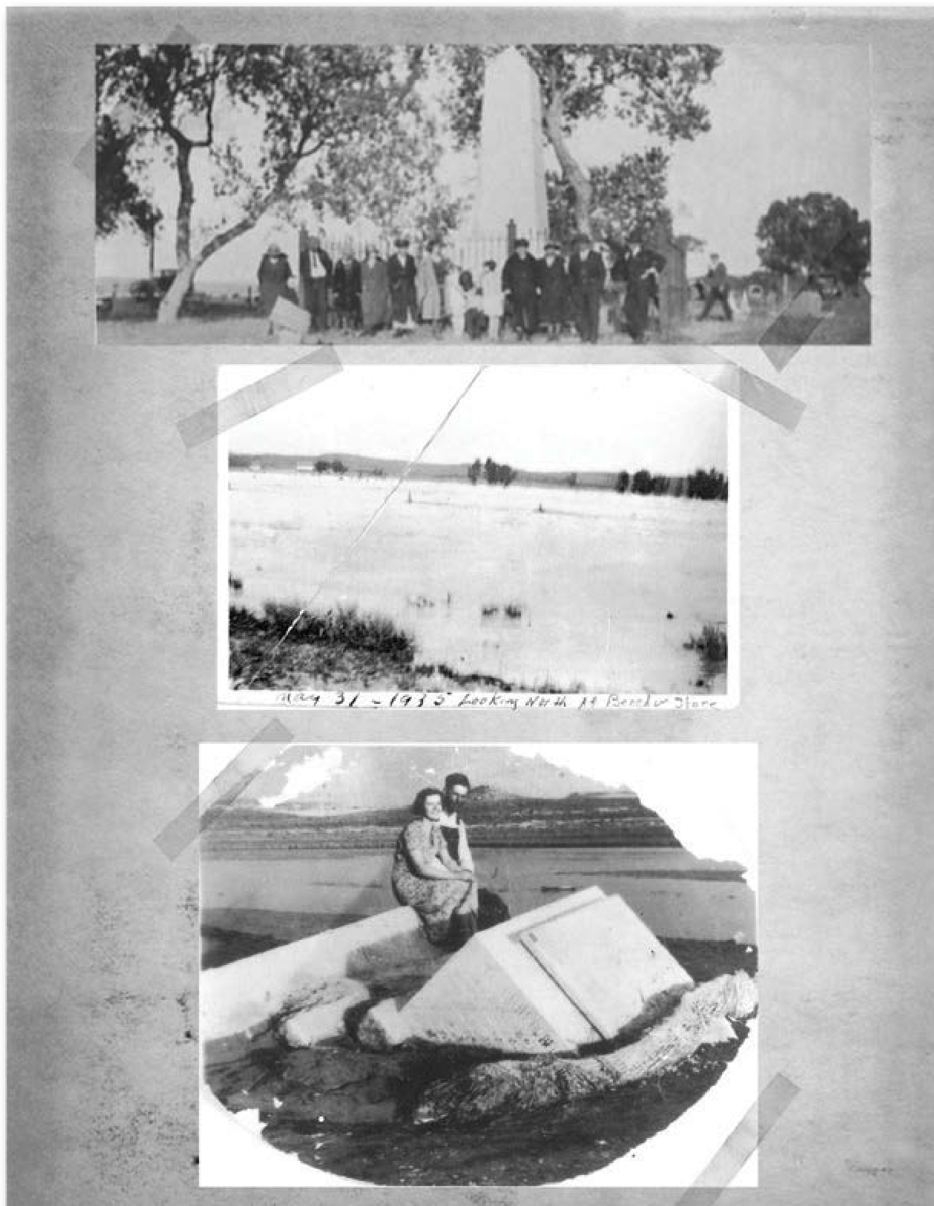


Figure 3. *When the 1935 flood passed through the Beecher Island area (south of Wray in Yuma County, middle photo), it took out a monument, of which only the base was recovered (bottom). The original monument (top) was 19 feet tall, and the current replacement is much smaller.*

Courtesy of the National Weather Service—Goodland Kansas Forecast Office

Report on Arkansas River Valley Irrigation Available

The Colorado Water Institute (CWI) Completion Report 221, *Irrigation Practices, Water Consumption, & Return Flows in Colorado's Lower Arkansas River Valley: Field and Model Investigations*, has been released and made available (see below for more information). The report is based on field investigations taking place over the 2004-2008 growing seasons in the Lower Arkansas River Valley of Colorado. The study's main purpose was to describe and compare surface irrigation and sprinkler irrigation practices and their interaction with the larger stream-aquifer system of the Lower Arkansas River Valley. Primary funding came via grants from the Colorado Water Conservation Board, the Colorado Division of Water Resources, the Colorado Department of Public Health and Environment, the Southeastern Colorado Water Conservancy District, the Lower Arkansas Valley Water Conservancy District, and the Colorado Agricultural Experiment Station.

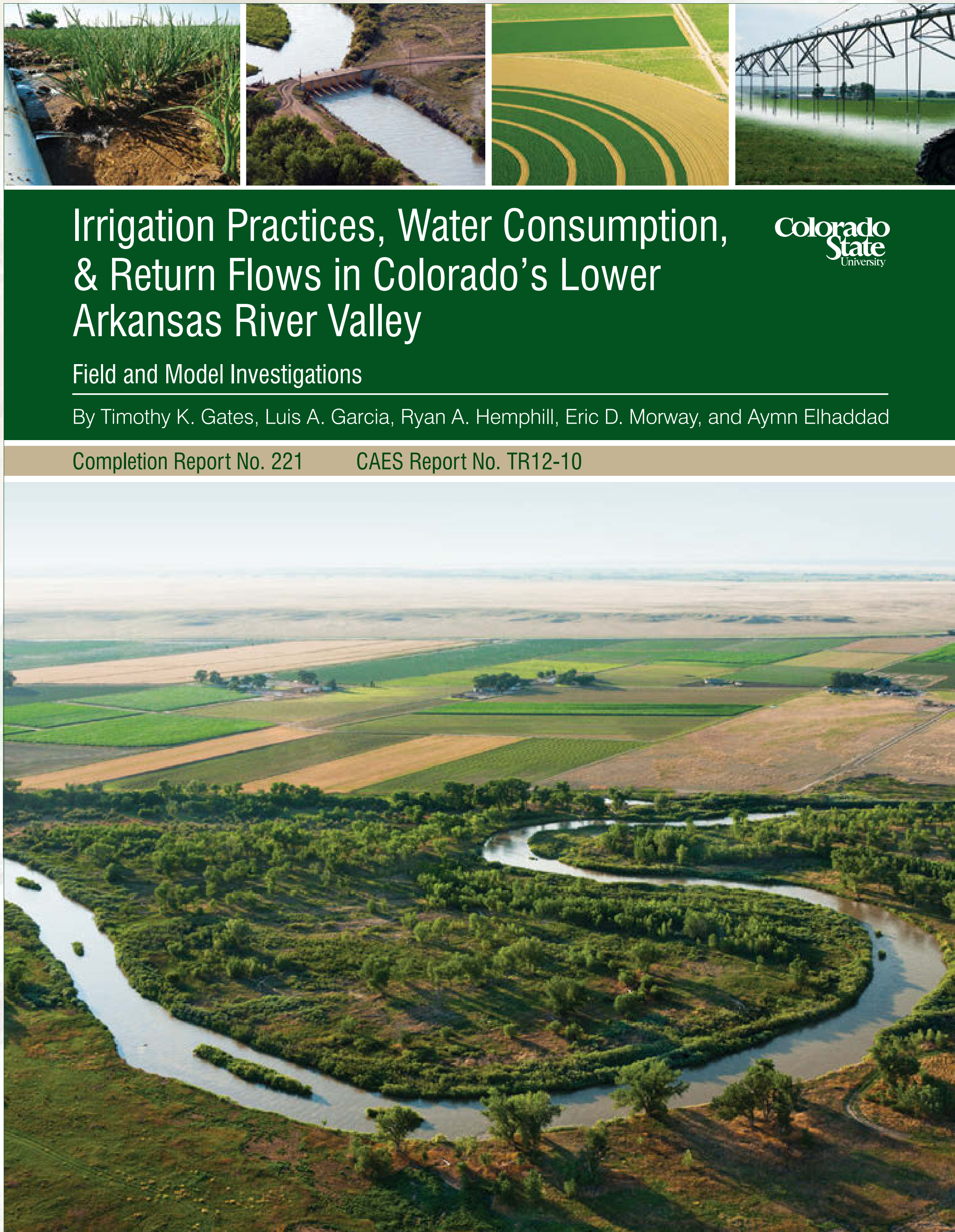
Summary

By Timothy K. Gates, Luis A. Garcia, Ryan A. Hemphill, Eric D. Morway, and Aymn Elhaddad

The LARV in Colorado has a long history of rich agricultural production, but is facing the challenges of soil salinity and waterlogging from saline shallow groundwater tables, high concentrations of salts and minerals in the river and its tributaries, water lost to non-beneficial consumption, and competition from municipal water demands. Significant improvements to the irrigated stream-aquifer system are possible, but they are constrained by the need to comply with the Arkansas River Compact. Making the best decisions about system improvements and ensuring compact compliance require thorough baseline data on irrigation practices in the LARV. This report summarizes the methods, analysis, results, and implications of an extensive irrigation monitoring study conducted by Colorado State University (CSU) during the 2004-2008 irrigation seasons in representative study regions upstream and downstream of John Martin Reservoir (referenced herein as Upstream and Downstream). A total of 61 fields (33 surface-irrigated, 28 sprinkler irrigated) were investigated. Results from 523 monitored irrigation events on these fields are presented. Data and modeling results from more extensive studies conducted by CSU between 1999 and 2008 also are provided.

Data on applied irrigation, field surface water runoff, precipitation, crop evapotranspiration (ET), irrigation water salinity, soil water salinity, depth and salinity of groundwater tables, upflux from shallow groundwater, crop yield, return flows to streams, and salt loads to streams are presented. Deep percolation and application efficiency for irrigation events on each field are estimated using a water balance method implemented within the CSU Integrated Decision Support Consumptive Use (IDSCU) Model. Tailwater runoff (surface water runoff at the end of a field) fraction ranges from zero to 69 percent on surface irrigated fields, averaging about eight percent, while deep percolation fraction ranges from zero to 90 percent, averaging about 24 percent. Application efficiency ranges from two to 100 percent on surface irrigated fields, with an average of about 68 percent. No significant runoff is observed on sprinkler-irrigated fields, and estimated deep percolation typically is negligible. On sprinkler-irrigated fields average application efficiency is about 82 percent, but in many cases these fields are under-irrigated. Upflux from shallow groundwater tables below irrigated fields is estimated to average about six percent of crop ET, ranging between zero percent and 40 percent. Average measured total dissolved solids concentration of applied surface irrigation water is 532 mg/L Upstream and 1,154 mg/L Downstream. Average estimated salt load applied per surface irrigation event is 997 lb/acre Upstream and 2,480 lb/acre Downstream. Average estimated salt load applied per sprinkler irrigation event is 1,217 lb/acre Upstream and 446 lb/acre Downstream. Soil saturated paste electrical conductivity averaged over all Upstream fields ranges from 3.7-4.7 deciSeimens per meter (dS/m) over the monitored seasons and from 4.5-6.4 dS/m over Downstream fields. Water table depth averaged over Upstream fields varies from 7.8-12.1 feet over the monitored seasons and average specific conductance (EC) of groundwater varies from 1.8-2.3 dS/m. Water table depth averaged over Downstream fields varies from 12.6-15.0 feet with average EC from 2.3-3.0 dS/m. Analysis reveals trends of decreasing crop ET with increasing soil salinity on several investigated fields. Trends of decreasing relative crop yield with increasing soil salinity on corn and alfalfa fields also are detected.

Calibrated regional groundwater models indicate an average recharge rate to shallow groundwater of 0.10 in/day and 0.06 in/day over modeled irrigation seasons 1999-2007 Upstream and 2002-2007



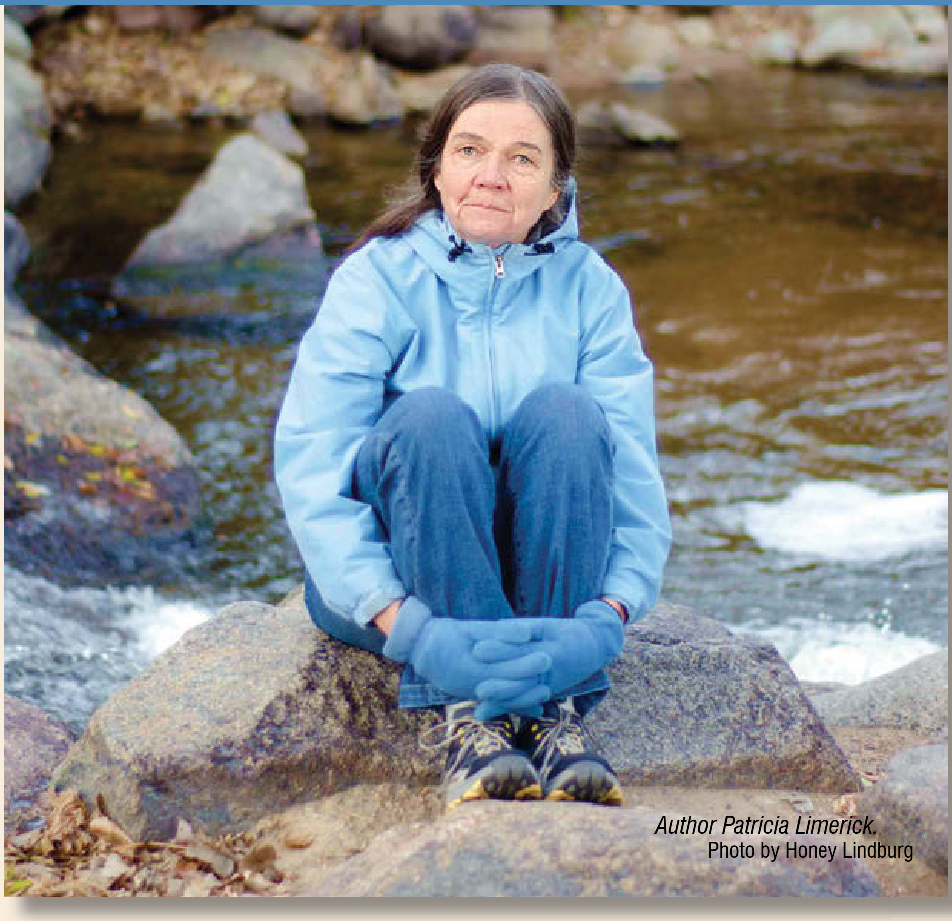
Downstream, respectively. Upflux to non-beneficial ET in the regions is estimated to be about 26,000 ac-ft/year Upstream and 35,000 ac-ft/year Downstream, with an approximation for the entire LARV being 82,000 ac-ft/year. Average groundwater return flow rate to the Arkansas River within the Upstream and Downstream regions is estimated as 30.9 ac-ft/day per mile and 12 ac-ft/day per mile along the river, respectively. Salt load in return flow to the river over the modeled years is estimated at about 93 tons/week per mile Upstream and about 62 tons/week per mile Downstream.

The significance and implications of these findings are discussed. Also, a number of specific questions of concern to water managers and regulatory agencies are addressed.

The full report will can be accessed at www.cwi.colostate.edu, or obtain a hard copy by contacting the Colorado Water Institute, E102 Engineering, 1033 Campus Delivery, Fort Collins, CO 80523-1033, 970-491-6308, or cwi@colostate.edu.

Book on History of the Denver Water Department Due in September

Patricia Limerick, History, University of Colorado - Boulder



Author Patricia Limerick.
Photo by Honey Lindburg

As a child, I slipped into unnecessary self-disclosure and confessed to my parents that I was interested in history. This put the idea in their minds that I would enjoy meeting old-timers and hearing about the olden days of my hometown, Banning. Although I was a shy child, my parents were relentlessly sociable, and so we soon set off on expeditions to the living rooms of the elderly.

On one outing, we visited with an old gentleman named Bert Jost, who had played a big role in the origins of Banning's water utility. As the intensity of Mr. Jost's memories accelerated, he took to grabbing his cane and waving it around for emphasis. My seat next to him on the sofa began to seem poorly chosen. Happily, his wife had acquired a survival skill of reaching over, seizing his cane, and declaring, "Bert, I'm just going to take that cane away from you if you can't hold it still!"

As I anticipate the publication of *A Ditch in Time: The City, the West, and Water*, in September of this year, thoughts of Mr. Jost's cane, thrashing through the air not far from my own head, inevitably come to mind. In the opinion of many members of the American public, a history of the Denver Water Department might seem intensely boring, a tedious tale of bureaucracy and infrastructure. But a considerably more knowledgeable group of citizens (some of them readers of this very newsletter!) are likely to respond in a very different way, reading *A Ditch in Time* intensely, critically, and argumentatively, and keeping a record of the lively remarks they will want to convey to its author.

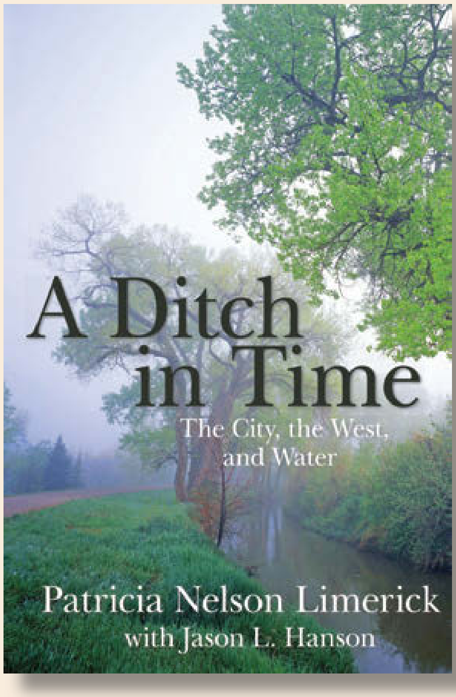
This background may explain my choice of a full-scale deployment of humor in *A Ditch in Time*. I will not conceal the hope that humor will act as literary equivalent to WD-40, reducing the factors of friction and tension in the responses of readers who are deeply engaged in the world of water themselves. On shelves bending low with books on Western water, *A Ditch in Time* is surely going to be the only book positioning original limericks between chapters. The chapters themselves contain all sorts of madcap comparisons and analogies, connecting Denver Water to Lemuel Gulliver's troubles with the Lilliputians, to the Delphic Oracle's crypticness, and to mischaracterized banshees. If *A Ditch in Time* proves to be a precedent-setter for demonstrating that the use of humor in studies of natural resources makes possible a more productive, problem-solving public discourse, this will make the author very, very happy. My choice to use humor was also a conscious and deliberate response to a maddening literary puzzle: thanks to the technicalities of law and engineering, writings about water history can be very dull, even though the control of water arouses such passion that it would seem that boredom would be the least of our problems.

The book, after all, has to cover a lot of ground, and general readers deserve all they can get in the way of incentives and encouragement to stay on the trail. The story starts in the times when Indian people in this area guided their movements and activities by their knowledge of streams and springs. It moves on to a consideration of the impressions of the early-nineteenth-century explorers Zebulon Pike and Stephen Long, who felt certain that the Plains along the Front Range were simply too arid to support American settlement. Pike and Long did not foresee the magnetism of gold discoveries, and so, with the founding of Denver as a mining supply town, the book tracks the competitive era of private water companies, and, starting in the late 1800s, the movement to replace private companies with a municipal agency.

The range of actions, events, developments, and initiatives that required coverage in this book was daunting to the author and may be daunting to the reader: the first diversion to Denver from the Western Slope through the Moffat Tunnel; the complicated negotiations of the Blue River Decrees that opened the way for Denver's second big diversion through the Roberts Tunnel; the 1970s controversy over the Foothills Treatment Plant in the context of revolutionary federal environmental laws; the struggle over the proposed Two Forks Dam; the striking change in the agency's operations signaled by the appointment of Chips Barry as manager; and the recent proposal to increase the diversion from the Fraser River through the Moffat Tunnel and to expand Gross Reservoir for greater Front Range storage.

Bringing the story up to the present was the most strenuous undertaking of all, though I did my best to evade and even deny this fact. A year ago, when I had finished the chronological chapters up to 1990, I indulged in an episode of astounding thick-wittedness and over-confidence. The book, I told many friends, was pretty much finished. My one remaining task would be simple and quick: to write the chapter on the last twenty years, and this, I said idiotically, would not take very long.

Here is what I learned in the four or five months that followed, as I slogged, dithered, and brooded my way through to the completion of this "simple" and "quick" last task: it is a lot easier to write about people who are long dead than to write about people who are still alive or who have recently departed. And, at this point, we also reach the dilemma created by the fact that my very sociable parents had powered past my youthful



shyness (yes, I am engaging in that enjoyable sport of "blaming my parents," while also giving them credit for a character trait that has given me a great deal of pleasure in life), and set me up for a unbreakable eagerness to meet the Bert Josts of the world, adept at dodging their canes but very much enjoying their company. In other words, I knew or know many of the people who figure in Denver Water's last two decades of history, and maintaining a cool and objective distance did not instantly appear in my skill-set.

Writing Chapter Seven, "Chipping Away at Tradition: The Conundrum of Change and Continuity," I could not evade the question, "Did Denver Water genuinely change its ways after the 1990 veto of the Two Forks Dam?" My answer was (and is) "Yes": collaboration and negotiation came to hold the balance over contention and litigation, and the recently signed Colorado River Cooperative Agreement to be evidence in support of this claim.

Will this interpretation win universal agreement?

I very much doubt it.

In a recent essay in the *Denver Post*, my comrade in the University of Colorado system, Professor of Law and Public Policy Lloyd Burton, wrote an opening paragraph that raised my spirits. Although he was writing about fire danger in the wildland-urban interface, I am happy to enlist his assertion on behalf of my own cause. "In politics and public policy," Burton declared, "narratives are a very big deal. Those who craft and control the dominant narrative exert a lot of influence over how we perceive public problems and how we identify them."[1]

Will my history of Denver Water, *A Ditch in Time,* become the "dominant narrative"?

I very much doubt it.

But I do think it will rattle the standing narratives in a useful way.

In an initiative co-sponsored by nearly a hundred agencies and organizations, 2012 has been designated the Year of Colorado Water, and *A Ditch in Time* is the book that Coloradans who participate in this initiative are to read in the final quarter of this year. Book discussion groups will convene in libraries and on the Web.

And so, to honor the spirit of Bert Jost and his many counterparts in the history of Western water, I offer this request. If you read *Ditch in Time*, please keep these questions in mind:

Do you see evidence that I lost my distance and slipped into sympathy for an organization that others have good reason to view in more critical terms?

Do you think I overstated the scale and depth of Denver Water's shift from forceful assertion to negotiation and compromise?

In accenting this shift, and in declaring that Denver Water has done a great deal more than improving its PR and grooming its image, did I (knowingly or not) do my part to place a velvet glove over an iron fist?

And, if you answered "Yes" to any or all of these questions, or had a strong response to other aspects of the book, will you let me know your reactions? Even better, if your community wants such an occasion, would you invite me for a direct conversation?[2]

People of a certain age are often exhorted by neurological experts to act on a "use it or lose it" principle. To keep our brains nimble and supple, we are told to take up solving jigsaw, crossword, Sudoko, or other such puzzles.

Taking a far more strenuous approach to the cultivation of cognitive spryness, I chose to write a history of the Denver Water Department, and to declare my eagerness to hear what readers make of the results.

After all, thinking about the history of water seems to have kept Mr. Jost's mind very energized.

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1. Lloyd Burton, "Problems in the Wild-land-Urban Interface," Denver Post, June 24, 2012. The tie between forests and downstream water supply is, of course, very direct.

2. The recent death of Salida writer Ed Quillen adds urgency to my request; if he were still with us, I have no doubt that he would take me on for a major Western Slope/Front Range exchange!

Enhanced dichloroethene biodegradation in fractured rock under biostimulated and bioaugmented conditions; 2012; Article; Journal; Remediation; Bradley, Paul M.; Journey, Celeste A.; Kirshtein, Julie D.; Voytek, Mary A.; Lacombe, Pierre J.; Imbrigiotta, Thomas E.; Chapelle, Francis H.; Tiedeman, Claire J.; Goode, Daniel J.

Dissolved oxygen as an indicator of bioavailable dissolved organic carbon in groundwater; 2012; Article; Journal; Ground Water; Chapelle, Francis H.; Bradley, Paul M.; McMahon, Peter B.; Kaiser, Karl ; Benner, Ron

Land change variability and human-environment dynamics in the United States Great Plains; 2012; Article; Journal; Land Use Policy; Drummond, Mark A.; Auch, Roger F.; Karstensen, Krista A.; Sayler, Kristi L.; Taylor, Janis L.; Loveland, Thomas R.

Estimated trichloroethene transformation rates due to naturally occurring biodegradation in a fractured-rock aquifer; 2012; Article; Journal; Remediaton Journal; Chapelle, Francis H.; Lacombe, Pierre J.; Bradley, Paul M.

Estimated trichloroethene transformation rates due to naturally occurring biodegradation in a fractured-rock aquifer; 2012; Article; Journal; Remediaton Journal; Chapelle, Francis H.; Lacombe, Pierre J.; Bradley, Paul M.

Biosolids, crop, and groundwater data for a biosolids-application area near Deer Trail, Colorado, 2009 and 2010; 2012; DS; 664; Yager, Tracy J. B.; Smith, David B.; Crock, James G.

Watershed scale response to climate change--Flint River Basin, Georgia; 2012; FS; 2011-3116; Hay, Lauren E.; Markstrom, Steven L.

Watershed scale response to climate change--Yampa River Basin, Colorado; 2012; FS; 2011-3117; Hay, Lauren E.; Battaglin, William A.; Markstrom, Steven L.

Watershed scale response to climate change--South Fork Flathead River Basin, Montana; 2012; FS; 2011-3124; Chase, Katherine J.; Hay, Lauren E.; Markstrom, Steven L.

Watershed scale response to climate change--East River Basin, Colorado; 2012; FS; 2011-3126; Battaglin, William A.; Hay, Lauren E.; Markstrom, Steven L.

Assessment of undiscovered oil and gas resources in the Paradox Basin Province, Utah, Colorado, New Mexico, and Arizona, 2011; 2012; FS; 2012-3031; Whidden, Katherine J.

In situ optical water-quality sensor networks - Workshop summary report; 2012; OFR; 2012-1044; Pellerin, Brian A.; Bergamaschi, Brian A.; Horsburgh, Jeffery S.

Summary and evaluation of the quality of stormwater in Denver, Colorado, 2006-2010; 2012; OFR; 2012-1052; Stevens, Michael R.; Slaughter, Cecil B.

Bathymetry of Groundhog Reservoir, Dolores County, Colorado, 2011; 2012; SIM; 3202; Kohn, Michael S.

Bathymetry of Totten Reservoir, Montezuma County, Colorado, 2011; 2012; SIM; 3203; Kohn, Michael S.

Integrated watershed-scale response to climate change for selected basins across the United States; 2012; SIR; 2011-5077; Markstrom, Steven L.; Hay, Lauren E.; Ward-Garrison, D. Christian; Risley, John C.; Battaglin, William A.; Bjerklie, David M.; Chase, Katherine J.; Christiansen, Daniel E.; Dudley, Robert W.; Hunt, Randall J.; Koczot, Kathryn M.; Mastin, Mark C.; Regan, R. Steven; Viger, Roland J.; Vining, Kevin C.; Walker, John F.

Charles D. Shackelford

Lindsey A. Middleton, Editor, Colorado Water Institute

Charles Shackelford, Professor and the recently appointed Associate Department Head of Civil and Environmental Engineering, describes himself as a geotechnical engineer who chose to broaden his background by learning environmental applications.

While many geotechnical engineers work with structures, soil mechanics, and soil dynamics, Shackelford says because of his formal educational background, which involved courses in a variety of disciplines, he is able to contribute to the hydrological and environmental fields as well.

His work falls into two areas—remediation, or cleaning up contaminated groundwater already in the subsurface environment, such as acid drainage from abandoned mining sites, and containment, usually applied at waste containment facilities, to prevent seepage and eventual contamination of fresh water. The primary goal of his research, he says, is protecting human health and the environment, particularly the water supply.

Although containment technologies, says Shackelford, have already been heavily researched, leaving fewer funding dollars for this area, he is currently working under a National Science Foundation grant on what he calls his most exciting research. One of the current containment technologies, a geosynthetic clay liner, is a thin layer of bentonite clay sandwiched between two geotextile fabrics that expands when exposed to water, creating a low-permeability boundary. Shackelford is currently studying the possibility of these bentonite barriers also acting as a permiselective membrane, which could filter certain contaminants. He describes the work as fundamental, and novel.

"In any good research, you answer questions," says Shackelford, "but really good research will raise questions you hadn't even considered." Shackelford says that previously, the membrane behavior of montmorillonite, the primary mineral in bentonite, was studied in the soil science areas several decades ago, but his research pertains to the potential importance of membrane behavior in bentonite-based containment barriers, and, as a result, "We're learning at the forefront of the area," he says. While Shackelford has been studying membrane behavior in such barriers for 14 years, other parts of the world, like Japan, have only taken up the research topic in the last couple of years.

Shackelford explains that, in the area of containment research, the technologies and materials are already fairly well established, so current research works toward perfecting the technologies in regard to efficiency, cost, and sustainability. The already existing materials include the geosynthetic clay liners, as well as natural compacted clay liners and geomembrane (polymer) liners.

As far as remediation goes, Shackelford noted that a primary focus of future research will be in the area referred to as "emerging contaminants." For example, contamination from prions, or protein substances that are responsible for mad cow disease and chronic wasting disease in deer and elk, have only relatively recently become a concern in terms of environmental protection. Also, the recent

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advent of nanotechnology has created a variety of tiny nanoparticles (10^{-9} m), and we have yet to understand their potential impact on human health or to implement treatment processes to remove them from drinking water.

Shackelford's research goals have also propelled his goals in teaching—he developed the CSU graduate program in Geoenvironmental Engineering. Shackelford explains geoenvironmental engineering as a, "broad-based term reflecting the multidisciplinary aspects of soil-environmental problems" that can include chemistry, biology, and other areas, according to a 2005 keynote presentation by Shackelford in Japan.

"I used my diverse background as a momentum to establish a program here that will benefit my students," says Shackelford of the geoenvironmental program at CSU.

Students in the program take two core classes in remediation and containment, and the elective class list varies from Aqueous Chemistry to Groundwater Engineering to the traditionally geotechnical Foundation Engineering. "I encourage them to take courses outside of Civil Engineering," he says. If nothing else, Shackelford says it's important for them to be able to communicate with professionals in related careers.

Shackelford says his recent appointment as Associate Department Head of Civil and Environmental Engineering will allow him to learn more about administration, which he says is completely different from his current research and teaching activities. He says he'll find out if he intends to move his career in that direction with his experience in this position.

While he's looking forward to the challenge of moving forward in his career, Shackelford says he'll always enjoy his research and teaching, which he says are one and the same. "That's the main reason I love my job," he says—"I essentially get paid to learn."

Water Research Awards

Colorado State University (May 16, 2012 to June 15, 2012)

Bailey, Larissa, Cooperative Fish & Wildlife Research, DOI-USGS-Geological Survey, Investigating the Impact of Introduced, Endangered Cutthroat Trout on Boreal Toad Breeding Success & Recruitment, $48,000

Bestgen, Kevin R, Fish, Wildlife & Conservation Biology Colorado Division of Wildlife, Anthropogenic Changes to Colorado's Eastern Plains Streams & Their Impact on Connectivity for Native Fishes, $67,937

Bestgen, Kevin R, Fish, Wildlife & Conservation Biology, Colorado Division of Parks and Wildlife, Fountain Creek Flathead Chub, $89,914

Brozka, Robert J, CEMML, State of Wyoming, Wetland Survey of the Osburn Tract, Camp Guernsey, WY, $24,999

Cooper, David Jonathan, Forest & Rangeland Stewardship, DOI-NPS-National Park Service, Restore Historic Wetlands near Mouth of Rodeo Lagoon at Golden Gate NRA, Marin County, California, Phase 2, $10,000

Cooper, David Jonathan, Forest & Rangeland Stewardship, DOI-NPS-National Park Service, Hydrological Analysis and Pilot Restoration of Artificially-Drained Wet Meadows at Florissant Fossil Beds National Monument, Colorado, $31,113

Duda, Joseph A, Colorado State Forest Service, USDA-USFS-Forest Research, 12CPG Denver Urban Waters Partnership, $150,000

Garcia, Luis, Civil & Environmental Engineering, USDA-ARS-Agricultural Research Service, Delivery of the OMS-based AGES-W Resource Concerns Assessment Model for Evaluating Water/Nutrient Management, $28,017

Garrity, Deborah Marie, Biology, NSF - National Science Foundation, REU Supplement for Collaborative Research: Inhibition of Snowfall by Pollution Aerosols, $6,000

Jha, Ajay K, Horticulture & Landscape Arch, DOS-AID-Agency for Inter. Development, USAID Efficient Water Management Study Tour 1, $13,774

Jha, Ajay K, Horticulture & Landscape Arch, DOS-AID-Agency for Inter. Development, USAID Efficient Water Management Study Tour 1, $105,247

Johnson, Brett Michael, Fish, Wildlife & Conservation Biology, DOI-NPS-National Park Service, Tracking Lake Trout Diet and Trophic Interactions in Blue Mesa Reservoir Using Stable Isotopes, $10,000

McKay, John K, Bioagric Sciences & Pest Mgmt, USDA-ARS-Agricultural Research Service, The Role of Root System Architecture in Drought Tolerance, $19,250

Myrick, Christopher A, Fish, Wildlife & Conservation Biology, Colorado Division of Parks and Wildlife, Investigation of the Effects of Whitewater Parks on Aquatic Resources in Colorado, $68,697

Ojima, Dennis, Natural Resource Ecology Lab, DOI-USGS-Geological Survey, North Central Climate Science Center Implementation Activities, $275,000

Poff, N LeRoy, Natural Resource Ecology Lab, USDA-USFS-Forest Research, Development of environmental flow standards: Routt National Forest, $30,000

Rathburn, Sara L, Geosciences, DOI-NPS-National Park Service, Evaluating River Morphologic Changes for Restoration Planning, Design & Monitoring Using Airborne LiDAR, $55,410

Schumacher, Russ Stanley, Atmospheric Science, NSF - National Science Foundation, CAREER: Multiscale Investigation of Warm-Season Precipitation Extremes, $140,820

Sovell, John R, Colorado Natural Heritage Program, City of Aurora, Survey of Biological Resources City of Aurora Triple Creek Greenway, $49,912

Swift, David M, Natural Resource Ecology Lab, DOI-NPS-National Park Service, Investigation of Nitrogen Deposition into Loch Vale, $30,000

Waskom, Reagan M, Colorado Water Institute, Bohemian Foundation/Pharos Fund, The Year of the River 2012, $10,000

Wilson, Kenneth R, Fish, Wildlife & Conservation Biology, Colorado Division of Parks and Wildlife, Statewide Aquatic Sonar Research Technician Training, $43,024

Zupanski, Milija, CIRA, NASA - Natl Aeronautics & Space Admin., Ensemble-Based Assimilation and Downscaling of the GPM-Like Satellite Precipitation Information, $101,999

Calendar

August

1-3 **2012 Western Water Seminar; Sun Valley, ID**
Future Threats to Water Supply Deliveries in the West www.nwra.org

11 **Riverfest 2012; Eagle, CO**
An afternoon of rafting, food, music, and dancing at State Bridge in celebration of Eagle County Open Space's new access points on the Colorado. www.erwc.org

15-17 **Colorado Water Congress Summer Conference; Steamboat Springs, CO**
Summer Conference and Membership Meeting. www.cowatercongress.org

18 **Celebrating 50 Years of Golden Benefits for the Fryingpan-Arkansas Project; Pueblo, CO**
Guest speakers, debut of The 50 Years of Golden Benefits video, balloon release, free refreshments, free pontoon boat tours of Pueblo Reservoir, free tours of the Pueblo Fish Hatchery and free admission to the Lake Pueblo State Park if attending the event.
www.secwcd.org/50years.htm

19-23 **StormCon Denver 2012; Denver, CO**
The North American Surface Water Quality Conference & Exposition
www.stormcon.com/index.html

September

13 **Colorado River District Annual Water Seminar; Grand Junction, CO**
Featuring a presentation on the history of the Colorado River District from George Sibley
www.crwcd.org/page_115

16-20 **Dam Safety 2012; Denver, CO**
The 5th Annual National Dam Security Forum will provide a unique opportunity to discuss a variety of technical and non-technical issues pertaining to the safety, security, and resilience of the nation's dams and related infrastructure.
http://damsafety.org/conferences/?p=a5db6ea2-9f93-4629-a41c-6ef46ed02727

19-20 **2012 CWCB Statewide Drought Conference; Denver, CO**
Building a Drought-Resilient Economy through Innovation
http://cwcb.state.co.us/Pages/CWCBHome.aspx

20 **Northern Colorado Water Conservancy Districts' 75th Anniversary; Berthoud, CO**
Open house celebration for the 75th Anniversary.
www.northernwater.org/AboutUs/75thAnniversary.aspx

October

9-11 **2012 Sustaining Colorado Watersheds Conference: Water2012; Avon, CO**
This annual conference expands cooperation and collaboration throughout Colorado in natural resource conservation, protection and enhancement by informing participants about new issues and innovative projects and through invaluable networking. www.coloradowater.org/Conferences

19 **The Fourth Annual Water Conservation Summit; Denver, CO**
This Summit is to learn more about what is happening at the state and local level relating to water conservation and water efficiency in general.
coloradowaterwise.org/Default.aspx?pageId=1104658

24-25 **23rd Annual South Platte Forum; Longmont, CO**
www.southplatteforum.org/2012_fourm.html

31-2 **NWRA Annual Conference; Coronado, CA**
www.nwra.org/events/2012/10/annual-conference-2/

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Colorado State University Civil and Environmental Engineering graduate student Greg Steed and undergraduate student Justin Kattnig collect data at a well on a ranch along the Arkansas River

Photo by Bill Cotton