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Colorado Water

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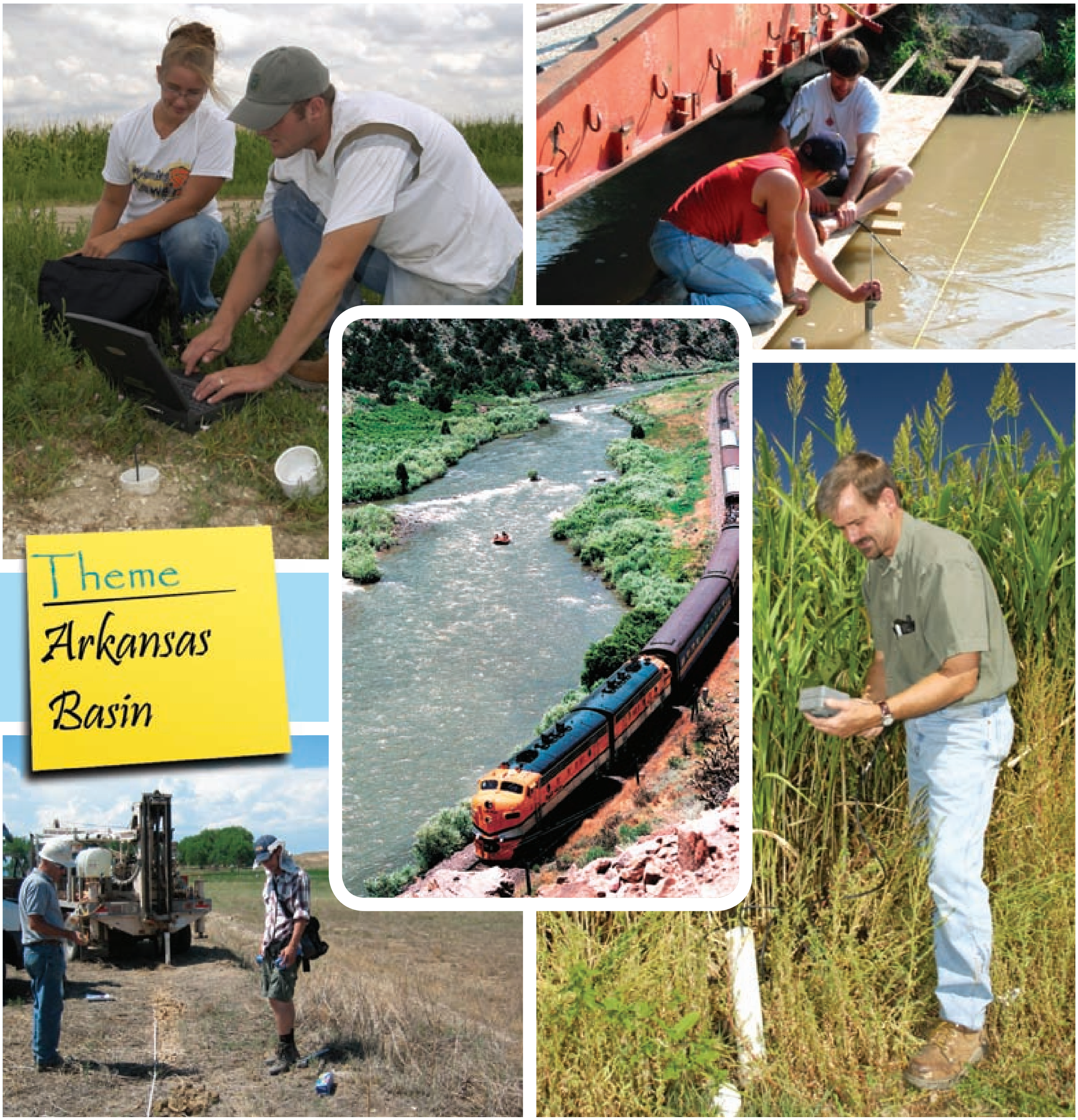

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Highlights

In Every Issue

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Editorial

by Reagan Waskom, Director, Colorado Water Institute and
Lee Sommers, Director, Colorado Agricultural Experiment Station

The Arkansas Basin of southeast Colorado is spatially the largest river basin in Colorado, with the river's headwaters beginning in the mountains of central Colorado near Leadville and eventually exiting southeast Colorado for Kansas near the town of Holly. The basin supports some 400,000 acres of irrigated farmland, provides one of the most popular rafting destinations in the nation, and is home to a growing population of nearly one million people. The Arkansas Valley is nationally famous for its produce, most notably the Rocky Ford melons we all look forward to each August.

Although the river most certainly supported Native Americans for thousands of years, the first Europeans to see the river were members of the Coronado expedition in 1541. They were followed by the Zebulon Pike expedition in 1806 and river trips by John Fremont and Kit Carson in the 1840s. Eventually, European settlers followed the Santa Fe Trail westward and began to colonize the Valley, beginning with the establishment of the Bent brothers' fort and trading post east of La Junta in 1833.

CSU also has a long history in the Arkansas Basin. The oldest continuously operating CSU research farm in Colorado is the Arkansas Valley Research Center (AVRC) near Rocky Ford, whose doors opened in June of 1888. The university has been a permanent fixture in the Valley since that time, working to solve agricultural, water, and natural resource challenges over the past 120 years. Issues surrounding water and irrigation have never been simple or easy—it was difficult to establish the system of ditches, diversions, and canals, and it has been no easier to sustain the system built by our predecessors. Changes in the basin since that time are evidenced by the current proposals, projects, and challenges—the Arkansas Conduit, Fountain Creek, irrigation consumption rules, Super Ditch, PSOP, SDS, and the on-going task of meeting the obligations of the Arkansas River Compact of 1948. Research, education, and outreach all have a role in meeting these challenges.

This issue of *Colorado Water* brings a focus to the current CSU efforts in southeast Colorado, where research and extension faculty still endeavor to implement the land grant university mission envisioned in the Morrill Act of 1862. The range of research topics is broad, but irrigated agriculture is sustained in the basin by helping farmers solve problems such as salinity, pests, and other production concerns. Drip irrigation has been the subject of research and extension going back to work by Don Miles and Jim Ells in the 1980s. More recently, CSU and a number of partners, notably the Colorado Water Conservation Board (CWCB), the Southeastern Colorado Water Conservancy District, and the Lower Arkansas Water Conservancy District, have focused on research to help the state optimize water use while meeting compact compliance. The State Engineer and the CWCB have partnered with CSU and the USDA Agricultural Research Service to install and operate massive weighing lysimeters at the AVRC to refine crop water use estimates under the unique climate and soil conditions of the Valley. This particular research program is designed and conducted specifically to help the state of Colorado in compact resolution.

Our purpose in focusing this issue of *Colorado Water* on research and extension efforts in southeast Colorado is to update our readers on what has become a major water focus for CSU, and to acknowledge the many partnerships we enjoy because of this work. These partners include individual farmers who work with us on their land, as well as local, state, and federal agency personnel too numerous to list here. We are indebted to each of the individuals we work with in the basin and believe the entire state of Colorado benefits from a healthy agricultural industry in southeast Colorado.

Discovering Favorable Prospects for the Lower Arkansas River Basin Using Data-Supported Decision Tools

by Timothy K. Gates, John W. Labadie, and Luis A. Garcia
Department of Civil and Environmental Engineering, Colorado State University

It was a little more than ten years ago that a team of CSU researchers launched an intensive data-gathering effort in Colorado's Lower Arkansas Valley. Our aim was to tackle some serious and widespread problems that had been nagging the Valley for many years. Groundwater tables with saline water were close to the land surface; soils were affected by salt build-up and poor moisture control, leading to reduced crop productivity; and the river was burdened with high concentrations of salts and other minerals. In addition, pressures were mounting to buy and transfer irrigation water rights to meet increasing urban demands along Colorado's Front Range. Though these issues had long been recognized, no large-scale coordinated research effort had been conducted to describe, understand, and solve them. With prompting from Jim Valliant, CSU extension irrigation engineer, and other interested parties, and with funding from the Colorado Agricultural Experiment Station, the time had come for a large-scale coordinated field-based study.

Since that time, more than 150 farmers and numerous agencies (Southeastern Colorado Water Conservancy District, Lower Arkansas Valley Water Conservancy District, Bent County Natural Resources Conservation District, Northeast Prowers County Natural Resources Conservation District, Prowers County Natural Resources Conservation District, Catlin Canal Company, Fort Lyon Canal Company, Rocky Ford Highline Canal Company, Amity Canal Company, Buffalo Canal Company, Lamar Canal Company, Oxford Farmers' Canal Company, Southeastern Colorado Resource Conservation and Development Council, Colorado Agricultural Experiment Station, Colorado Water Conservation Board, Colorado Water Institute, Colorado Division of Water Resources, Colorado Department of Public Health and Environment, U.S. Department of Agriculture, U.S. Bureau of Reclamation, U.S. Geological Survey) have joined together to assist CSU in building an unprecedented database. Hundreds of wells have been drilled to make possible thousands of groundwater level and water quality measurements. Thousands of water quality samples have been taken from streams, drains, and canals; and tens of thousands of soil salinity and soil moisture measurements have been gathered and analyzed. Records have been compiled and measurements have been made of crop practices, climatic factors, irrigation applications, economic indicators, topography, rainfall, river flows and levels, canal and reservoir characteristics, geologic characteristics, soil and aquifer properties, canal seepage losses, and artificial drainage systems. These data help describe numerous elements of the water balance of the Valley's irrigated stream-aquifer system, as depicted in a number of articles in this issue of *Colorado Water*. Beyond that, these data have allowed us to develop, calibrate, test, and apply computer models of this system.

Computer models of water systems use data and equations to mimic the real processes of flow and chemical transport that occur in nature. In so doing, researchers can use the models as "decision tools" to explore what might happen if alternative management scenarios were employed to change the way water is controlled and managed. CSU has

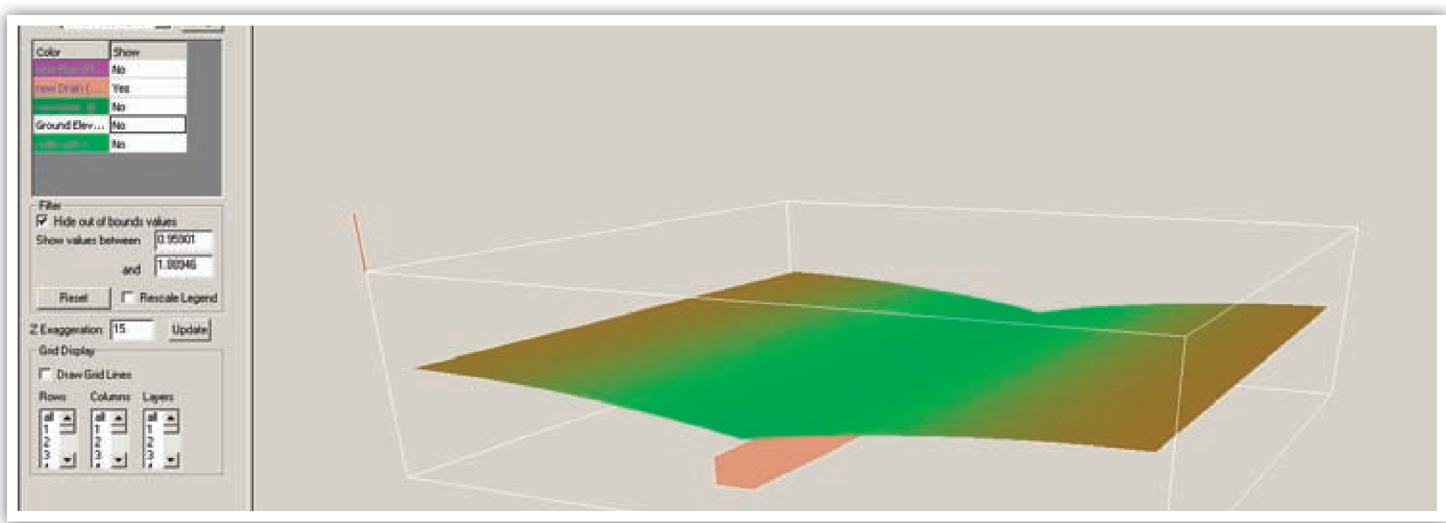


Figure 1. Field-Scale Model Display Showing Water Table Affected by Subsurface Drain

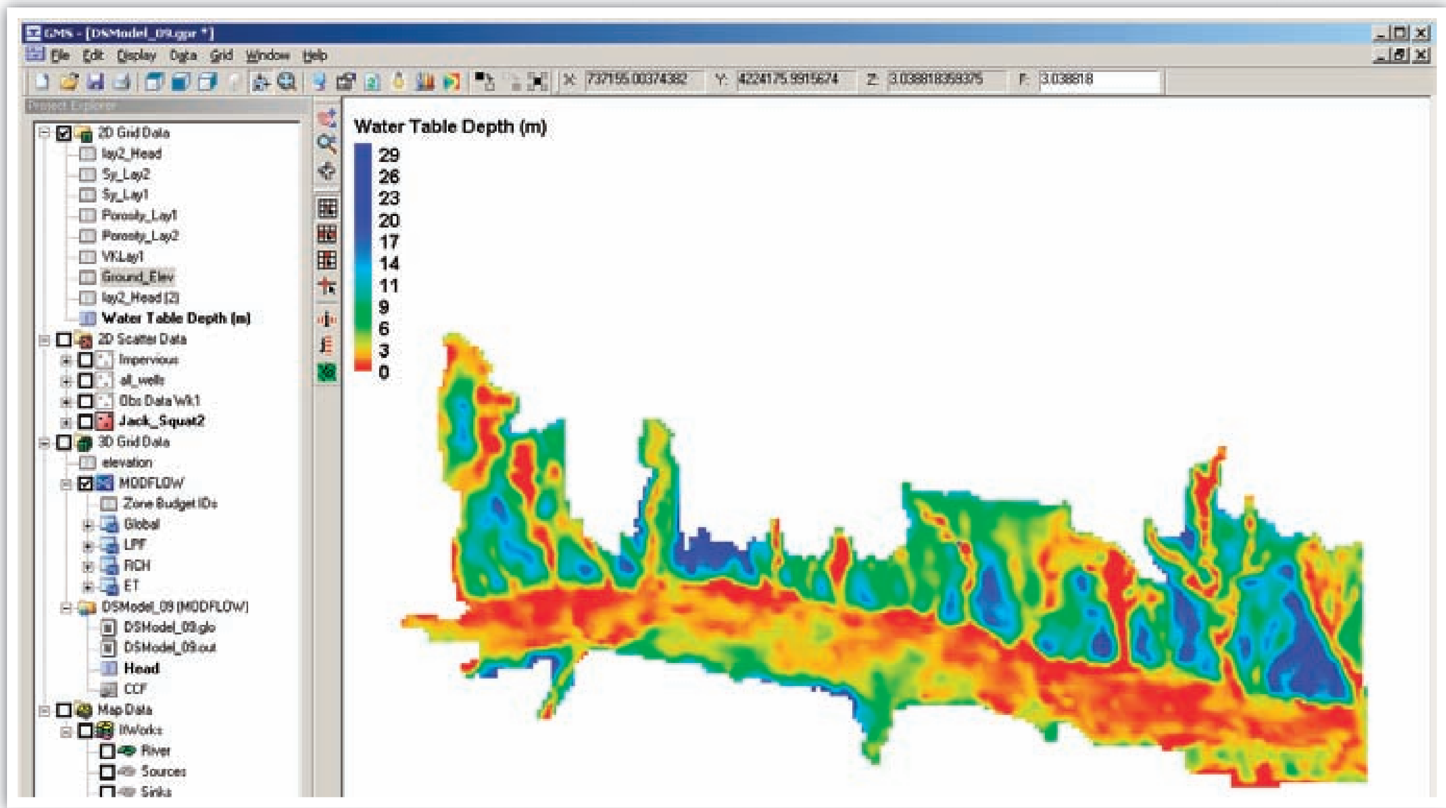


Figure 2. Regional-Scale Model Display of Predicted Water Table Depth in a Valley Region

built models that can be used at the field scale, the regional scale, and the river basin scale.

A field-scale model is being used to study different irrigation and drainage methods on individual fields. For example, the model can alter the amounts and timing of irrigation water applied to predict their impact on soil moisture, crop water use, salt accumulation in the soil, and, ultimately, crop yield.

Regional-scale models are used to predict groundwater levels and concentrations, flows and transport of solutes to streams, consumptive use of water, and soil moisture and salinity over areas that cover tens of thousands of acres. The models are used to determine how these features would change if improvements were made in irrigation efficiency, canals were sealed to reduce seepage, pumping patterns were altered, subsurface drains were installed, or land were fallowed due to water leasing. Field data are being used to refine and test these models for more reliable and widespread application over the Valley.

A basin-scale model is being developed that focuses on predicting the effects of improvement alternatives on in-stream flows and solute concentrations, flows and concentrations of diversions along the river, groundwater return flow rates and concentrations, and flows and concentrations across the state line as governed by state water law and the Arkansas River Compact. Examples of alternative interventions that can be explored with the model include:

- Establishing new accounts in existing on-stream and off-stream reservoirs to store volumes of water resulting from reduced canal diversions (derived from canal lining and improved irrigation efficiency) and then releasing this water in a manner that would adequately preserve historic river flow patterns in compliance with Colorado water rights and the Arkansas River Compact
- Exercising water exchange agreements along the river
- Implementing projects (like the Southern Delivery System) that would trade releases from Pueblo Reservoir for lower-quality return flows down Fountain Creek
- Removing tamarisk plants from the river corridor
- Altering well pumping patterns in the alluvial aquifer
- Operating a rotational land fallowing and water leasing program through the proposed “Super Ditch” cooperative

Models being developed and refined at CSU are providing a comprehensive set of tools to help water users and agencies make decisions about structural and management changes that can preserve and enhance the Arkansas River system. Calibrated and supported by extensive field data, these models are providing (1) a picture of the extent and severity of existing problems in the watershed, (2) a methodology for systematically assessing alternative ways to address these problems, and (3) an indication of the prospects for achieving marked improvements to the land and to the river when these solution strategies are implemented. (Information about journal articles and reports that describe model details are available from the authors.)

Initial results from application of the CSU models are encouraging and indicate that actions could be taken in the Arkansas River Valley that would cause:

- Groundwater levels to be markedly lowered, soil salinity to be significantly reduced, and average crop yields to be increased
- Salt (and likely other mineral) loads to the river to be reduced substantially and in-stream and stateline concentrations to be markedly lowered
- Non-beneficial consumptive use of water under uncultivated and fallow fields to be considerably reduced, leading to Valley-wide water conservation

These possibilities will be verified and refined by additional data-calibrated modeling. So far, however, it is encouraging to find that the same strategies that would boost agricultural productivity would also benefit the land and stream environment.

We are continuing to gather basic water quality and quantity data and explore new insights about the Lower Arkansas River water system. However, at this stage of the research effort, it is increasingly important to disseminate project findings more widely and clearly and to engage key stakeholders in the Valley in discovering the improvement strategies that best fit their goals and constraints. This dialogue is currently underway. The aim is to prompt feedback and discussion that will lead to pilot field testing and eventual widespread adoption of the most effective and practical strategies.

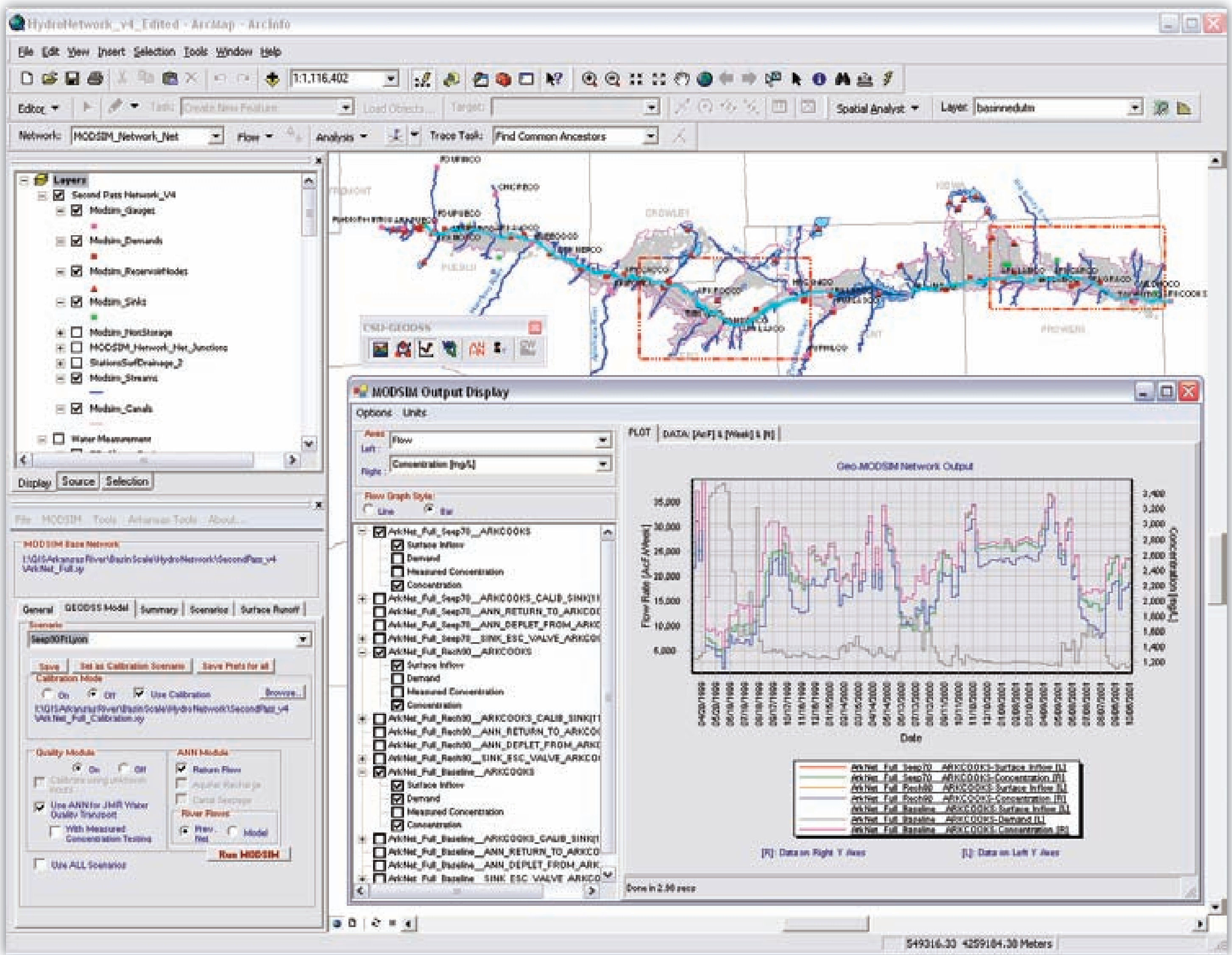


Figure 3. Basin-Scale Model Display of Lower Arkansas River Basin and Plots of Predicted River Salt Concentration

Demonstration of the Colorado Agricultural Meteorological Network (COAGMET) for Improved Irrigation and Pest Management in the Arkansas Valley

by Troy Bauder, Department of Soil and Crop Sciences
Nolan Doesken, Department of Atmospheric Sciences
Howard Schwartz, Department of Bioagricultural Sciences and Pest Management
Michael Bartolo, Arkansas Valley Research Center

Agriculturalists have long understood that weather events and patterns greatly influence their chances for establishing, growing, harvesting, and often marketing a successful crop. Thus, farmers and ranchers have always depended on weather information to aid in making production decisions. However, the information or data available for these decisions and the methodology used to interpret these data have not always been sound. Fortunately for the present-day crop producer, agricultural scientists have found ways to utilize meteorological data to develop tools that have the potential to improve and enhance the farmer's management decisions. The need for this information has led to the installation of weather station networks to gather and report basic meteorological data.

Colorado producers have access to decision support information produced from a weather station network called the Colorado Agricultural Meteorological Network, or CoAgMet. Two information products supplied by CoAgMet are daily crop evapotranspiration (ET) rates and disease forecasting. These products are available at www.coagmet.com and www.colostate.edu/Orgs/VegNet/.

Weather station at the Arkansas Valley Research Center (AVRC)

The information supplied by this network can be used to help irrigating producers advance their irrigation and pest management. However, recent survey data suggest that only a small number of growers are taking advantage of these products to improve their management. The reasons for this low adoption are unknown but may include (1) a lack of knowledge that the information exists, (2) a need for assistance in adopting the technology, and (3) the perception of the products' usefulness and reliability. Gathering and reporting meteorological data and associated crop decision reports will not produce the desired impacts unless these products are adopted by crop producers. Typically, direct interaction and assistance must take place before producers will adopt new technology and change their decision-making process. This interaction affords the producers an opportunity to influence the development of a product designed to help them make farm-level decisions.

Thus, a team is conducting a validation and demonstration effort in the Arkansas Valley. The Arkansas Valley area was chosen because recent survey results suggest that only a few growers (3–7%) use weather station ET as either their primary or secondary irrigation scheduling method in this basin. The same survey showed that only 7% of respondents were using pest forecasting in their pest management program. Additionally, the CoAgMet weather station network in the Arkansas Valley has undergone a comprehensive enhancement with new and relocated stations, an improved maintenance schedule, and data review to support the Colorado v. Kansas litigation. These improvements to the weather station network will also provide users in the Arkansas Valley with better ET and disease-forecasting tools.

Identification of Barriers to CoAgMet Adoption

To successfully achieve adoption of a given management practice, the user must see that the benefits of adopting a practice to their operation, the community, and/or

Identified Barrier	Identified Solution
Irrigation timing is completely out of grower's control as ditch water delivery determines watering schedule. Thus, watching crop water use reports may not improve irrigation management.	This is a real-world barrier that cannot be ignored. Although the information in ET reports in these situations may not help the grower decide when to irrigate, it can help them determine how much to apply to replace depletions.
"Use it or lose it" philosophy	Requires a change in knowledge of water rights and attitude.
Time – too busy during summer growing season to check ET reports	Offer different ET media outlets. This project expanded ET reports to local radio and changed the options available for web and email reports. Investigating the ability to receive reports through text messaging.
Lack of internet access	Same as #3
ET reports are not reliable	Review methods used to calculate ET reports, improve station maintenance and data quality
The farm is in deficit irrigation mode already (i.e., the ET reports would only tell the grower what s/he already knows….that they are deficient in irrigation water)	May not be a solution for this situation, although watching ET reports may help grower with crop insurance verification and help them set appropriate yield expectations based on deficit situation.
Understanding – growers don't fully understand ET concepts or how to use reports.	Outreach and education through this project is addressing this barrier
Awareness – users do not know about the CoAgMet reports or the SECO Water Wise web site.	Outreach and education through this project is addressing this barrier

the environment are greater than the barriers and costs associated with such practice. Through conversations with growers and other interested parties in the region, we developed a list of barriers to adoption of CoAgMet ET and disease reports for the Arkansas Valley. We then identified solutions that could potentially increase adoption of CoAgMet outputs to improve irrigation or pest management. Many of these solutions were implemented through this project.

Irrigation Management Field Demonstrations

For cropping years 2007-2008, we used six fields to demonstrate the irrigation management portion of the project. Crops include corn, alfalfa, and melons, and locations ranged from Fowler to LaJunta. On selected fields we also installed soil moisture sensors with logger displays to offer growers the opportunity to see how their ET reports relate to actual soil moisture depletion in the field. Loggers are set to read soil moisture every eight hours and display the instantaneous soil moisture conditions when prompted by a push-button response. The loggers were installed at the top of the field where they were accessible to the cooperating grower.

For some growers, weekly ET reports were emailed throughout the growing season to aid in irrigation management and to test alternative methods of ET delivery. Weekly ET sum and daily average ET rates were provided. Precipitation amounts were also provided to produce a water balance; however, some of the fields were far enough away from the weather station that the rain gauge on site provided a better number for rainfall. Some producers preferred to access the CoAgMet ET reports via the internet. Daily ET reports were also delivered on KTHN-92.1 FM and KBLJ-1400 AM by Pat McGee during his morning broadcasts. He delivered ET reports for corn, alfalfa, wheat, drybean, and onions.

This Hansen displaying logger for WaterMark soil moisture sensors was installed at the top of a corn field near Fowler, Colorado.

Disease Management Field Demonstrations

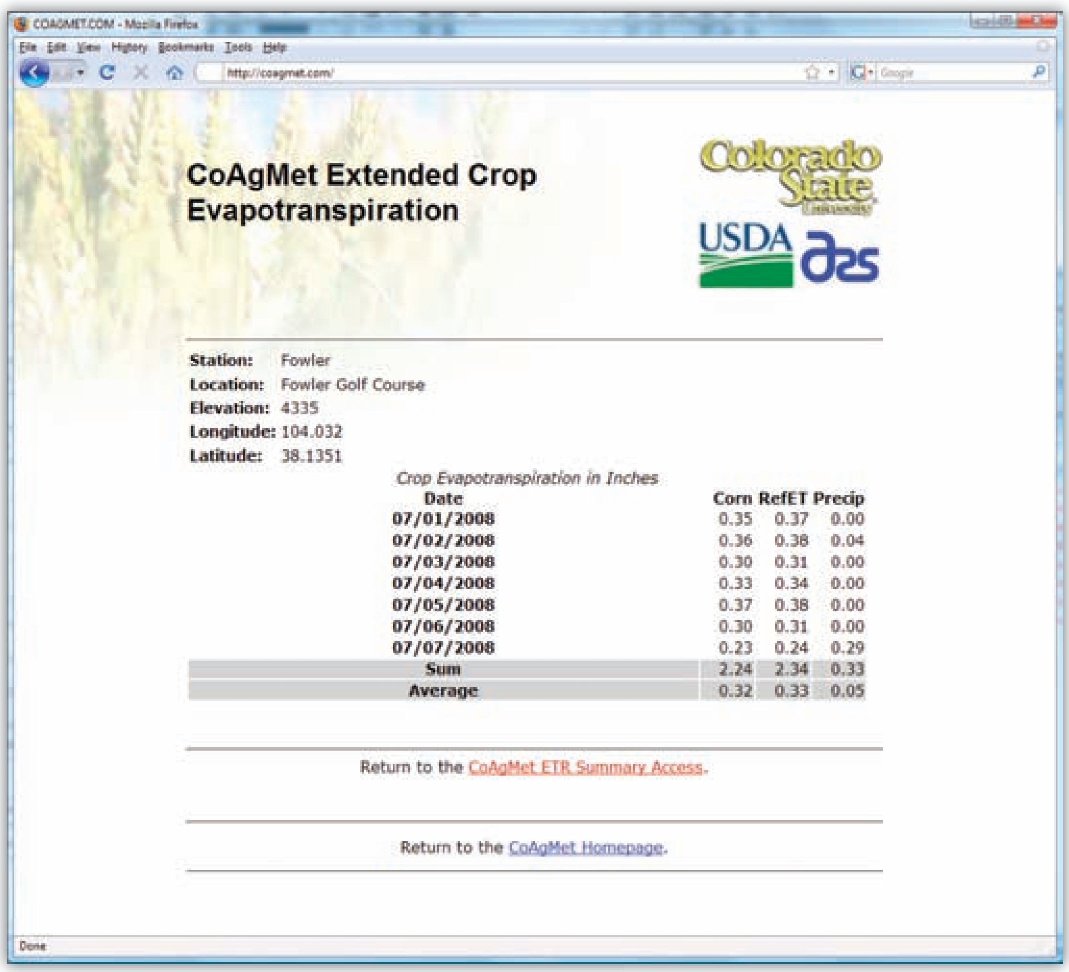
For the plant disease portion of this projection, ten monitoring onion fields in the Arkansas Valley were periodically scouted for the presence of foliar diseases, such as Xanthomonas Leaf Blight, during the 2007 and 2008 growing seasons. Disease presence was related to local environmental conditions as measured by the nearest CoAgMet weather station and in-field (Spectrum Watchdog 450) weather monitoring data loggers. Bacterial disease pressure was low in relation to the relatively dry growing seasons, which were not conducive to survival, dissemination, and infection of the pathogen in the monitored region. Hot and dry conditions prevented the development of disease at all sites during both growing seasons and, thus, validation of the disease model during these years was limited to verification of disease absence during unfavorable weather conditions as predicted by disease models.

CoAgMet Web Programming

Improving the usefulness and ease of retrieval of ET reports provided at www.coagment.com is a primary objective of this project. While communicating with several growers in the target area, we learned that many folks who use or may use the CoAgMet system would prefer to only download ET reports once or twice a week, due to their limited time or access to internet. However, the system previously only provided crop ET reports for one day, and users had to re-submit their requests for the reports each day. This was tedious and represented a barrier that discouraged CoAgMet use. Thus, the Colorado Climate Center developed code that would allow the user to choose any range of dates and get daily ET reports and summations in one request. This system debuted prior to the 2008 growing season and has received positive reviews. Another significant outcome involved color coding the weather stations for reference ET conditions (irrigated, partially irrigated, and dryland) so that users know whether stations are suitable for obtaining irrigated ET values. Finally, resources from this project were used to develop code to calculate the ASCE Penman Monteith reference ET equation.

Outreach

Outreach is a critical component of this project, and the project has been promoted through multiple presentations and posters at winter meetings for conservancy districts, ditch companies, the Arkansas River Basin Forum, the NRCS State Technical Committee, and field days. Additional training was conducted at a winter Irrigation and Nutrient Management Workshop held in Rocky Ford, Colorado. The project has attempted to generate publicity and overcome as many adoption barriers as possible to increase CoAgMet use. However, several institutional barriers beyond the scope of this project remain, and these barriers may limit adoption of these tools, particularly for irrigation management in this region.



This screenshot shows an example of a weekly ET report sent to a grower via www.coagmet.com.

Irrigation Monitoring in the Lower Arkansas River Valley of Colorado

by Luis A. Garcia, Timothy K. Gates, and Ryan Hemphill

Department of Civil and Environmental Engineering, Colorado State University

Evaluation of ongoing water use practices and the potential for improvements to any water resources system requires an accurate description of current, or baseline, conditions in the system. In the irrigated alluvial lands of Colorado's Arkansas River Basin there is a need to determine the baseline for irrigation application practices and efficiencies. Colorado State University (CSU) has been making field measurements, conducting laboratory experiments, performing data analyses, and building computer models of the irrigated stream-aquifer system of Colorado's lower Arkansas River Valley for approximately ten years.

In 2004, CSU obtained funding from the Colorado Water Conservation Board to monitor irrigation events in a number of fields in the Lower Arkansas River Basin. Data were gathered in two regions within the Basin. The first region is centered around Rocky Ford (upstream of John Martin Reservoir), and a second region extends from near Lamar (downstream of John Martin Reservoir) to the Colorado-Kansas state line. An important research goal is to obtain more detailed knowledge of conditions at the field scale, where the "nuts-and-bolts" changes in water management for some of the alternative solutions would take place. Between 2004 and 2007, 329 irrigation events were monitored; additional data were collected in 2008 and are still being analyzed. Collected data included total amount of irrigation water applied, amount of excess water running off the field, rainfall amount, amount of crop water use, soil properties, and crop characteristics.

The most common irrigation system used in the Lower Arkansas Valley is "surface (or flood) irrigation," in which water is channeled through canals and ditches and directed onto fields by siphon tubes, gated pipe, or ditch cutouts. Within the last decade, however, center pivot sprinkler and sub-surface drip irrigation systems have been used more frequently in the region. Between 2004 and 2007, CSU monitored the irrigation practices in 31 fields. The number of fields monitored varied between years, with 14 upstream fields and 17 downstream fields being monitored at various times throughout the study.

The method for measuring the amount of applied irrigation water differed depending on whether the field was surface irrigated or sprinkler irrigated. For fields using surface-supplied flood irrigation, flumes (Parshall, trapezoidal, EZ Flow Ramp, cutthroat) and/or weir structures were used to measure application and tailwater amounts. Each measurement structure was fitted with a stilling well containing an automatic water level recorder programmed to measure and record absolute pressure every five minutes. Atmospheric pressure was also recorded every five minutes to derive the net water level in the measurement structure. Based on the known dimensions of each measurement structure, the measurements listed above, and manual calibration readings taken throughout the season, the irrigation application and tailwater volumes were calculated for each irrigation event on each field. For fields using well-supplied surface irrigation, center pivot

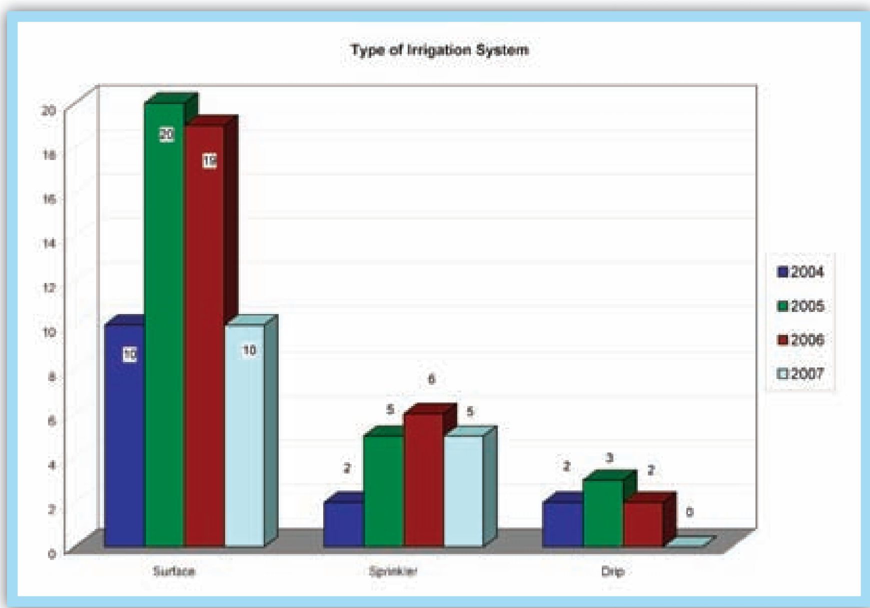


Figure 1. Type of Irrigation System Used for Monitored Fields (2004-2007)

sprinkler irrigation, or sub-surface drip irrigation, application amounts were recorded directly from a totalizing flow meter located on the system. Tailwater runoff was not observed from any sprinkler or drip irrigated field during the course of the study.

The area of each irrigated field was mapped based on Global Positioning System (GPS) points collected during the irrigation event and overlaid on a map of each field. Total application depth was calculated by dividing the total application volume by the irrigated area for each event. Tailwater depth was calculated in a similar fashion. Infiltrated depth was calculated as the difference between the total application depth and the tailwater depth for each irrigation event.

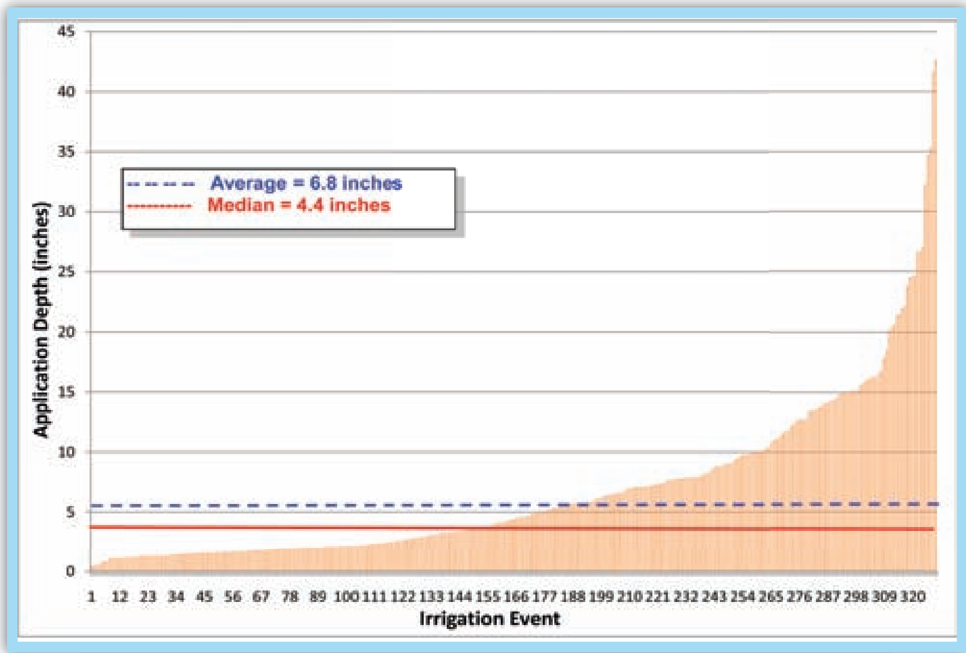


Figure 2. Total Application Depth for each Monitored Irrigation Event (2004 to 2007)

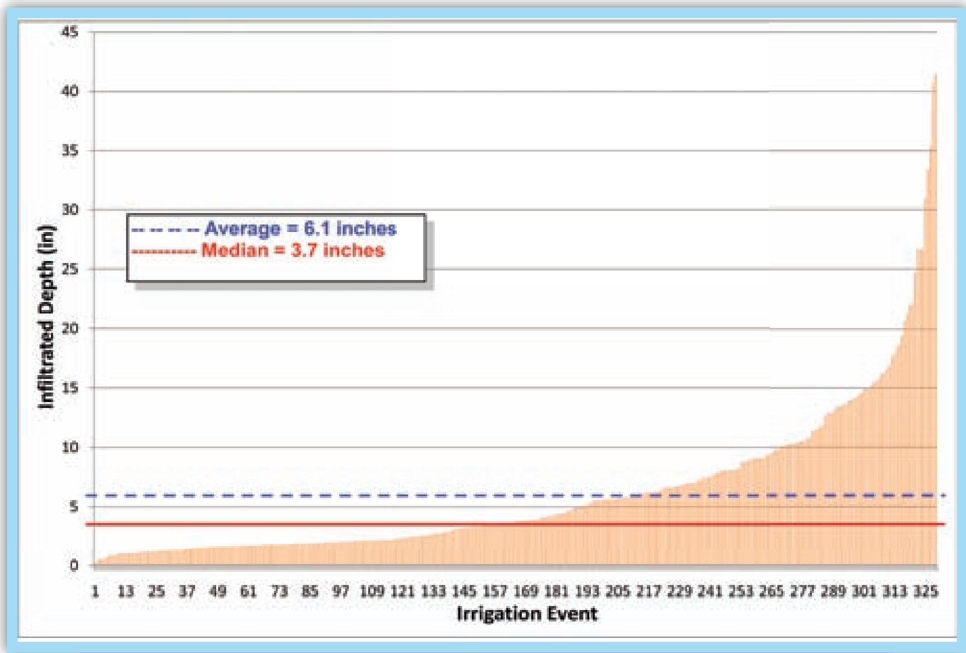


Figure 3. Tailwater Depth for each Monitored Irrigation Event (2004 to 2007)

Figure 1 shows a summary of the irrigation systems used on the monitored fields for each year of the study. This figure includes fields from both upstream and downstream study sub-regions. Upstream fields were not monitored during the 2007 season.

Figure 2 shows a histogram of the total application depth for each irrigation event monitored during the first four years of the study. The average application depth measured during this period was 6.8 inches. It is important to note that the duration of irrigation events varied significantly from field to field, based primarily on water source (well vs. surface) and canal system (for surface supplied systems). Irrigation practices on some fields were characterized by frequent, short-duration events, while other fields used infrequent, long-duration events.

Figure 3 shows a histogram of the tailwater depth for each irrigation event monitored during the first four years of the study. The average tailwater depth measured during this period was 0.65 inches. Tailwater depths for irrigation events under sprinkler and drip systems are depicted as having values of 0.

During 2008, additional irrigation data were collected in the two study sub-regions focusing mainly on fields using center pivot sprinkler irrigation systems. These data are currently being analyzed. A comprehensive report related to the data collected during the five-year project is expected to be released in 2010. The report will evaluate the interrelationships between water application, runoff, soil salinity, groundwater levels, and crop yield, as well as the work being done to estimate the volume of water that percolates below the soil zone containing the crop roots and other related topics. This information will strengthen the foundation for understanding and modeling alternative improvement strategies to increase agricultural productivity while improving environmental quality in the whole system. It will also ensure that these improvements comply with Colorado's Arkansas River compact with Kansas.

Progress on the Lysimeter Project at Rocky Ford

by Allan Andales, Assistant Professor, Department of Soil and Crop Sciences, Colorado State University

Accurate estimates of crop consumptive water use are needed to effectively manage irrigation in the Arkansas River Basin of Colorado and to maintain compliance with the Arkansas River compact with Kansas. Consumptive water use is normally defined as water that is lost from the crop root zone of the soil through the processes of soil surface evaporation and transpiration from crop leaves. The two processes occur simultaneously and are difficult to separate. Therefore, the term evapotranspiration (ET) is commonly used to refer to both processes.

The concept of "reference crop ET" was developed in the 1970s to represent the potential amount of ET from a standardized un-stressed crop, given adequate water and actual weather conditions at a particular location. Historically, alfalfa has been used as the reference crop in Colorado. The ET of other crops can then be estimated by multiplying reference crop ET by a crop coefficient (Kc). At any given point in the growing season, the Kc for a crop is simply the ratio of its ET over reference crop ET. The Kc can be thought of as the fraction of the reference crop ET that is used by the actual crop. Values of Kc typically range from 0.2 for young seedlings to 1.0 for crops at peak vegetative stage with canopies fully covering the ground.

The American Society of Civil Engineers (ASCE) standardized reference ET equation (from here on referred to as the ASCE standardized equation) has been approved by the U.S. Supreme Court as the method of determining reference crop ET for compact compliance. This equation calculates the daily or hourly alfalfa reference ET based on inputs of solar radiation, air temperature, wind speed, and humidity data that are usually available from weather stations. However, it has not been tested in the Arkansas Basin. Furthermore, localized crop coefficients that can be used to estimate the ET of crops grown in the area are not available. A validated ASCE standardized equation, along with locally derived crop coefficients, can be a widely applicable tool for irrigation management in the Arkansas River Basin of Colorado.

Figure 1. This image shows the retainer tank of the reference lysimeter after being set on the foundation. (Image courtesy of Lane Simmons)

An accurate way to measure alfalfa reference ET and the ET rates of other crops is to use a precision weighing lysimeter that directly measures ET based on changes in weight of an intact block of soil (monolith) containing an actively growing crop. By 2003, plans for building two weighing lysimeters in the Arkansas River Basin were in full swing, one to be used for measuring alfalfa reference ET and the other for measuring ET of other crops. In 2006, construction of the precision weighing lysimeter for measuring crop ET was completed at CSU's Arkansas Valley Research Center (AVRC) at Rocky Ford, Colorado. The monolith tank dimensions of the crop lysimeter are 10 feet wide by 10 feet long by 8 feet deep (3 m x 3 m x 2.4 m). By 2007, construction began on the reference lysimeter for measuring alfalfa reference ET. The monolith tank dimensions of the reference lysimeter are 5 feet wide x 5 feet long x 8 feet deep (1.5 m x 1.5 m x 2.4 m).

Completion of the Reference Lysimeter

The reference lysimeter monolith tank and retaining (outer) tank were constructed at the USDA-Agricultural Research Service workshop in Fort Collins, Colorado. Work began in 2007 and was completed in spring 2008. The monolith tank was then transported to the installation site at AVRC. On June 23, 2008, the tank was hydraulically pulled into the ground to fill the tank with an undisturbed block of soil (monolith). Excavation for the installation of the retainer tank proceeded shortly afterwards. The laying of the reinforced concrete foundation for the retainer tank was slightly delayed because of shallow groundwater at approximately 14 feet below the ground surface, but the retaining tank was eventually transported to the installation site and set on the foundation in September 2008 (Figure 1).

The weighing mechanism on which the monolith tank was to be set was assembled in December 2008. It consists of a mechanical lever scale-load cell combination that operates similar to a truck scale. The load cell output is in millivolt

Figure 2. In this photo, the soil monolith tank is being installed in the retainer tank of the reference lysimeter. The monolith tank was set on the weighing mechanism inside the retainer tank. The manhole (right of photo) allows access to the underground chamber that houses the weighing mechanism, drainage tanks, and data loggers. (Image courtesy of Lane Simmons)

Figure 3. This image shows calibration of the reference lysimeter weighing scale. Certified weights of varying size were placed on top of the monolith to derive the relationship between load cell output and monolith tank weight. (Image courtesy of Lane Simmons)

per volt. Changes in weight of the monolith tank (caused by evapotranspiration of water, for example) cause changes in the load cell output. The load cell output can thus be calibrated to give equivalent weights of the monolith tank. Partial backfilling of the excavated soil and painting of the retainer tank interior were also done in December. The soil monolith tank was set on the weighing scale on December 17, 2008 (Figure 2).

In February 2009, a steel "top hat" was installed to fit around the top of the monolith tank to prevent water from entering through the small clearance between the monolith and retaining tanks. A thin rubber sheet was applied along the top edge of the monolith tank and surrounding top hat edge to seal the small clearances between them without restricting the movement of the monolith tank. On March 24, 2009, the weighing scale was calibrated using certified weights (Figure 3).

Weather and soil sensors are currently being installed and will be connected to the data loggers mounted in the underground chamber of the retainer tank. Weather and soil heat flow data from the sensors will be used in the ASCE standardized equation. Oats will be planted on the reference lysimeter and surrounding field to keep them under a short-duration crop during the summer. The reference lysimeter and surrounding field will then be seeded to alfalfa in August 2009. They will be permanently cropped to alfalfa for making measurements of alfalfa reference ET each growing season.

Preliminary Comparison of ASCE Standardized Equation ET Estimates with Lysimeter Data for 2008

The 2008 growing season was the first full season of data collection from the crop lysimeter. The hourly alfalfa ET rates measured from the lysimeter throughout the season provided a basis for evaluating the accuracy of the ASCE standardized ET equation. Because the equation estimates ET from a tall reference crop that is assumed to be at a constant height of 20 inches (0.5 meter), similar to full cover alfalfa, lysimeter ET data taken before alfalfa achieved full cover, or a couple of weeks after cutting, could

Figure 4. This view of the crop lysimeter is looking to the east. The manhole for accessing the data logger, weighing mechanism, and drainage tanks is on the left; and micrometeorological (weather) sensors are mounted above the lysimeter.

not be compared with equation estimates. Hourly weather data measured by the sensors mounted directly above the monolith (Figure 4) were used in the hourly version of the ASCE standardized equation and included solar radiation, air temperature, wind speed at 2-meter height, vapor pressure (a measure of humidity), and heat flow at the soil surface.

June 7, 2008, (Figure 5) is an example of a day (early season) when hourly ET estimates from the ASCE standardized equation and hourly measurements from the lysimeter matched well throughout the day. Wind conditions were relatively calm, and humidity was relatively stable.

In contrast, June 2 (Figure 6) was also early in the season but had elevated afternoon temperatures, higher afternoon wind speeds, and a drop in humidity. There was a drop in solar radiation after 12:00 hours due to increased cloud cover, which was reflected in the drop in both the lysimeter and ASCE standardized ET rates. However, the ASCE standardized ET equation seemed to be overly sensitive to higher wind speed and decreased humidity that occurred after 14:00 hours. The equation over-predicted ET under these conditions.

Based on preliminary analysis of the 2008 data, the ASCE standardized equation generated alfalfa reference ET estimates that agreed well with lysimeter measurements when sensible heat advection (movement of warm air mass from another area) was not significant. The equation tended to over-estimate hourly ET rates when high wind speeds (> 5 m s-1) occurred with elevated air temperature and decreased humidity. On the other hand, the equation under-estimated mid-day alfalfa ET rates on some days late in the season (data not shown), possibly because of the assumed canopy height (0.5 m) being lower than the actual canopy height and/or soil water and leaf transpiration dynamics not being accounted for in the equation. Further analyses are needed to evaluate the accuracy of the ASCE standardized ET equation in estimating alfalfa reference ET for different conditions in the Arkansas River Basin.

Technical Meeting and Open House

On the morning of April 3, 2009, 14 individuals working directly with or having interest in the weighing lysimeters

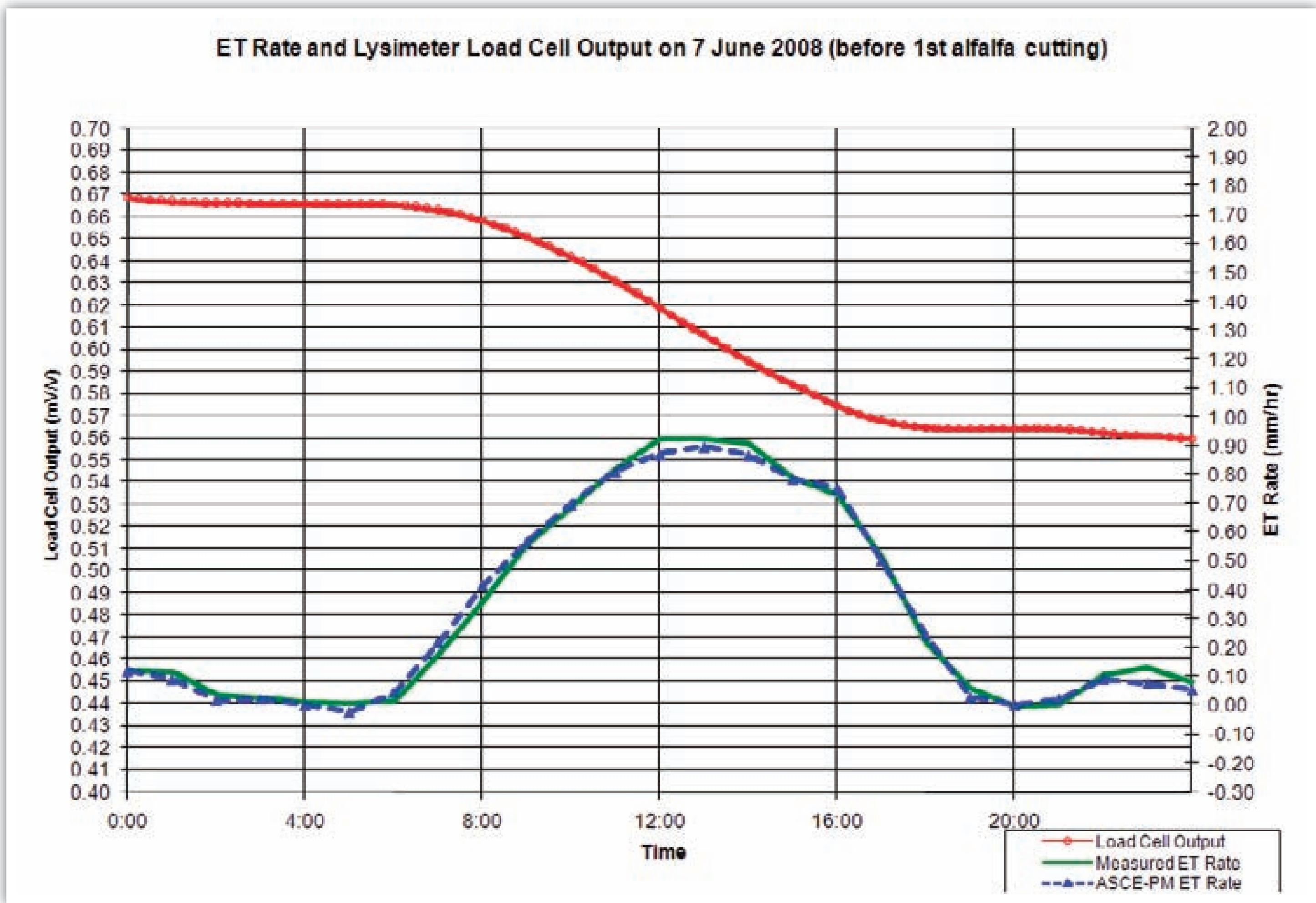


Figure 5. Example lysimeter load cell output (top line) and corresponding hourly ET rates measured by the lysimeter (solid line) and estimated by the ASCE standardized reference ET equation (dashed line).This example shows very good agreement between the ASCE standardized ET equation and lysimeter measurements.

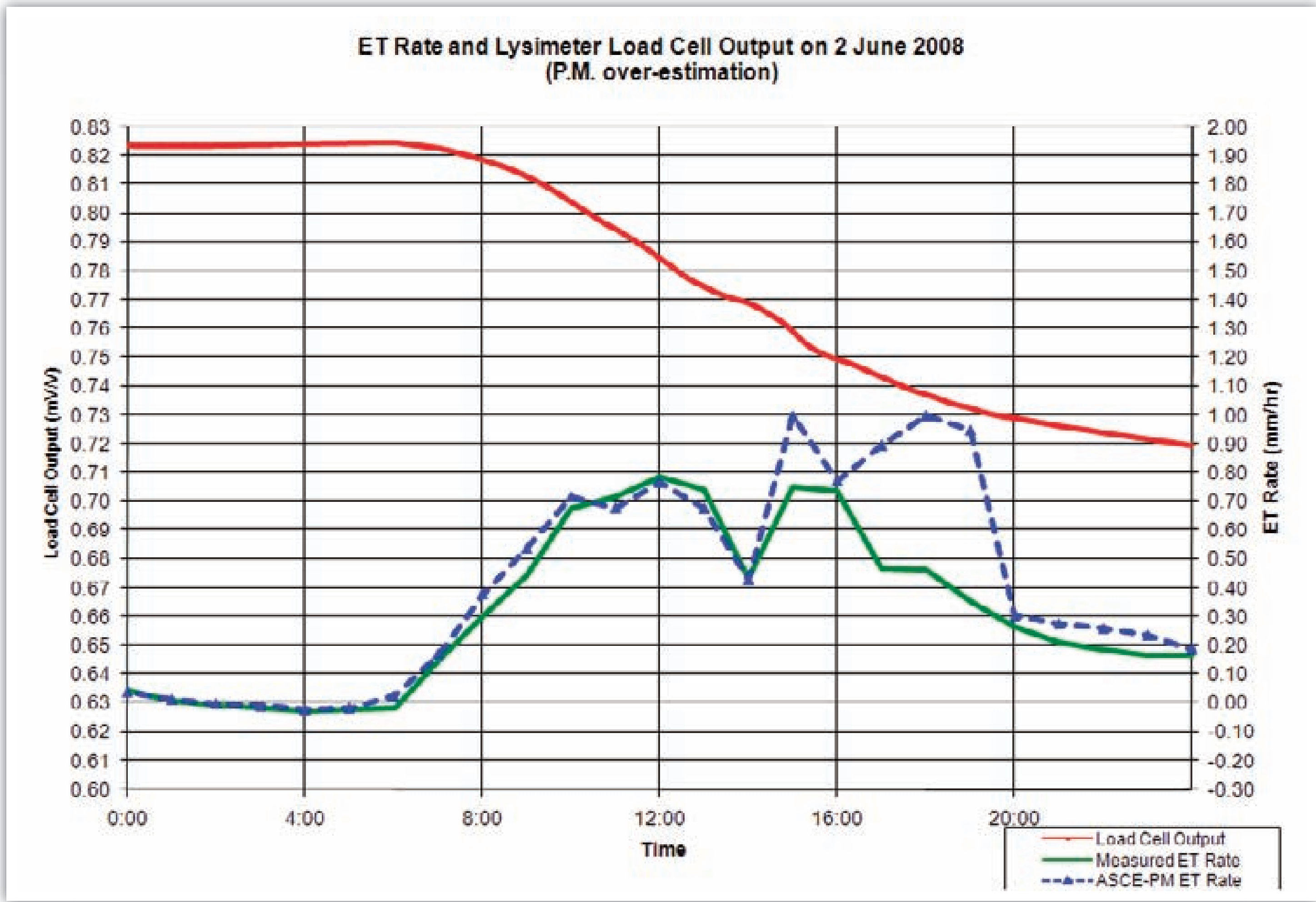


Figure 6. Example of over-estimation of afternoon hourly ET rates by the ASCE standardized reference ET equation (dashed line), compared to measured alfalfa ET from the lysimeter (solid line). In the afternoon of June 2, 2008, dry, warm wind originating from a nearby prairie blew from the southwest.

held a technical meeting. Representatives from CSU, Colorado Division of Water Resources, and USDA-Agricultural Research Service talked about the operation of the two lysimeters, preliminary analyses of 2008 data, and future data collection and management. In the afternoon, local producers, state personnel, and representatives of water conservancy districts were updated on the lysimeter construction and data collection. Attendees then visited the lysimeter site and were given the opportunity to view the underground chamber of the reference lysimeter that was nearing completion. Approximately 27 people attended the event.

Future Plans

The reference lysimeter will be permanently cropped to alfalfa to make measurements of alfalfa reference ET each growing season. The crop lysimeter will be cropped to alfalfa through 2011 to verify that the reference lysimeter is measuring similar alfalfa ET rates. Beginning in 2012, the crop lysimeter and surrounding field will be planted to corn and other major crops in the Arkansas Valley (wheat, sorghum, onions, etc.) to determine their crop coefficients. Simultaneous measurements of alfalfa reference ET from the reference lysimeter and crop ET from the crop lysimeter are needed to calculate crop coefficients. It will take at least two years per crop (planted in the crop lysimeter) to generate reliable crop coefficient values that cover the entire growing season.

Acknowledgements

The lysimeter project is a joint effort between the Colorado Water Conservation Board, Colorado Division of Water Resources (CDWR), Colorado Water Institute, and Colorado State University. Technical support has also been provided by USDA-Agricultural Research Service engineers and scientists in Fort Collins, Colorado, and Bushland, Texas. Lane Simmons, Michael Bartolo, and Abdel Berrada of CSU; and Dale Straw and Thomas Ley of CDWR contributed to the data collection described in this article.

Drip Irrigation Development and Research in the Arkansas Valley

AGRICULTURAL EXPERIMENT STATION

by Michael E. Bartolo, Senior Research Scientist, Arkansas Valley Research Center

Growers in Colorado's Arkansas Valley face increasing pressure to better manage their water resources. Droughts, heightened competition for water from municipalities, and increased labor costs associated with furrow irrigation have compelled many growers to adopt more efficient irrigation methods. Drip irrigation is one of these improved methods and has been adopted on approximately 2,000 acres in the Arkansas Valley.

Onion trials are irrigated with drip and furrow irrigation. (Image courtesy of Michael E. Bartolo)

At the Arkansas Valley Research Center (AVRC), drip irrigation was first conducted in the early 1980s by regional irrigation specialist Don Miles and campus-based vegetable crops specialist Dr. Jim Ells. Over the years, research continued, encompassing a wide array of topics and crops, but drip irrigation did not come into practice on a commercial basis until the mid 1990s. At the time (and the same is largely true today), drip systems were used to produce higher-value crops like cantaloupe. Melons proved to be highly responsive to drip irrigation, and today nearly 90% of the cantaloupe produced in the Valley is grown with drip irrigation. In addition, drip irrigation made it feasible to adopt other aspects of plasticulture, including plastic mulches. In combination, drip irrigation and plastic mulches dramatically improved yields, earliness, and quality of cantaloupe crops.

Many of the drip systems currently in place in the Valley are subsurface types. Drip lines are placed at a depth of approximately 8 inches, and systems have a projected longevity of 5-10 years. For the most part, the systems were designed with melon production in mind; however, over time, a wide variety of crops have been grown in rotation, including vegetables such as onions, peppers, and tomatoes, and field crops like corn, wheat, and soybeans.

In nearly all instances, growers adopting drip irrigation rely on groundwater from relatively shallow alluvial wells rather than surface water. Groundwater has several attributes that make it amenable to drip irrigation. Namely, it is relatively free of sediment and is available on a more timely and reliable basis than most surface water sources. Further, in the Arkansas Valley, pumped groundwater is fully augmented, so there are no complications with efficiency issues related to the Colorado v. Kansas Compact. On the downside, groundwater often contains two to three times more salt than surface water does. Given the fact that high salinity is already an issue in many parts of the Valley, there are concerns that drip irrigation with high-salinity water may accentuate yield declines and lead to the accumulation of salts in the soil over time.

With these concerns in mind, several field studies were conducted at the AVRC to characterize the response of onion, watermelon, and cantaloupe to irrigation waters of varying quality delivered by drip irrigation. Two irrigation water sources were examined as the treatments: surface water diverted from the Arkansas River and groundwater derived from a shallow (25-30 feet deep) alluvial aquifer on the AVRC site. The surface water varied slightly in salinity during the course of the season but had an average electrical conductivity (EC) of approximately 1.0 dS/m. The groundwater had an EC of 2.8 dS/m. Other characteristics of the water sources are noted in Table 1.

Component	Groundwater	Surface
Calcium	283 ppm	111 ppm
Sodium	133 ppm	64 ppm
Hardness - CaCO3	1022 ppm	420 ppm
Sulfate	1053 ppm	365 ppm
Specific Conductance	2.77 ds/m	1.00 ds/m
TDS	1764 ppm	720 ppm

Table 1: Physical and chemical properties of ground and surface waters.

The peppers in this image have been grown with drip irrigation and plastic mulch. (Image courtesy of Michael E. Bartolo)

In 2005 and 2006, several onion varieties were evaluated for their response to different water qualities, each representing a cross-section of the types grown in Colorado (yellow, white, and red-skinned). Onions are one of the highest-value and most widely grown vegetable crops in the state. Unfortunately, they are also one of the most salt-sensitive crops and are very susceptible to water deficits due to the shallow nature of their root system. Based on historical studies, it was assumed that maximum onion yields might be reduced by 50% when the EC of irrigation waters reached 2.9 dS/m, about the same salinity as the water used in our studies.

Our studies showed that onion yields under drip irrigation (regardless of irrigation water source) were high compared to yields obtained with furrow irrigation. Nonetheless, total marketable yield was significantly less for all varieties when drip irrigated with high EC groundwater compared to low EC surface water. The relative yield decrease ranged from just over 7% for a yellow-skinned onion variety to over 23% for a red-skinned variety. Generally, onion size (diameter) also decreased with higher-salinity irrigation water. Despite some yield depression, the relative yield declines were not nearly as dramatic as what would have been predicted based solely on the EC of the groundwater. In fact, some of the yellow-skinned cultivars were only slightly affected. Red varieties were consistently the most salt-sensitive type, but still to a lower degree than anticipated.

In 2008, the same experiment was conducted with cantaloupe and watermelon. Once again, watermelon and cantaloupe yields were exceptionally high with drip irrigation regardless of the irrigation water source. For both crops, yields were only slightly lowered (but not statistically significant) by the use of high-salinity groundwater compared to the lower salinity surface water. Other yield components like fruit size and fruit number were unaffected. Interestingly, one measure of cantaloupe fruit quality was positively influenced by irrigation with high salinity water. Percent brix (soluble solids), a relative measurement of fruit sugar content, was significantly higher in cantaloupe that had been irrigated with the higher salinity groundwater This phenomena has been noted by other researchers and is likely related to osmotic competition between the developing fruit and soil.

Overall, in the crops studies thus far, irrigation with higher salinity groundwater did not reduce yields as much as anticipated. On closer examination, this may be attributed to two factors. First, the nature of drip irrigation itself facilitates the maintenance of higher soil water levels and thus lessens the osmotic competition effect salts may have in the soil. Second, much of the historical evidence concerning crop salinity tolerance is based on soils and water containing sodium and chloride-based salts. In the Arkansas Valley, calcium and magnesium salts are the major contributors to salinity in the soils and waters, and these salts have relatively less osmotic and physiological effects on plants.

Another consideration is the long-term (multiple years) effects of irrigating with high salinity water. All of the aforementioned studies represent just the first year of irrigation with the respective water sources. Over several years, salts may accumulate in soils consistently irrigated with groundwater and ultimately cause more significant yield declines than was observed in these studies. However, based on the accompanying soil sampling data in trials, it did not appear that salt levels continued to increase over the course of a season in the rooting zone. That is, they reached a certain level and then stabilized. Further, growers with "permanent" drip systems have not noticed an increase in soil salinity in the rooting zone, even after 10 or more years of drip irrigating with groundwater. Managing the drip system to ensure salts are leached out of the root zone seems to be essential in preventing accumulation of salts over time.

Overall, drip irrigation has remarkably improved crop yields and quality in the Arkansas Valley. Although not discussed in this article, drip irrigation also reduced crop water use for many of the crops studied. Despite relying on high salinity groundwater, growers may be able to manage salinity problems by choosing varieties that are more tolerant to salinity and irrigating with sufficient volumes of water to prevent excessive build-up of salt in the soil profile over time.

Estimating the Water Lost Due to Evaporative Upflux from Shallow Groundwater

by Jeffrey D. Niemann, Timothy K. Gates, Niklas U. Halberg, and Brandon M. Lehman
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Introduction

Many agricultural water systems in the western U.S. are facing extraordinary pressures that constrain water availability and use, and the Lower Arkansas River Valley (LARV) is no exception. In the face of such pressures, various strategies have been proposed to conserve water in agricultural systems like the LARV. One conservation strategy is the removal of invasive phreatophytes, such as tamarisk (salt cedar). Another proposed strategy is the application of polyacrylamides or polysaccharides to canals, which promote settling of clay particles out of canal water and reduce seepage losses. Improved irrigation practices, such as drip irrigation, have been suggested as another possible method for water conservation.

All of these conservation strategies aim—directly or indirectly—to reduce the amount of non-beneficial consumptive use in the system, which is mostly the evapotranspiration (ET) from uncultivated areas. The ET from uncultivated lands within the Arkansas Valley is likely a major component of the overall water balance, but much uncertainty persists regarding the magnitude of this loss and the effectiveness of proposed water conservation strategies at reducing this loss. A key source of uncertainty is the actual reduction of the non-beneficial consumptive use that would occur if the water table is lowered by a particular amount.

The overarching objective of this project is to quantify the controls on non-beneficial consumptive use of water from uncultivated lands in the LARV. In particular, we seek to determine: (1) the portion of total ET from uncultivated lands that comes from groundwater upflux, (2) the sensitivity of the non-beneficial ET to the water table depth, and (3) the role that vegetation and soil properties play in mediating the relationship between water table depth and upflux. A better understanding of the evaporative upflux from fallow fields and naturally vegetated lands in the Arkansas Valley will improve the assessment of water conservation strategies in the valley. It is also expected to benefit soil salinity and water quality assessments.

Approach

Our strategy has focused on making detailed measurements at three uncultivated field sites in the LARV. The field sites were selected to represent different topographic and land-use conditions found in the valley (Figure 1). One of these sites is a retired field north of the town of Swink and close to the Arkansas River. The field is no longer cropped because it lies in a conservation easement that aims to reduce agricultural losses from floods. Roughly one third of this site is vegetated by legacy alfalfa; the remainder has relatively natural grasses and forbs, but about half of this section is currently grazed. Because the site lies within the alluvial valley, it has very little topographic relief.

The second site is located southeast of the town of Manzanola and adjacent to the Rocky Ford Highline Canal. It is naturally vegetated and has some topographic relief because it lies at the edge of the alluvial valley. The third site, which is located south of the town of Rocky Ford between the Catlin Canal and Timpas Creek, is vegetated with grasses and forbs. It has little topographic relief, but it is situated several meters above the creek.

Both ET and vegetation greenness at the three field sites were estimated from remote-sensing data. The thermal

Figure 1. (a) Researcher downloading data from a raingage at the Swink field site, (b) Raingage and atmometer at the Manzanola field site, and (c) monitoring well at the Rocky Ford field site.

infrared and visible band information from the Landsat5 and LandSat7 satellites are used in an energy balance approach called ReSET to estimate ET in the LARV. These estimates were calibrated using weather station observations and are expected to have an accuracy of 10–20%. This approach provides ET estimates on a 30-meter grid each time a satellite passes over the site if cloud cover is not present. Both LandSat5 and LandSat7 pass over the sites every 16 days, but their timing is offset so that one of the satellites passes over the site every 8 days. LandSat5 is the preferred satellite for this project because LandSat7 covers changeable regions where data are unavailable. The remote sensing algorithm also produces the so-called normalized difference vegetation index (NDVI), which measures the greenness of the vegetation.

The three field sites were extensively instrumented to quantify potential influences on the variation of ET. At the Swink site, 39 wells were drilled on a 60-meter grid, 29 wells were drilled at the Manzanola site on an irregular 45-meter grid, and 17 wells were drilled at the Rocky Ford site on a 60-meter grid (the layout of the monitoring wells is shown in Figure 2). Automated water level loggers were placed at the base of most wells to continuously measure the water level above the sensor. One water level logger was also placed at the ground surface at each field site to measure variations in atmospheric pressure, which improves the accuracy of the water table estimates.

At each site, precipitation was measured using two tipping bucket gages, and reference crop ET was estimated using two atmometers. Reference crop ET also was computed using data from a CoAgMet weather station at Rocky Ford, which is located about 5 miles from the Swink site, 15 miles from the Manzanola site, and 6 miles from the Rocky Ford site. On cloud-free days that the satellite passed over, measurements were made in each field of potential explanatory variables. Spot measurements of water table depth were made at all wells, soil moisture was measured near all wells at 2-, 3-, and 4-foot depths, and soil salinity was estimated using a calibrated electromagnetic induction probe.

Key Results

The contribution of groundwater upflux to the total ET was estimated using a water balance approach. Water for the actual ET can be supplied by changes in soil water storage, precipitation events, and groundwater upflux. No significant lateral flow or runoff is expected due to the dry condition of the soil during the period of analysis. It is assumed that all precipitation became ET (i.e., groundwater recharge was negligible), and changes in soil water storage were found to be negligible over long time periods. Thus, the cumulative groundwater upflux for a period of time can be estimated as the cumulative ET minus the recorded precipitation depths. Figure 3 shows results from this analysis for two of the field sites for 4/1/2007 to 3/21/2008. On average, 2.4 millimeters per day (mm/day) of groundwater was lost to ET at the Swink site, and 2.0 mm/day was lost to ET at the Manzanola site during this period. Both the ET and the groundwater upflux rates are greater during the summer than in the winter. Total cumulative groundwater upflux is estimated to be 0.79 m and 0.68 m at the Swink and Manzanola sites, respectively. This suggests that about 75% and 70% of the total estimated ET was supplied by groundwater upflux at the Swink and Manzanola sites, respectively. These estimates suggest that the non-beneficial consumptive use of water is primarily supplied from upflux

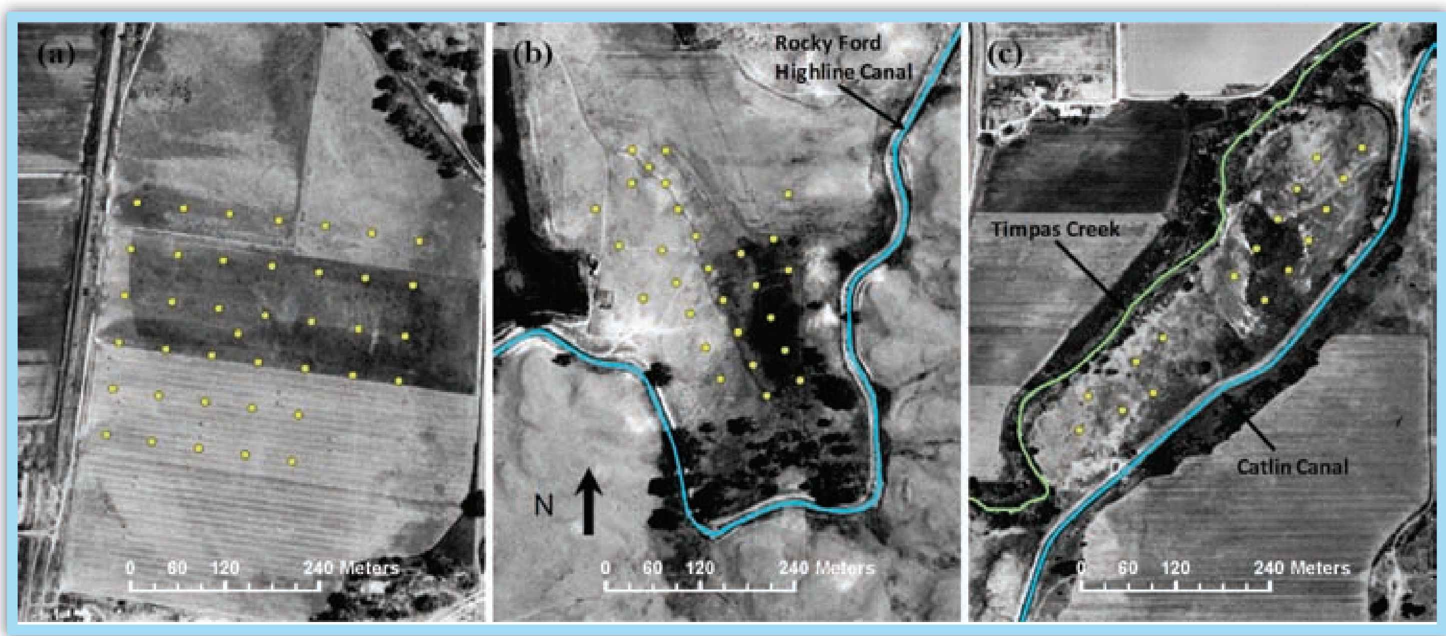


Figure 2. These views show the layout of monitoring wells at the (a) Swink, (b) Manzanola, and (c) Rocky Ford sites.

from the shallow water tables at both sites.

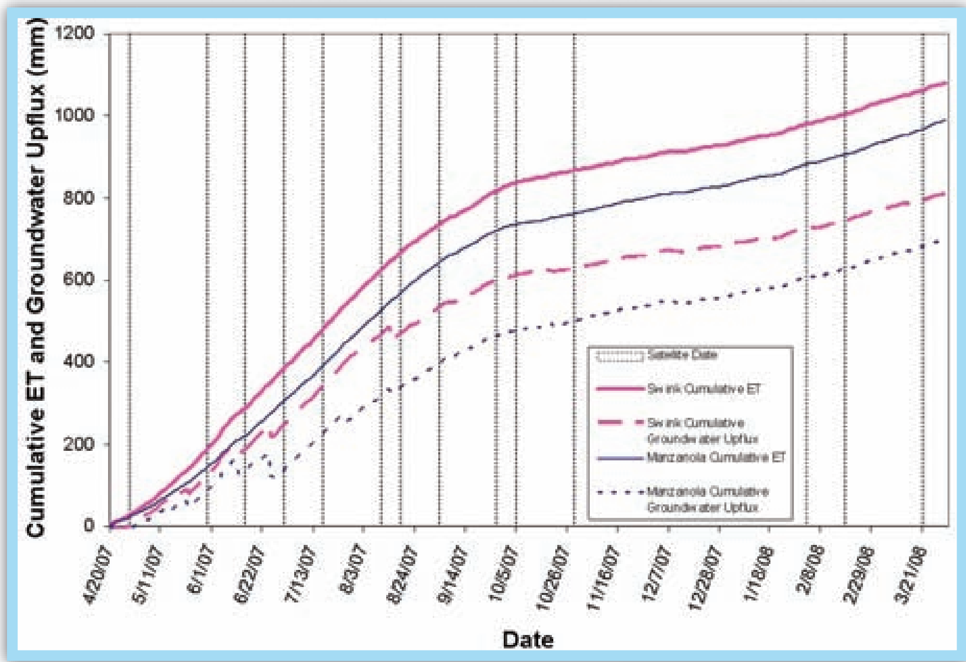


Figure 3. Estimated cumulative groundwater upflux in support of ET (mm) for the Swink and Manzanola field sites. Vertical lines indicate dates on which ET is estimated from remote sensing.

Figure 4 shows the temporal average ET rate plotted against the temporal average water table depth at each monitoring well for the Swink and Manzanola field sites. At the Swink site, the average ET rate does not clearly vary with the average water table depth. However, if the monitoring wells are divided according to their associated vegetation types (alfalfa, grass, and grazed grass), possible relationships are observed for the alfalfa and grass sections (not shown), but the number of wells in each group is small. For the Manzanola site, the range of water table depths is larger and the vegetation cover has fewer disturbances. At this site, the average ET rate approaches 5 mm/day when the water table is close to the surface and drops to roughly 4 mm/day when the water table reaches 2.5 meters in depth.

Key Conclusions

Although monitoring and data analysis are ongoing, these preliminary results demonstrate that groundwater upflux was the dominant contributor to ET at both the Swink and Manzanola sites during the period of analysis. This finding confirms that non-beneficial ET is closely linked to the presence of a shallow water table under the uncultivated lands in the LARV. More research is needed to determine the water savings that might be achieved by lowering the water table by a specified amount. In particular, the vegetation patterns observed in this study have likely adapted to the spatial variations in water table depth within these sites. If the water table is abruptly lowered, the vegetation would require a significant period of time to adapt to the new conditions, which would potentially alter the relationship between water table depth and non-beneficial ET.

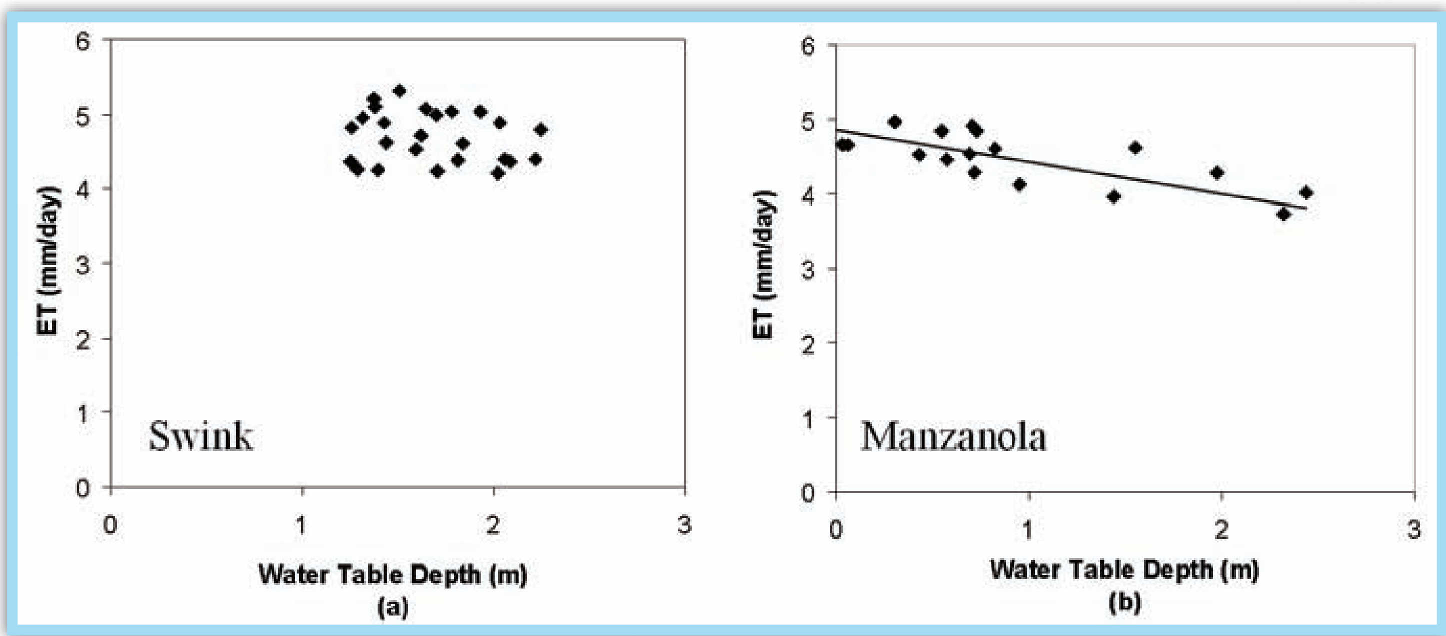


Figure 4. The average ET rate plotted against the average water table depth for 4/1/2007 to 3/21/2008 at each monitoring well at the (a) Swink and (b) Manzanola sites.

Research and Demonstration Projects for Irrigation Management of Arkansas Basin Water

by Jim Valliant, Research Scientist, Arkansas Valley Research Center
Perry Cabot, Extension Water Resources Specialist, Colorado State University

Introduction

Water transfers in the Arkansas River Valley have been conducted on a "buy-and-dry" basis for many years, as anyone who knows the history of the Colorado Canal can explain. Agricultural water rights have been sold to cities on the Front Range, and as the water rights are shifted to these cities many acres of agricultural land have been removed from production. Even if these lands revert to dryland production, they have limited agricultural productivity in the arid environment of the southern high plains. In many instances, these formerly irrigated lands experience erosion and weed problems that are difficult to reverse.

An old idea, but recently used practice, is the leasing of agricultural water rights (or simply "ag water") to the cities during time of drought. These leases give the ag shareholders a new crop—namely, water—and provide additional on-farm revenue. Under leasing programs, land is not permanently dried up but is fallowed or set aside from irrigation for a number of years, depending on the conditions of the lease.

Leasing of these ag waters could improve the economic stability of farming towns throughout the Valley. Farmers could keep much of their land under production, fallowing only the necessary acres to meet the requirements of the leasing agreements. Leasing water would allow farmers to upgrade their tractors, implements, irrigation systems, and other farm equipment. Also, when the fallowed land is put back into production during years of adequate water supplies, monies would be spent locally for seed, fertilizer, and other production items.

In May 2008, shareholders from six of the large ditch and canal companies joined together and incorporated the "Super Ditch Company" to market their water in times of drought. One of the questions growers are asking is, "How will fallowing my ground for a period of years affect my yields, nutrients needs, and the economics of corn production when I decide to farm this ground again?"

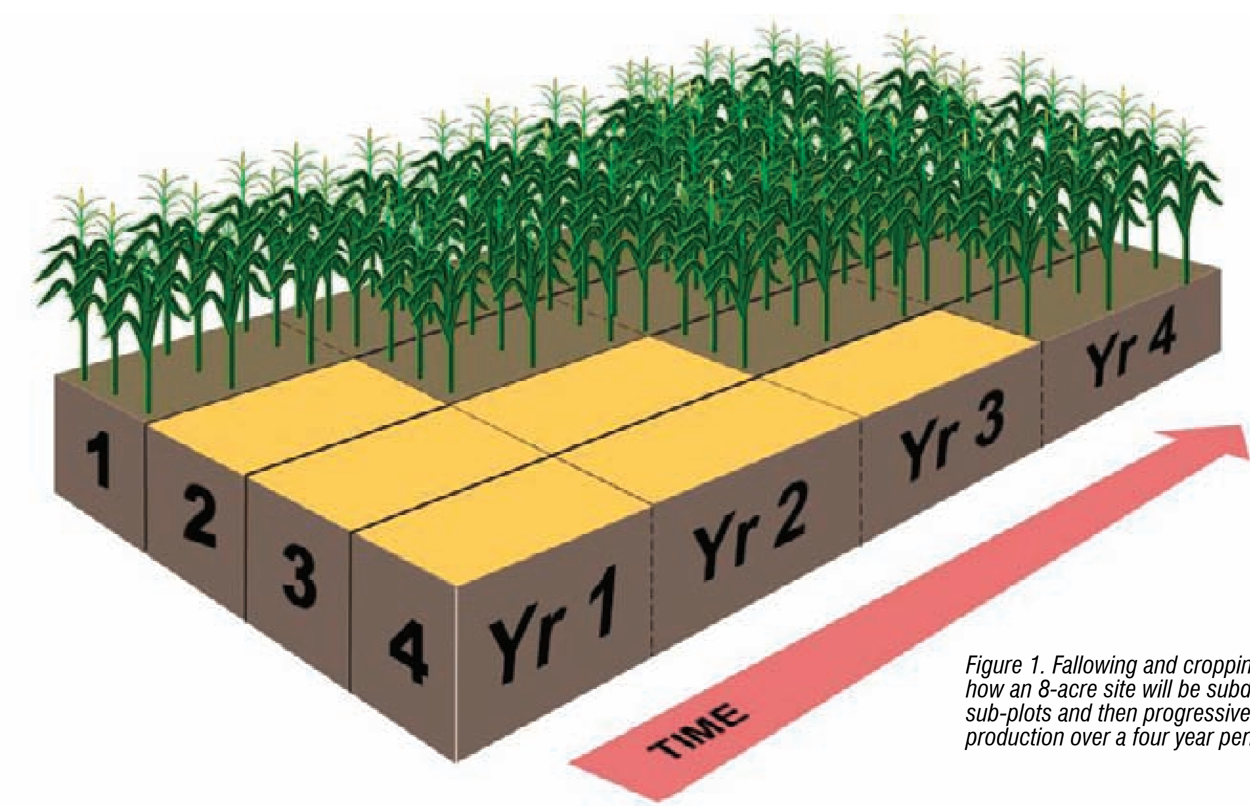


Figure 1. Fallowing and cropping regime shows how an 8-acre site will be subdivided into four sub-plots and then progressively brought back into production over a four year period.

AVRC Corn-Fallow Study 2007-2010

In an effort to determine the effect of fallowing land for one, two, or three years, the Colorado State University Arkansas Valley Research Center (AVRC) began a study in 2007 with corn as the index crop. The study has looked at the effect on yield, nutrient needs, and the economics of maintaining or improving yields on these fallowed lands when put back into corn production, as compared to growing corn on land for a four-year period.

Soil test results showed adequate carry-over of fertilizer, N, P, and K applied in 2006 and fallowed in 2007 to produce 232 bushels of corn in 2008. This is significant because it shows the 2006 investment in fertilizer was not lost after fallowing the land for one year. The corn-corn areas needed 204 pounds per acre of nitrogen to produce the same 232 bushels per acre.

It should also be noted that there is still sufficient carry-over fertilizer, N, P, and K applied in 2006 to produce an optimum corn crop in 2009. This finding is significant because it shows that the initial investment in fertilizer, N, P, and K was not lost after fallowing the land for two years. This also emphasizes the need to soil-test these lands instead of just assuming the need for additional fertilizer. The carry-over of these nutrients may have been due to weed control on the fallow areas and low rainfall.

The economics of corn production and fallowing will be reported in future articles. This study is being sponsored by the Lower Arkansas Valley Water Conservancy District.

Corn-Fallow Demonstrations

Beginning in May 2009, two demonstration sites will be initiated on the Highline and Holbrook Canals. These sites will be established on the working farms of Paul Rossi (Highline Canal) and Hansen Farms (Holbrook Canal) to test annual crop response to the previous years' fallow period. Demonstrations will also be prepared for the 2009 season, with one area planted to corn in 2009 and three other areas fallowed. Using continuous corn as reference, the other areas will be fallowed one, two, or three years (Figure 1). These demonstrations are being sponsored by the Colorado Water Conservation Board.

The proposed activities will quantify the changes in yield, nutrient needs, and profitability that result on irrigated fields when they are brought back into production after fallowing. Farmers in the Arkansas Valley have expressed a need for such assessments in order to consider water rights leasing arrangements individually or collectively.

The results of these demonstrations will also allow CSU Extension to provide recommendations on land fallowing and returning fallowed land back to production. These recommendations are needed because of the expectation that farming will continue to occur on rotationally fallowed lands, but little information exists on the technical aspects of this farming practice. Conducting demonstrations "on the ground" in the context of working farms is a proven approach for documenting and quantifying emergent challenges inherent to untested strategies. Demonstration of leasing amid these variables will help document the economic and technical impacts of fallowing for different periods. When deciding whether to enter a lease arrangement, farmers need this information to accurately calculate the market value of their water shares, relative to the value of continuing to farm in a time when corn prices are steadily rising.

Winter Canola Studies

Winter canola studies are being conducted at the AVRC to produce fuel and food-quality oil. In cooperation with Kansas State University, a 30-entry variety trial is being grown to determine which varieties are most productive and most suitable for fuel and/or food oil. In cooperation with Texas A&M and New Mexico State Universities, two varieties of winter canola are being tested with optimum and limited irrigation. Date of planting, desiccation, and the use of hydrogel (a cross-linked polymer) with two varieties are also part of the project.

Drip and Sprinkler Irrigation Demonstration on Seeded Onions

The Arkansas River is one of the most saline rivers in the United States. Average salinity levels increase from 300 parts per million (ppm) in total dissolved solids (TDS) near Pueblo to over 4,000 ppm TDS near the Colorado-Kansas border. More than 200,000 acres along the river are irrigated with Class C4 water, which is the highest classification for salinity hazard.

Salt accumulation in the surface water is exacerbated by inefficient irrigation. Water running over or through the soil has long been known to contribute to significant increases in salt concentration in the Arkansas River. Other pollutants, such as sediment, nitrates, selenium, and pesticides, are also transported by runoff and leaching. As a result, the U.S. Environmental Protection Agency (EPA) has declared several areas of the watershed to be selenium impaired.

Research at the AVRC has shown that drip irrigation can substantially reduce water applied to the crop and positively affect crop yield, quality, and returns. Most drip systems in the Arkansas River Basin are sub-surface drip irrigation (SDI) systems and have allowed producers to significantly increase yields of some crops with substantially less water than furrow irrigation. These increases in yields and reductions in water are encouraging producers to use SDI or increase acres of SDI.

Drip systems apply amounts of water for crops daily needs, so a constant source of irrigation water is required. Most of the surface irrigation canals in the Basin don't have a constant flow, so most producers using SDI must use wells that can be pumped as needed for these systems. The water from these wells is usually much higher in salts—near 2,000 ppm TDS—than the surface water.

The effect of SDI on soil and water quality has not been fully studied, and it is not clear how irrigation with these waters will alter salinity and selenium, and nitrate movement, deposition, and accumulation. Because of the small amounts of water being supplied by SDI, leaching of nitrates, salts, and selenium below the root zone is minimal and could result in accumulation around the drip lines in amounts that are damaging to crops. Studies and demonstration work addressing these concerns are now part of a two-year study by CSU being funded by a NRCS Conservation Innovation Grant at the farm of a local cooperator (Matthew Proctor).

With sub-surface drip lines buried 6 to 15 inches below the surface and spaced from 30 to 60 inches, seed germination and emergence is not as uniform as with surface irrigation unless the seed is placed close to the drip line. Rainfall or snow provides moisture for germination and emergence in areas east of Colorado, but arid conditions in the Arkansas River Basin make dependency on natural moisture extremely risky, especially when growing high-income, high-input crops like onions. High-yielding, high-quality onions can return several thousands of dollars per acre, especially in a good market year.

Because the input is costly and the dependency on natural moisture is risky, some producers are looking at sprinkling for germination of seeded onions on their SDI systems. However, sprinkling can cause severe crusting of the soil and can retard or prevent emergence of the seeded onions. Sprinkling can also move nitrogen, a very essential nutrient in onion production, below the shallow root system.

The use of a sprinkler on SDI, with and without hydrogel, will help determine the value of each method and/or treatment in seeded onion production and will allow other producers to determine if they should incorporate one or both into their seeded onion production.

SDI was used to fill the upper root zone in 2008, and this pushed the salts into the top two inches of the bed, resulting in an electrical conductivity (EC) of 3.22 dS/m even though the area was sprinkler irrigated after planting. The seeded onions germinated and emerged, but with an EC tolerance of 1.2 the seedling stand died off and was judged insufficient for commercial production.

The demonstration was planted on another area in March of 2009, but SDI was not used prior to planting to prevent pushing the salts up into the shallow seedling zone. About 16 inches of snow fell in late March, so the areas will not be sprinkler irrigated until necessary to maintain surface moisture. Results of the demonstration will be reported in the future.

Arkansas River Basin Climate

by Nolan Doesken and Wendy Ryan, Colorado Climate Center, Colorado State University

Introduction

Abundant sunshine, hot temperatures, low humidity, and moderate winds punctuated by an occasional nasty storm are some of what comes to mind when we think about the climate of southeastern Colorado. But there is much more to the climate than that.

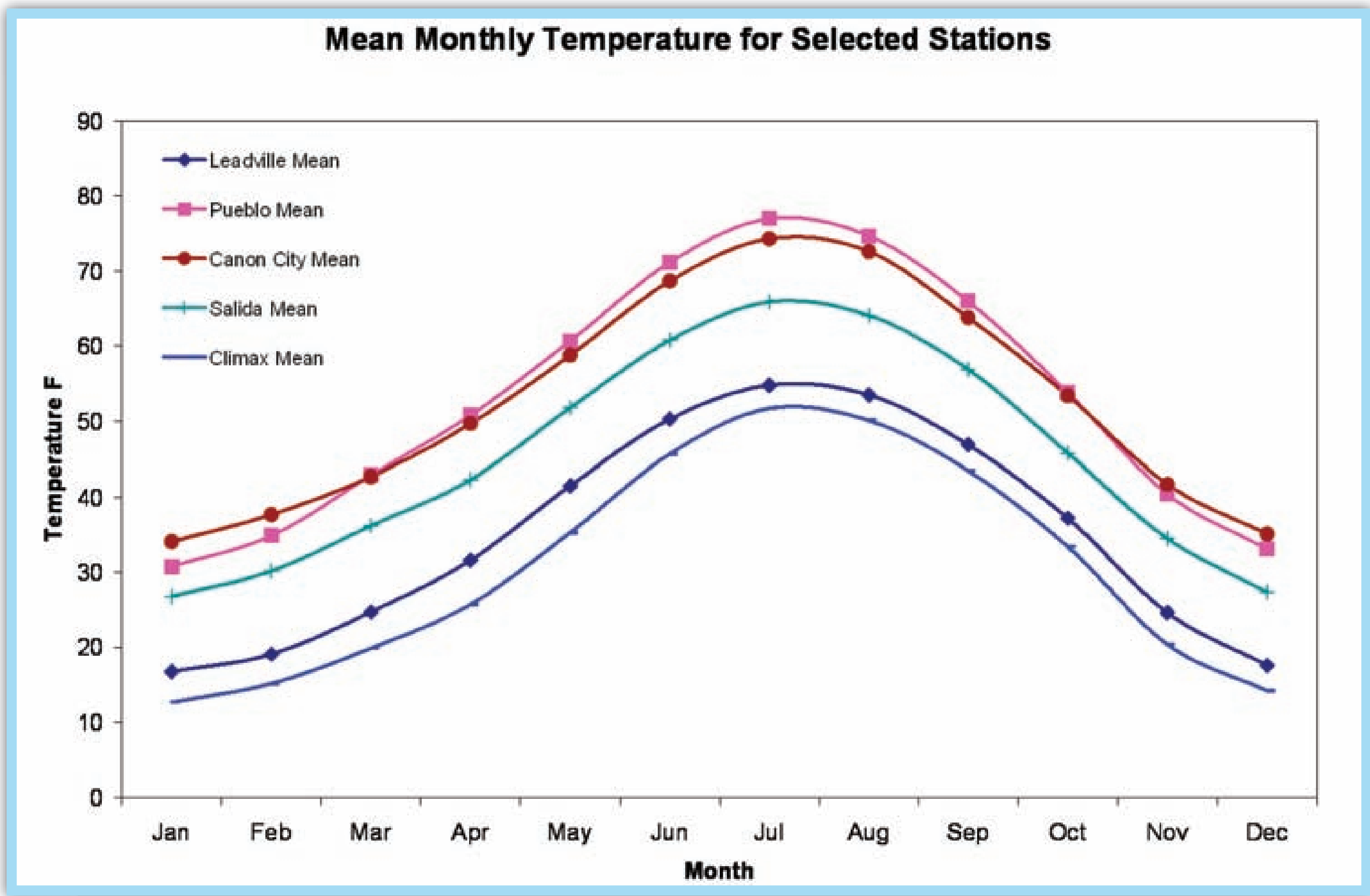
From the headwaters of the Arkansas River Basin in Lake County, through the "Banana Belt" region of the upper basin in Chaffee County shadowed by the Collegiate Peaks, then downstream to Royal Gorge and Pueblo Reservoir, and finally out to the high plains of eastern Colorado, the Arkansas River Basin covers thousands of square miles—forest, grassland, towns, cities, and irrigated and dryland farms. Elevations rise more than 10,000 feet, from near Holly, where the river crosses the Kansas border, to the many high mountain peaks at the basin's western fringes.

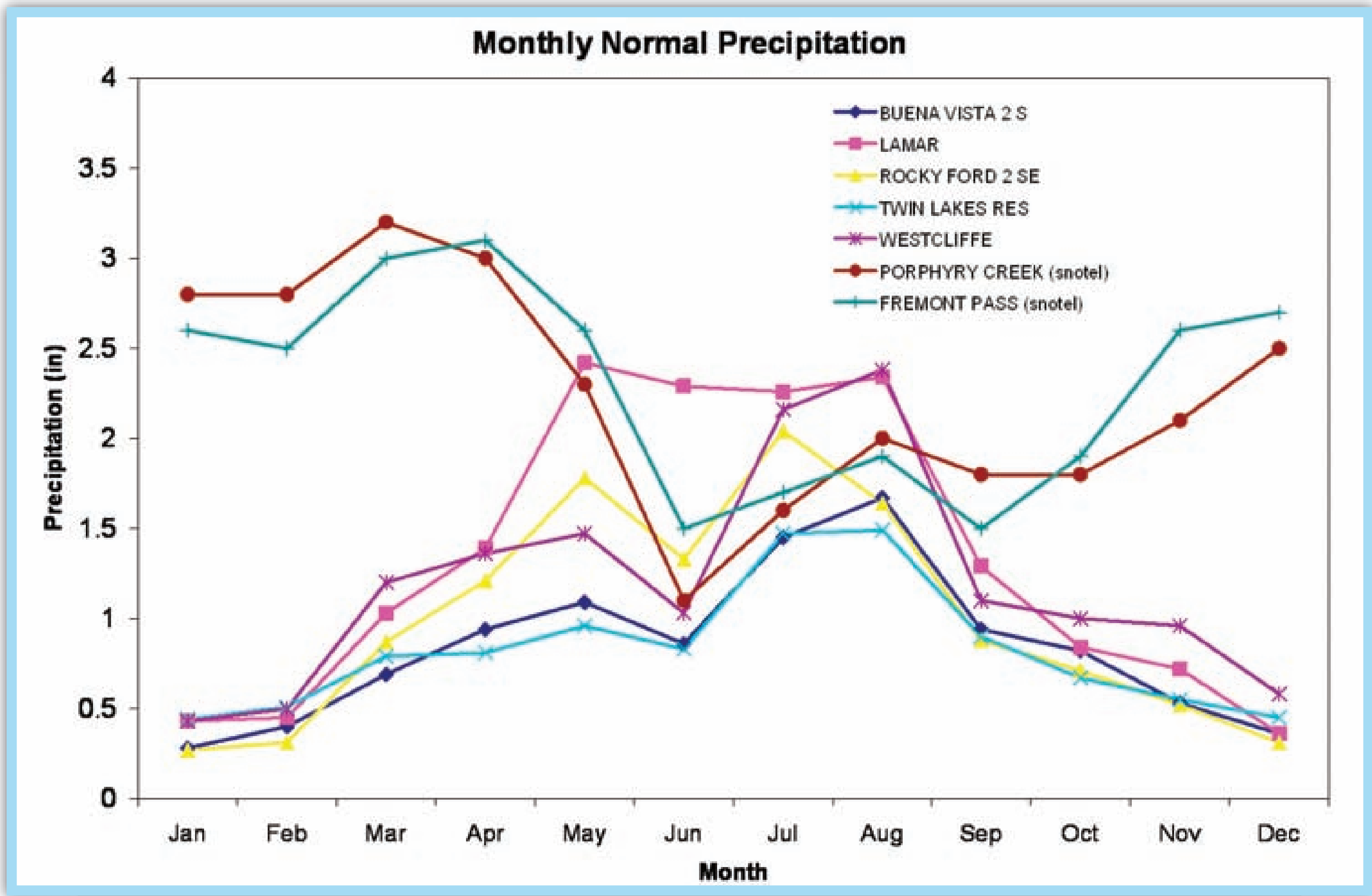
The basin's climate is a product of this diverse high elevation topography combined with the basin's mid-latitude position (37-39 degrees N) and its great distance from the predominant source of western U.S. moisture—the Pacific Ocean.

Temperatures

Day length, solar intensity, and elevation are important factors that help determine temperatures in the Arkansas Basin. The coldest weather of the year usually comes in the weeks following the winter solstice. Similarly, there is a lag of a few weeks from the longest day of the year to when the hottest temperatures occur—typically in July. Seasonal temperature ranges are very wide in the lower valleys, where cold air settles in the winter but blistering heat prevails in summer. Higher in the mountains, daily and seasonal fluctuations are not as significant. Relatively mild winters and comfortable summers are part of what attracts people to the area from Canon City to Buena Vista.

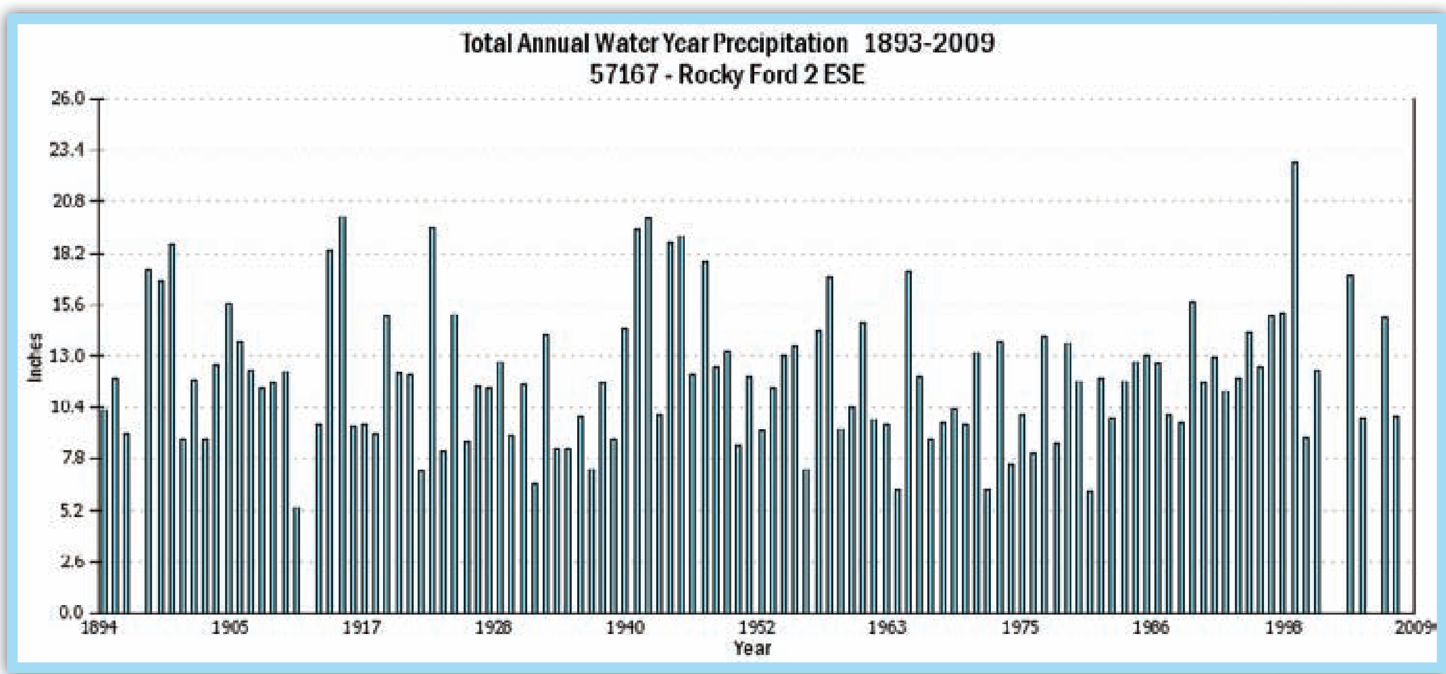
With frequent clear skies and low humidity, large day-night temperature changes are normal. It is common in the basin east from Pueblo to see 40-60° F fluctuations from sunrise to mid afternoon during fair weather. Sharp cold fronts moving down from the Canadian prairies can cause similar dramatic changes.





Precipitation

In the mid-latitudes, winds at and above mountaintop level typically blow from the southwest, west, or northwest, especially during the cool half of the year. This means that most of the Arkansas Basin is in the "snow shadow" on the east side of the southern Rocky Mountains, with winds warming and drying as they descend the eastern slopes. As a result, much of the basin is very dry, especially in the valley bottom from Pueblo eastward past La Junta to Las Animas. Fortunately, the high peaks of the Sangre de Cristo Mountains northward to beyond Mount Elbert near Independence Pass and Mt. Lincoln near Fremont Pass are



Arkansas Valley CoAgMet Station

able to harvest moisture from the wintertime jet stream that crosses the Pacific Ocean and rises up and over the Rockies. A few areas above 11,000 feet receive an annual average of 30-40 inches of precipitation. These areas, most of which lie in a strip only about five miles wide along the top rim of the basin, are responsible for the bulk of the runoff that ends up in the Arkansas River.

Winds slow down as the seasons shift towards summer. Pacific moisture is no longer the dominant source for atmospheric water, and the Gulf of Mexico begins to play a larger role.

Seasonal Precipitation Patterns

During the winter, periodic storms moving with the jet stream bring moisture from the Pacific and drop substantial precipitation in the high mountains. At the same time, the eastern plains and lower valley get very little moisture. During the spring months, precipitation at lower elevations often increases as storms slow down and occasionally pull moisture from the Gulf of Mexico into Colorado from the southeast. Early summer tends to be dry in the mountains, followed by an increase in daily thunderstorm activity in July and August. Light winds during summer and occasional pulses of subtropical moisture from the south result in a monsoon-like circulation, which produces a late summer wet season for much of the basin. The wettest areas in late summer are the Pikes Peak area, the Wet Mountains, and the Sangre de Cristo Mountains.

In areas of the lower basin east of Lamar, only about 10-15% of annual precipitation falls in the form of snow, while in the mountains 50-75% of the annual average precipitation falls as snow.

An interesting aspect of precipitation that sets the Arkansas Basin apart from other parts of Colorado is that rain and snow fall less frequently there than in other parts of Colorado. However, when it does rain, it tends to rain harder than in other parts of the state. This is especially true in extreme southeastern Colorado, due to its relative proximity to moisture from the Gulf of Mexico.

Variability and Extremes

While it is instructive to know climatic averages and seasonal patterns, the reality is that no two years are ever alike. Of all the basic components of our climate, precipitation is especially variable, ranging from less than half the long-term average in very dry years to as much as double the average in very wet years. Drought periods seem to occur every few years in southeastern Colorado; the 1930s are especially memorable for extreme drought over eastern Colorado. The wettest decade on record for southeastern Colorado was the 1990s and included the blizzard of October 1997 and the floods of late April 1999. And within a few short years, we were back to drought again in 2002, which was one of the driest years in recorded history. A few years later, the snow blitz of December-January 2006-07 left Prowers and Baca Counties in extreme southeastern Colorado covered in snow for three months, surpassing the snow depth in many high mountain valleys that winter.

Help Us Measure Rain and Snow

Over 120 years of tracking climatic conditions over southeastern Colorado have made it very obvious that precipitation varies dramatically from place to place and from year to year.

Official weather stations are too few and too far apart to capture the variability and extremes in precipitation. But you can help.

The Community Collaborative Rain, Hail and Snow network (CoCoRaHS) is a low-tech, low-cost way to gather precipitation data. The program originated at Colorado State University in 1998 as a result of a localized but devastating flash flood that struck Fort Collins in 1997. Since then, we have encouraged as many people as possible to join CoCoRaHS and help track precipitation patterns in Colorado. Here is how you can help:

- Register as a volunteer for CoCoRaHS (go to http://www.cocorahs.org and click “Join CoCoRaHS”).
- Place a rain gauge in a good location in your yard.
- Report your measurements on the CoCoRaHS web site.

The result is an exceptional climate data resource for tracking drought, floods, and everything in between. Please sign up today.

Temperatures in the Arkansas River Basin have reached over 110° F during extreme heat waves and have dipped below -30° F during extreme cold waves. Windstorms blackened the skies with dust clouds in the 1930s, the 1950s, and even more recently. Despite the dominant dryness, extreme floods have also occurred. Over a foot of rain poured down in a matter of hours near Penrose in early June 1921, east of Colorado Springs in May 1935, in several places during the flood blitz of 1965, and east of Trinidad in July 1981. Heat waves, extreme drought, giant hail stones more than four inches in diameter, tornadoes, blizzards, cold waves, and floods are all a part of the climate that have occurred in the past and will return again in the future.

Climate Data: A Rich History

Much of what we know about the climate of the Arkansas River Basin we owe to previous generations who helped establish and maintain weather stations in the Valley. The Arkansas River Basin has more long-term weather stations than any other area of Colorado. Weather stations were set up at Fort Lyon, Pueblo, and on top of Pikes Peak in the early 1870s. Subsequently, weather stations were established at Holly, Lamar, Las Animas, Rocky Ford, Canon City, Trinidad, Leadville, and elsewhere in the basin as early as the 1880s. Many of these stations still operate today as a part of the National Weather Service's Cooperative Weather Observing network. Because of this wealth of data and the commitment to long-term monitoring, we are now able to look back to see how variable our climate has been over the past 120 years.

CoAgMet (Colorado Agricultural Meteorological Network)

Irrigated agriculture has been a way of life for several generations in the Arkansas Valley. To serve the specific weather information needs of agriculture, Colorado State University, in collaboration with the USDA and other interested groups, established the Colorado Agricultural Meteorological Network (CoAgMet) in the early 1990s. This network of automated weather stations measures and reports temperature, humidity, wind speed, wind direction, solar energy, precipitation, and soil temperatures on an hourly basis. Data are compiled and available from a database and web site maintained at CSU. The network began with three stations in the 1990s and has expanded to a dozen stations in the Arkansas River Valley downstream from Pueblo. In recent years emphasis has been on collecting top quality data to help monitor evapotranspiration from irrigated cropland. This effort compliments the new large and small lysimeters at the Arkansas Valley Research Center at Rocky Ford.

To access current or historic CoAgMet data, visit the Colorado Climate Center online at http://ccc.atmos.colostate.edu and select "CoAgMet" from the list of resources.

Fountain Creek and CSU-Pueblo: An Important Partnership for Studying Water Quality in the Arkansas River Basin

by Del Nimmo, Scott Herrmann, Jim Carsella, Chad Kinney, Dave Lehmpuhl, and Brian Vanden Heuvel; Colorado State University-Pueblo

and Perry Cabot, Extension Water Resources Specialist; Colorado State University Extension

Introduction

The Fountain Creek sub-basin of the Arkansas River watershed links the cities of Colorado Springs and Pueblo, which together comprise approximately 12% of the state population (Figure 1). Population growth in Colorado Springs and the surrounding region has altered the hydrologic regimes and water quality of several reaches throughout the Fountain Creek watershed. These effects are poised to escalate as urban development progressively adds more impervious surfaces to the watershed each year. Fountain Creek and Monument Creek also have reaches listed as being "water quality impaired" by the Colorado Department of Public Health and Environment (CDPHE) 303(d) List for *E. coli* and selenium (Se) (Figure 2). Several segments contain pollutants of concern including organic compounds and heavy metals, attached to the high levels of suspended sediments in the creek.

Growth in the Fountain Creek sub-basin has also prompted greater demands for water and spurred plans for the Southern Delivery System (SDS) project. The simplicity of this project's name understates its technical enormity, not to mention the political sensitivity hovering over it at every turn. The SDS will deliver water to Colorado Springs, Security, Fountain, and Pueblo West. The project will bring about 78 million gallons per day (mgd) from the Arkansas River and return most of it through Fountain Creek, in effect altering its "baseflow" and subjecting the creek to increased wastewater discharges. These and other water quality issues have focused the eyes of many Arkansas Basin stakeholders on Fountain Creek.

In March 2006, then-Senator Ken Salazar (D-CO) initiated a dialogue on restoring Fountain Creek. Wastewater spills, sedimentation, loss of wetlands, flash floods, stream bank destabilization, and high concentrations of *E. coli*, selenium, and phosphorus topped the list of "festering problems." Noting the successes of other watershed restoration projects in Colorado, Salazar offered a *21st Century Vision for the Fountain Creek Corridor*, aimed at developing it into a "Crown Jewel" for the region. "Success of the Crown Jewel Project," as stated in the Vision Statement, "lies in the entire region's willingness to fix problems associated with Fountain Creek and all of its tributaries and their commitment to restoring the watershed and its habitat to as natural a state as possible." This commitment has been acted upon with sincerity and dedication, evidenced by the recent formation of the Fountain Creek Watershed District, a consortium of local governments and organizations working collectively on enhancing the creek for public benefit and the natural environment.

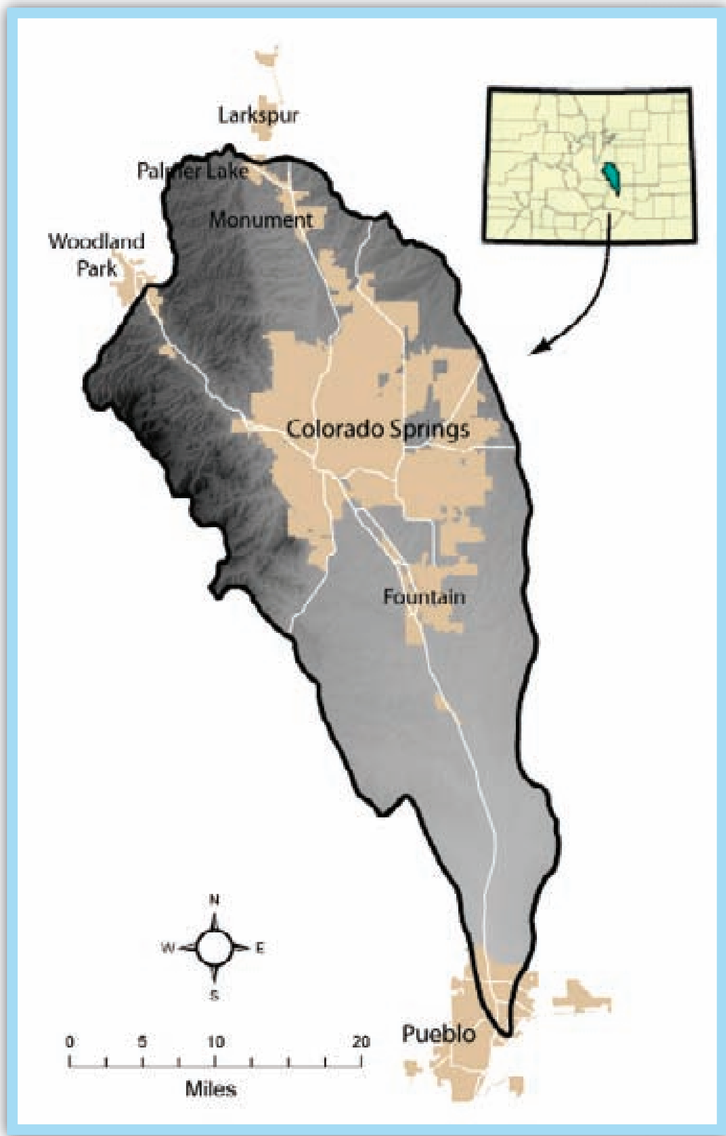


Figure 1. The Fountain Creek sub-basin comprises much of Colorado Springs, Fountain, and Pueblo.

CSU-Pueblo Involvement

Beginning in late 2005, the Lower Arkansas Valley Water Conservancy District (LAVWCD) and Colorado State University-Pueblo (CSU-Pueblo) began discussing the need for a "different type" of water quality study on Fountain Creek. Whereas past studies had focused mostly on hydrologic conditions and sedimentation, a new focus on the current and future biological conditions in the stream was necessary. The LAVWCD has made the restoration of Fountain Creek one of its priority issues, in part because upstream activities ultimately affect the quality of water available in their district. Furthermore, the LAVWCD understood the need to evaluate the biological conditions of the creek—in other words, its "aquatic health"—in order to restore it and plan for future sustainability.

Questions by the CSU-Pueblo team complemented the LAVWCD goals. For instance, the team wanted to know if it was possible for the water quality in the stream system to support biological communities, provided that other physical factors were mitigated. Also, CSU-Pueblo wanted to include in their study the under-examined upper segments of the upper Fountain Creek in Chipita Park and the lower Fountain Creek (in El Paso and Pueblo Counties) to its confluence with the Arkansas River. Future plans will involve a study on the Arkansas River from the Pueblo Dam to the John Martin Reservoir.

Early funding for the project was acquired in November 2006, with matching grants of $100,000 from the LAVWCD and $50,000 from CSU-Pueblo to purchase an inductively-coupled plasma mass spectrometer (ICP-MS). Following two supplemental grants for supplies and staff from the LAVWCD, the research began in spring 2007. Subsequent support in 2008 and 2009 has been received from the LAVWCD with additional support from the City of Pueblo, the Pueblo Board of Water Works, and Pueblo County Commissioners.

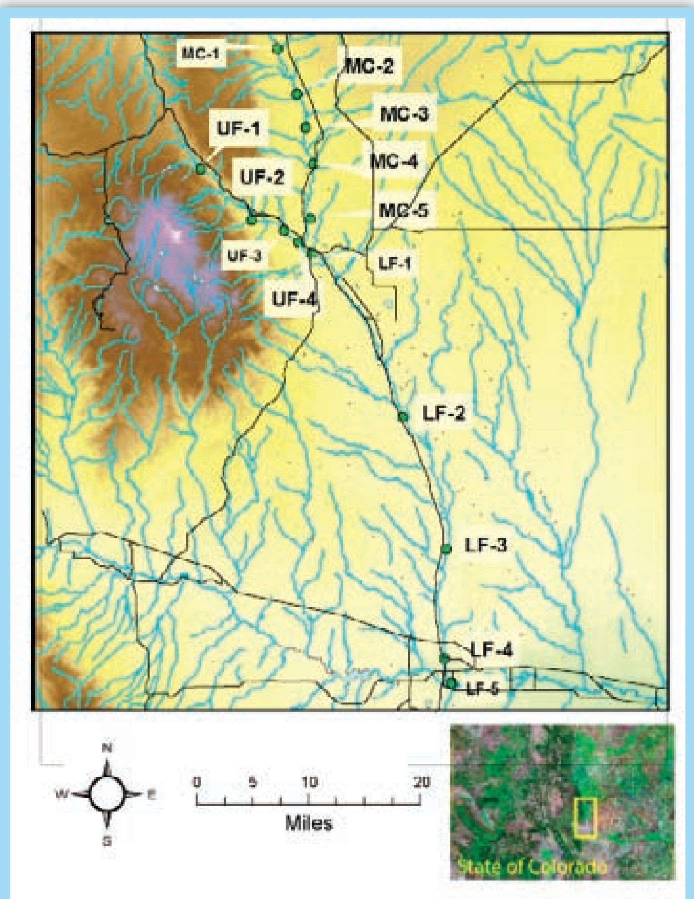


Figure 3. Map of site locations in study area: Upper Fountain Creek (UF-1-4), Lower Fountain Creek (LF-1-5), and Monument Creek (MC-1-5). The figure in the lower right is a satellite view of the state of Colorado with the study area outlined by the rectangle.

Figure 2. This map shows Fountain Creek segments that are registered on the 303(d) list for E. coli and selenium (USDA, 2007).

Five sub-projects were identified for the study:

1. Chemical characterizations of water, fish tissue, and sediment
2. Microbial source tracking and enumeration of *E. coli*
3. Addressing the bioavailability of toxic elements using aquatic bryophytes (moss-like aquatic plants) as "bioaccumulators"
4. Documentation of metal and organic compound toxicity using microcrustaceans and fish as indicators
5. Assessment and verification of Fountain Creek "stream-quality changes" by analyzing chironomid (midge) community structure.

Recently, a sixth initiative has focused on organic compounds found in fish tissues, such as pharmaceuticals and industrial and agricultural chemicals.

Results and Future Plans

Monitoring sites have been established for regular sampling throughout the entire sub-basin (Figure 3). One of the unexpected results of the research on Fountain Creek is the ability of bryophytes to sequester elements from the water to a sufficient level for measurement by ICP-MS. These plants behave as natural "bioconcentrators" of metals or metalloids, signaling where further research and targeted study may be needed at sites in Fountain Creek and the Arkansas River. Early results show site and seasonal differences in selenium availability using the bryophytes at various places in the watershed (Figure 4).

In addition, 27 *E. coli* contamination sites have been sampled. Source tracking analysis involving the use of Bacteroidales-based polymerase chain reaction (PCR) markers for fecal contamination (human, cow, horse, pig, and dog) has also been conducted. The agarose gel slide depicts a specific DNA "fingerprint" that is unique to dogs, and can be distinguished from other animals, including humans.

In March and June of 2008, two synoptic (i.e., comprehensive) sampling excursions of these same 27 sites were done by eight separate teams of faculty and students. These synoptic samples provided a "snapshot of concentrations" of *E. coli*, metals, metalloids, and water characteristics (e.g., hardness, alkalinity, and pH), all within the entire watershed within one hour. A plot of these results from upper to lower Fountain Creek shows the change in *E. coli* and phosphorus concentrations through the stream system as flows move through the city of Colorado Springs (Figure 5).

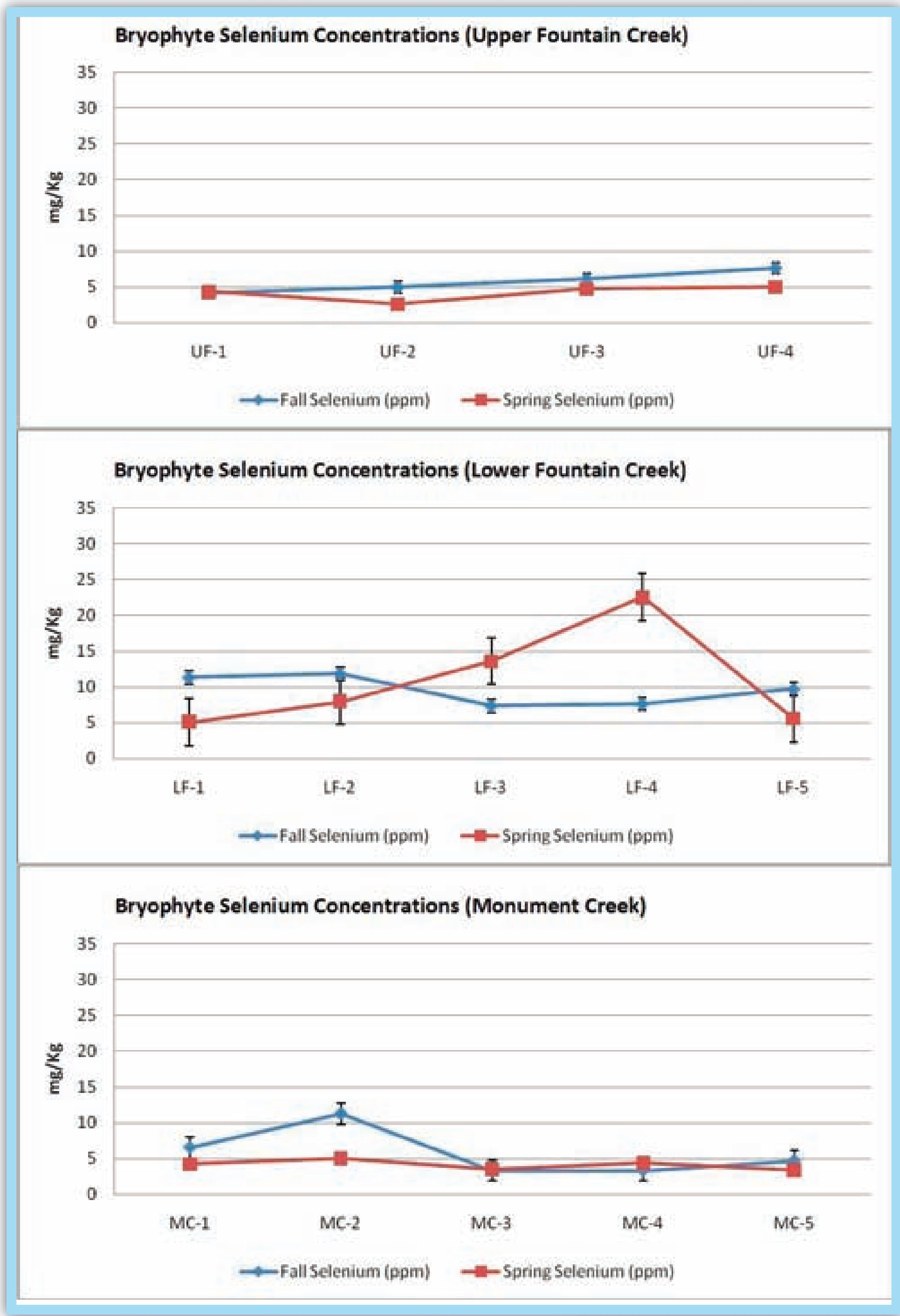


Figure 4. Bryophyte tissue concentrations of selenium in plants, exposed in situ for 10 days, in Upper Fountain Creek (UF), Lower Fountain Creek (LF), and Monument Creek (MC) Colorado.

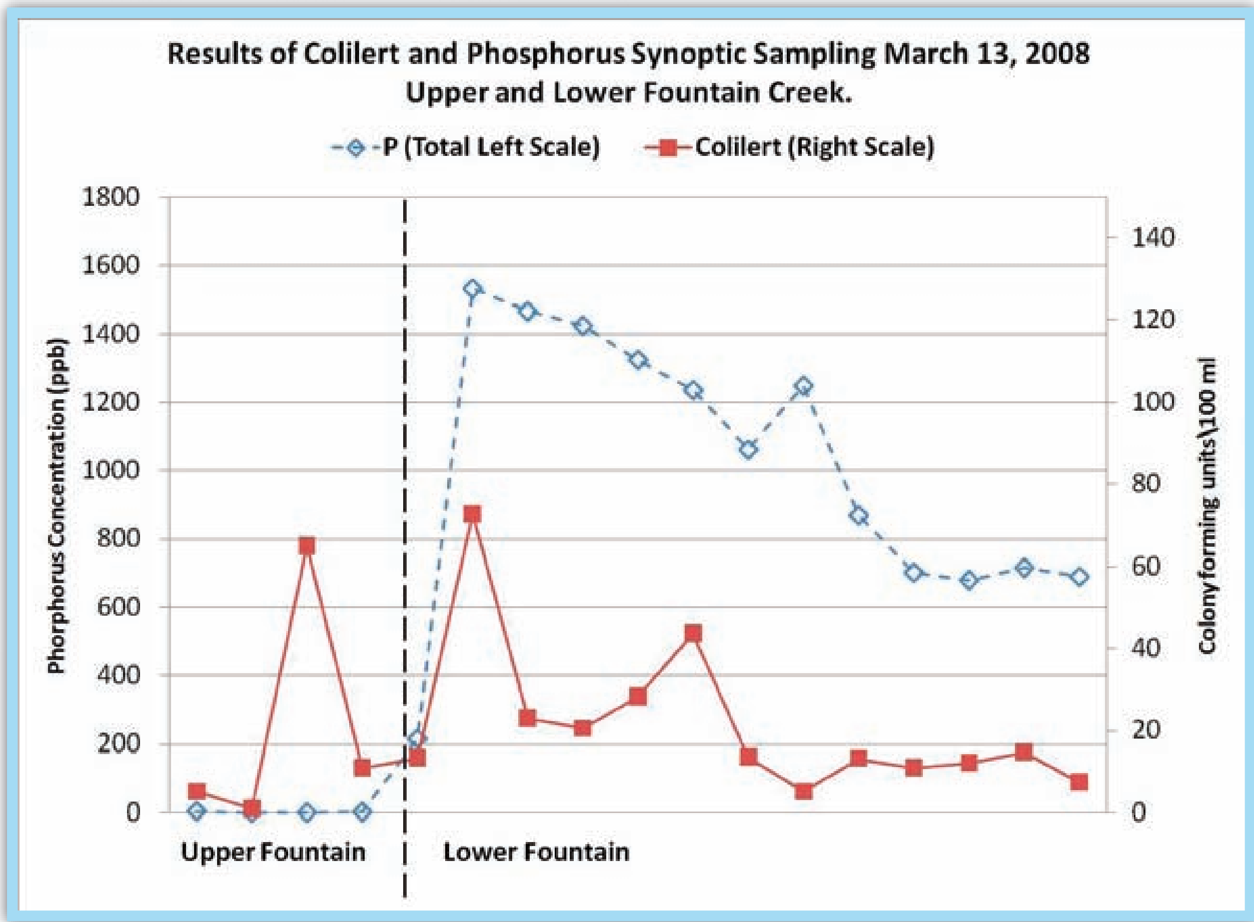


Figure 5. Results of colilert (E. coli) and phosphorus synoptic sampling (March 13, 2008) in Upper and Lower Fountain Creek.

Given the project focus on ecosystem health and water quality, the study applies the theory of "biomonitors," whereby living species or assemblages of organisms provide information on the conditions of water and sediment and the biotic communities found in them. In effect, they are all linked. A separate study using bryophytes and macro-invertebrate assemblages, which resulted in the detection of metals coming from a historic mining operation below Manitou Springs called Gold Hill, was completed in December 2007. The question about metal-contamination from the mine site dealt with food-chain biomagnifications of zinc, selenium, and copper in the upper Fountain Creek. Beginning in summer 2008, we began monitoring Fountain Creek water and sediment for a select group of organic contaminants commonly associated with anthropogenic activities. We also anticipate starting a series of field and laboratory studies that involve the measurements of organic contaminants accumulated by biota exposed to Fountain Creek water or sediment. The enumeration and identification of adult chironomids (midges) collected in 2007 has been completed, and the 2008 collection has been processed for identification. These activities are integral components of student projects at CSU-Pueblo.

Future plans are to broaden CSU-Pueblo's research efforts to include additional projects in the Arkansas River Valley, particularly the segment from Pueblo Reservoir downstream to the Kansas state line. Public interest in our research capabilities and team of investigators has prompted the need for a recognized research entity at CSU-Pueblo. Currently, we informally use the designation Aquatic Research Center (ARC), and plan to formalize this campus unit in the future. The ARC will include faculty, technical staff, and graduate students who will focus on research projects leading to master's degrees in the Departments of Chemistry and Biology.

The Arkansas Valley Research Center: A Brief History

Adapted from *A History of the Department of Agronomy/Soil & Crop Sciences*; Wayne F. Keim, Editor; Colorado State University; December 2004.

When the original Bent County was subdivided into several counties, the name of the new research center was changed to the Arkansas Valley Agricultural Experiment Station, which was located near Rocky Ford. It is the oldest continuously operated agricultural experiment station in Colorado, outside of Fort Collins, and was established to serve the research needs of the irrigated farming area of the Arkansas Valley in southeast Colorado, extending from Pueblo County on the west to the Kansas border. It also includes irrigated areas associated with the tributaries to the Arkansas River in El Paso, Huerfano, and Las Animas Counties. The history of the Arkansas Valley Station's first four years was poignantly described in a handwritten report by F. L. Watrous, the Station's first superintendent, in 1892. The following is a summary of that report:

In June 1888, the Arkansas Valley Agricultural Experiment Station was located at its present site after the State Board of Agriculture decided that Rocky Ford offered a good representative location for the territory on all sides. The site had previously been state land held under a five-year lease by G.W. Swink, who very generously donated his lease and, along with other stockholders, provided water from the Rocky Ford ditch for irrigation. Thus, the Station acquired 200 acres of level, fertile land situated near the Atchison, Topeka and Santa Fe Railway line.

The farm on the property comprised a 160-acre tract, partly fenced but unplowed, and a 40-acre tract cultivated for the first time in 1888 by a Belgian family that had sub-leased it from Swink. The land on the 40 acres had been poorly cultivated and irrigated, leaving many deep ruts and a rough, uneven surface.

On September 10, 1888, the Station was placed in charge of F.L. Watrous of Fort Collins, who arrived in Rocky Ford on September 15 and on the following day surveyed the Station's grounds and surroundings. During the next week sites were selected for buildings, and construction of the Station house was contracted to local architects with the stipulation that the superintendent would be allotted $2.50 per day for work on the buildings, and the same amount would be deducted from the contract price. During the fall of 1888, new fences were built, old ones were repaired, and the vigorous growth of sunflowers along ditch banks was destroyed. In the winter, a 10 x 50-foot shed was built to serve as a stable and tool storage facility.

On about February 20, 1889, a Special Committee from the State Board of Agriculture visited Rocky Ford and authorized a series of experiments for the coming year. An orchard of 200 trees was set out that spring, as well as a nursery of 10,000 root grafts, 15 varieties of grapes, 200 shade trees, and a variety of shrubs and garden plants. Nearly all crops were successful the first year, and the Board commended the Station for its work.

During 1889, the 160-acre tract was rented to several individuals who were given all they could produce from the land as payment for breaking the sod. This necessitated the building of a fence along the west side of the tract, and the field was leased to several parties who received two-thirds of the crop, deriving a substantial income.

The 1890 season was a satisfactory one, as the Station adopted a system of half-acre plots of various crops. A careful record of expenses and net profit/loss for each crop was kept, and the Board and visitors commended the Station for the practical benefit the half-acre plots offered the local region.

In the spring of 1891, a new orchard was set from Station-grown trees, and about 7,000 trees were sold in various areas of the state. These trees were mostly hardy varieties of apple and pear and were sold at seven cents each, the low price being an incentive to farmers to make a start in fruit culture. The 160-acre tract was farmed by the Station, with 55 acres being seeded to alfalfa and the balance in wheat, oats, and corn.

The highlight of the 1891 season was the successful results attained with Irish potato experiments. Potatoes were produced at the rate of 252 bushels per acre and were equal in quality to the best potatoes produced in any section of the state—some of the tubers weighed up to two pounds. This success encouraged local farmers, because the experiment was a true verification of the results obtained the previous year.

In 1891, the farm generated a cash income of $424.76. A large addition to the orchard was set out in the spring of 1892, consisting of a variety of plum, peach, cherry, and apricot trees. These did not grow as well as the balance of the orchard; the trees were of inferior growth, and many never started to grow because they had been damaged in shipment.

The coldest weather in 1891 was 18 degrees below zero, with the last killing frost occurring on May 23. Only one severe hailstorm struck the Station during Watrous' tenure as superintendent, in April 1889, when hailstones "as large as

This June 1943 photo shows three unidentified men surveying a potato crop in the Arkansas Valley. (Image from University Historic Photograph Collection, Colorado State University Archives, Colorado State University).

walnuts came completely through the door glass, striking the floor with force and bounding against the wall."

In June 1892, Watrous was notified that the Board had selected him to serve as assistant to the Professor of Agriculture of the Agricultural College at Fort Collins. Although he deeply regretted leaving the place whose growth he had watched since its reclamation from the desert, and the good friends and acquaintances he and his wife had made there, he accepted the position in Fort Collins, and the Station was turned over to his successor.

By the early 1900s, the Arkansas Valley Station had placed special emphasis on fruit trees, sugar beets, and cantaloupes. A number of orchards were established in the area, and two beet sugar factories were built in 1900. The cantaloupe industry was recognized nationally, and during the next three decades considerable research focused on cantaloupe diseases, alfalfa forage and seed production, and sugar beet production. In 1922, a soils laboratory was initiated to study the effect of soil nitrates on crop production.

Some people believed that high soil nitrates were adversely affecting alfalfa seed production and purity of sugar in beet production. When Robert Gardner joined the Agronomy Department faculty in 1929, he was assigned to the Rocky Ford Station to work on this "nitrate problem." Gardner thought it highly unlikely that the problem was one of excessive nitrate levels due to runaway microbial nitrogen fixation, as had been concluded from earlier research. Instead, he predicted that the problem was likely related to an excessive accumulation of soluble salts. After drainage canals were installed in the area and increased crop production was observed, Gardner concluded in 1931 that the problem indeed was primarily one of excessive soluble salts.

Breeding projects, cultural practices, and variety tests became the Center's research focus between 1930 and 1945, including work related to onions, tomatoes, sweet corn, soybeans, peas, spring and fall grains, hybrid corn and sorghums, small fruits, and alfalfa. Research on crop pest problems was also increased, and in 1961 Dr. Frank Schweissing was employed to work on insect problems in the Arkansas Valley.

In 1980, Schweissing assumed the duties of superintendent when Jerre Swink retired. When Swink announced his retirement, personnel from Fort Collins and others who frequented the Arkansas Valley Station for Field Days were concerned that Swink's wife, Midge, would take her scrumptious cinnamon roll recipe with her. Fortunately, Joyce Schweissing (Frank's wife) had quite a delectable recipe of her own, so the tradition of gooey cinnamon rolls was maintained.

Following Watrous, the following men supervised the operation of the Arkansas Valley Research Center: Fred Huntley, Philo Blinn, Frank Crowley, Harvey Griffin, Justus Ward, Herman Fauber, Jerre Swink, Frank Schweissing, and Michael Bartolo. Blinn, Fauber, Swink, and Schweissing provided leadership for almost 100 years of the Center's existence.

Since 1993, research emphasis has turned to production efficiency and environmental protection, as evidenced by projects on tillage practices, fertilizers, irrigation, and pest management. In 2004, work began on the installation of two weighing lysimeters to study crop water use. Currently, Michael E. Bartolo from the Department of Horticulture and Landscape Architecture serves as the Center's manager and senior research scientist and Kevin Tanabe and Lane Simmons serve as research associates.

Limited Irrigation Research at the Plainsman Research Center

by Kevin Larson, Dennis Thompson, Deborah Harn
Plainsman Research Center

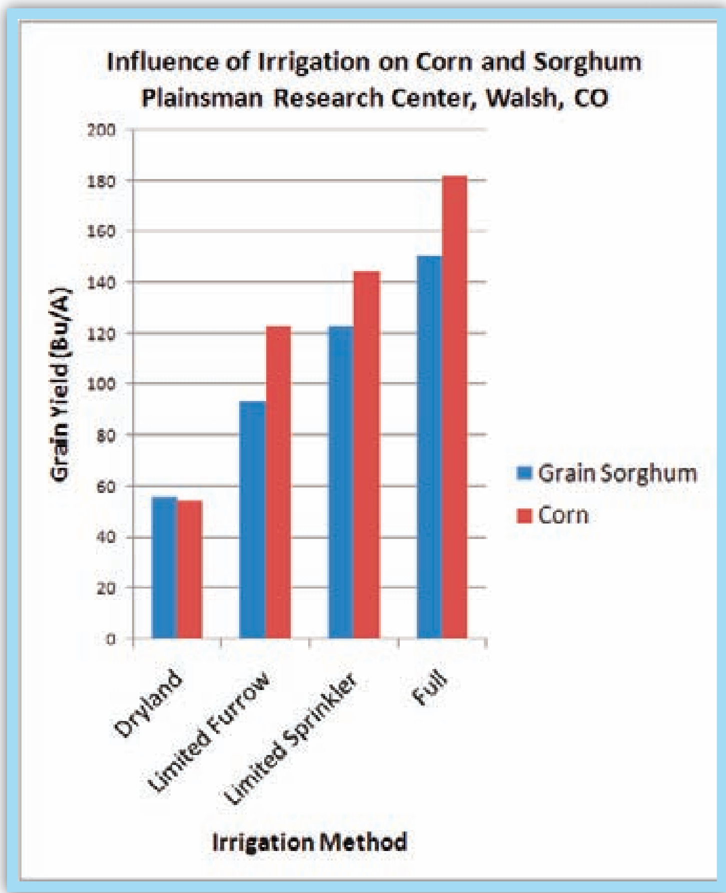
The Plainsman Research Center is located in the irrigation area known as the Southern High Plains Groundwater District in extreme southeastern Colorado. Since its establishment at Walsh, Colorado, in 1974, the Center has focused its research on limited irrigation and low input crop production. All irrigation in the District is from well pumping. Well drilling in the District began in the early 1950s and continued into the early 1970s. The capacity of these early wells varied greatly; however, many were large-capacity wells suitable for full irrigation crop production.

Initially, irrigated sugar beet production was the mainstay of these irrigated farms, but with the collapse of the area's sugar industry, sugar beet production was replaced by irrigated corn production, another high water use crop. Huge volumes of water were pumped to irrigate these high water use crops, which far exceeded the recharge of most of the area's aquifers. Over the years, these high water extraction rates caused water tables to drop and reduced the capacity of most wells in the area. The Plainsman Research Center was established when many wells in the District were experiencing diminished capacities.

During Plainsman's formative years, limited irrigation research performed by the Center's first agronomist, Edward Langin, and its first superintendent, Herbert Mann, found that irrigations timed at corn silking and grain sorghum flowering resulted in highest yields. Since Langin and Mann's and initial report, numerous limited irrigation studies have been conducted at the Center concerning irrigation timing of corn and grain sorghum, all of which have confirmed their findings.

The current research staff at the Plainsman Research Center also found that limited irrigated seeding rates of corn and grain sorghum were dependent on the type of water delivery system used. Low seeding rates, closer to dryland rates, produced higher yields with limited furrow irrigation, and high seeding rates, similar to full irrigation rates, produced higher yields with limited sprinkler irrigation.

Limited irrigation produced lower yields than full irrigation (Figure1). Since yields were reduced with limited irrigation, we found that yield goals and inputs needed to be lowered to obtain maximum return from limited irrigation. Reduced inputs, such as water, fertilizer, and seed, often produced higher variable net incomes compared to full irrigation and full inputs. We have studied various row crops (corn, grain sorghum, and sunflower) and various water delivery systems (furrow, surge irrigation, sprinkler, LEPA sprinkler, and subsurface drip) under limited and full irrigation and found that net returns were dependent on commodity prices and input costs. We discovered that limited irrigation and reduced inputs provided higher net incomes when commodity prices were low and input costs were high. With the reversed economic climate of high-commodity prices and low input costs, full irrigation and increased inputs produced higher net returns.



This graph illustrates the influence of irrigation on corn and grain sorghum yields. Yields are average yields at Plainsman Research Center at Walsh, Colorado. Limited furrow and sprinkler irrigation regimes averaged 9 a-in./a of irrigation, and full sprinkler irrigation averaged 17 a-in./a of irrigation.

Throughout the years, we have studied a progression of irrigation systems, including furrow irrigation, surge irrigation, sprinkler irrigation, LEPA sprinkler irrigation, and subsurface drip irrigation. With each water delivery advancement, we realized higher water efficiency. Higher water efficiency gains produced either more yield with the same amount of applied water, the same yield with less water, or the same yield but with increased production area. Equipment and installation costs increased with each system. Because of the increased water and labor savings, area growers rapidly converted from furrow irrigation to sprinkler irrigation, despite the high capital costs. Subsurface drip irrigation has the highest water efficiency of the systems we studied; however, we found that system and installation costs were too high to justify production of the current row crops grown in our area. Unlike the conversion from furrow irrigation to sprinkler irrigation, few irrigated growers have installed subsurface drip systems. However, with the potential introduction of higher value crops to our area, subsurface drip irrigation may gain momentum.

Recently, we have studied limited irrigated cotton as an alternative, high-value crop for extreme southeastern Colorado. Thus far, our irrigation efforts have not increased lint yields enough to justify the irrigation expense. We found that irrigation increased plant growth, but only marginally increased lint yields. For future limited irrigated cotton studies, we plan to apply well-timed, hormonal applications that may reduce excessive plant growth and produce higher irrigated lint yields.

Although the limited irrigation research conducted at the Plainsman Research Center focused on diminishing well capacities in the Southern High Plains Groundwater District, we believe it is applicable to the other areas experiencing reduced availability of irrigation water.

34th Annual Colorado Water Workshop
July 22–24, 2009

Theme and Keynote

On July 22-24, 2009, the Colorado Water Workshop will investigate non-consumptive water use in Colorado and the American West. The proceedings will offer a wide range of speakers, including well known biologists, ecologists, attorneys, elected officials, non-profit organizations, engineers, planners, historians, and interested members of the public. Drawing on their passion and expertise, we will address topics as diverse as climate change, the economic value of non-consumptive use, invasive plant and animal species, the law of the river, the ski industry, the right to float (or not), and many others. We are fortunate to have the current Superintendent of Grand Canyon National Park, Steve Martin, as our keynote speaker. Few people in the West have more knowledge of the challenges of balancing water use demands between consumptive and non-consumptive uses.

Venue and Lodging

This year we will be moving "up valley" to the Mountaineer Square Lodge in Mt. Crested Butte. Not only does this venue offer fine dining and plush accommodations, it also boasts ample conference and exhibitor space. We have negotiated a reduced room rate ($109 base rate) with Crested Butte Mountain Resort for a limited number of rooms. To reserve your room call 1-888-443-6715 and tell them you are with the Colorado Water Workshop. Reduced rate rooms are on a first call, first serve basis.

Additional Events

We have partnered with the Crested Butte Policy Forum, which has invited Colorado Supreme Court Justice Hobbs to offer the keynote address on the evening of July 22. We have also included an optional field trip to the Roaring Judy Fish Hatchery for the morning of July 23, and live music to coincide with our Banquet on July 23. For more information, registration forms, and exhibitor forms, visit www.western.edu/water.

The Arkansas Basin Roundtable and Colorado State University

by Perry Cabot, Extension Water Resources Specialist
Jeff Tranel, Extension Agricultural and Business Management Specialist

Extension

A "New Rationality" about Water

If John Wesley Powell, the great soldier-explorer of the West, were alive in Colorado today, one has to speculate that the concept of "Basin Roundtables" would meet with his approval. In his time, Powell argued that the political boundaries of the arid West should be adjusted to the contours of the landscape. In his book R*ivers of Empire: Water, Aridity and the Growth of the American West*, Donald Worster (1985) summarizes Powell's thinking:

> *It was, in a sense, a strategy of ecological adaptation he was proposing. The watershed gives shape to the technology that conquers it, and the efficient functioning of that technology requires a society organized along watershed lines, so that the jurisdiction of laws and courts and community planning are coextensive with the resource base. An eminently scientific, modern approach, one Americans had never tried before—had never felt the need to try. In the West, Powell was saying, the scarcity of water imposes on us, if we are to make the most of the place, a new rationality.*

Although this "new rationality" was never adopted as a model for state boundaries, the abundance of irrigation and water conservancy districts throughout the West affirms the core merits of Powell's ideas. Remnants of the idea also exist in the *Colorado Water for the 21st Century Act* (HB 05-1177), which established an institutional framework for water management between and within the state's major river basins. This act established the Interbasin Compact Committee (IBCC), a central state-wide entity charged with addressing issues that link one or more basins. It also set up nine Basin Roundtables (including a "Metro Roundtable" for the Denver area), tasking them with developing basin-wide water needs assessments.

Arkansas Basin Roundtable

Home to two large cities, Colorado Springs and Pueblo, and an important agricultural population, the Arkansas Basin Roundtable has a sizeable membership. With over 50 voting members, it is a true reflection of the intensity and diversity of water use within the basin. Its large membership reflects the stakeholder interests you would expect in a basin where regional economies supported by agriculture, recreation, urban growth, and industrial development are competing for water. Because the Arkansas Basin is both an importer and exporter of water, roundtable-style cooperation and interbasin communication are especially important.

Water demand in the Arkansas is projected to increase by 98,000 acre-feet (AF) in municipal and industrial (M&I) and self-supplied industrial (SSI) uses by 2030. Among the state's basins, this is the second largest increase. Gross water demand (e.g., total amount of water delivered to users) forecasts for the Arkansas Basin are summarized in the table below. The majority of the demand is expected to be met through existing supplies and water rights, and through the implementation of various projects and processes. However, even with Level 1 Conservation (updated plumbing codes, ordinances, and standards) an 18% shortfall—also known as "the Gap"—is still anticipated in the basin.

The Colorado General Assembly passed SB 06-179 and established the Water Supply Reserve Account (WSRA), which provides funding for grants and loans to help the Basin Roundtables act on their needs assessments.

Sub-Basin Designation	2000 Gross Demand (AF)	Projected 2030 Gross Demand (AF)	Projected Conservation Savings (AF)	Increase in Gross Demand (AF)	Identified Gross Demand Shortfall (AF)
Upper Arkansas	22,700	36,400	2,400	13,700	6,600
Urban Counties	212,900	292,800	14,500	79,900	8,000
Lower Arkansas	12,200	13,000	900	800	800
Eastern Plains	4,300	5,500	300	1,200	1,200
Southwestern Arkansas	4,800	7,200	500	2,400	500
TOTAL	**256,900**	**354,900**	**18,600**	**98,000**	**17,100**

Table 1. Demand Projections and "Gap" Analysis from the Statewide Water Supply Initiative (SWSI)

Colorado State University Involvement

Colorado State University (CSU) is involved in the Arkansas Basin Roundtable by virtue of the Public Education, Participation, and Outreach (PEPO) mandate written into the *Colorado Water for the 21st Century Act* legislation. Each basin roundtable is charged with developing a PEPO Workgroup to inform the public regarding the Interbasin Compact Committee's activities and to develop the means for public feedback to the Committee. CSU Extension played an early role in the organization of the roundtable by hosting a basin-wide town hall meeting to provide opportunities for public inquiry about the purpose of roundtables, funding for water projects, and agriculture-to-urban water transfers.

CSU faculty have played an advisory role at the roundtable on the issue of water leasing arrangements. Several faculty members, including Tim Gates, James Pritchett, and John Wilkens-Wells, have helped roundtable members conceptualize scenarios that would allow water transfers to benefit both the leasers and lessees.

Extension now participates in the educational mission by sending an education liaison to the PEPO Workgroup of the IBCC. Recent efforts by the PEPO Workgroup involved conducting a roundtable survey to determine the primary needs required by the roundtable members to fulfill their educational goals. In doing so, Extension draws on the resources of the Colorado Water Institute.

In summary, the goals of the Arkansas Basin Roundtable are to address "the Gap" while maintaining agricultural viability in the lower basin, providing for in-basin augmentation in the upper basin, and ensuring adequate water quality. The Arkansas Basin Roundtable has proven its ability to work collaboratively in establishing the groundwork for the Roundtable process. Many challenges lay ahead for the members of the Arkansas Basin Roundtable, but a successful framework has been built to tackle the serious water resource issues coming around the bend.

USGS science for a changing world

Recent Publications

Biosolids, Crop, and Groundwater Data for Biosolids-Application Area Near Deer Trail, Colorado, 2004 Through 2006 by T.J.B. Yager, D.B. Smith, and J.G. Crock; http://pubs.usgs.gov/ds/379/

Changes in Water Levels and Storage in the High Plains Aquifer, Predevelopment to 2007 by V.L. McGuire; http://pubs.usgs.gov/fs/2009/3005/

Estimated Colorado Golf Course Irrigation Water Use, 2005 by T. Ivahnenko; http://pubs.usgs.gov/of/2008/1267/

Intertonguing of the Lower Part of the Uinta Formation with the Upper Part of the Green River Formation in the Piceance Creek Basin During the Late Stages of Lake Uinta by J.R. Donnell; http://pubs.usgs.gov/sir/2008/5237/

Review of Available Water-Quality Data for the Southern Colorado Plateau Network and Characterization of Water Quality in Five Selected Park Units in Arizona, Colorado, New Mexico, and Utah, 1925 to 2004 by J.B. Brown; http://pubs.usgs.gov/sir/2008/5130/

Rocky Mountain Snowpack Physical and Chemical Data for Selected Sites, 1993-2008 by G.P. Ingersoll, M.A. Mast, D.H. Campbell, D.W. Clow, L. Nanus, and J.T. Turk; http://pubs.usgs.gov/ds/369/

User Guide for HUFPrint, A Tabulation and Visualization Utility for the Hydrogeologic-Unit Flow (HUF) Package of MODFLOW by E.R. Banta and A.M. Provost; http://pubs.usgs.gov/tm/06A27/

Geology and Ore Deposits of the Uncompahgre (Ouray) Mining District, Southwestern Colorado by W.S. Burbank and R.G. Luedke; http://pubs.er.usgs.gov/usgspubs/pp/pp1753/

Meteorological Data near Rabbit Ears Pass, Colorado, U.S.A., 1984-2008 by D.R. Halm, L.D. Beaver, G.H. Leavesley, and M.M. Reddy; http://pubs.usgs.gov/ds/415/

U.S. Geological Survey Colorado Water Science Center: http://co.water.usgs.gov

Unique Perspectives on Arkansas River History

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

Diaries, letters, and even data sheets capture the unique perspectives of their creators. These primary sources provide the raw materials of history. When they are made available through archives, all people have the opportunity to benefit from them.

The Water Resources Archive at Colorado State University collects and preserves such materials to document water resources development and use across the state. Three of the archive's most significant collections contain substantial documentation of the Arkansas River. Materials of Delph E. Carpenter and James L. Ogilvie, as well as the Groundwater Data Collection, give first-hand perspectives on some important developments concerning the Arkansas River.

Papers of Delph E. Carpenter and Family

Colorado and Kansas agreed to the Arkansas River Compact in 1948. However, legislation moving the two states in this direction was enacted in 1921 in Colorado and in 1923 in Kansas. Commissioners, including Colorado's Delph Carpenter—known as the father of interstate river compacts—drafted a compact in 1924.

The early history of these meetings and the drafting of the compact are documented in the Papers of Delph E. Carpenter and Family. Approximately 500 pages of correspondence from 1921 to 1931 give details of the emerging ideas and the negotiations between the two states. Additional materials in the collection concerning the Arkansas River Compact include compact drafts, maps, reports, and court documents.

Papers of James L. Ogilvie

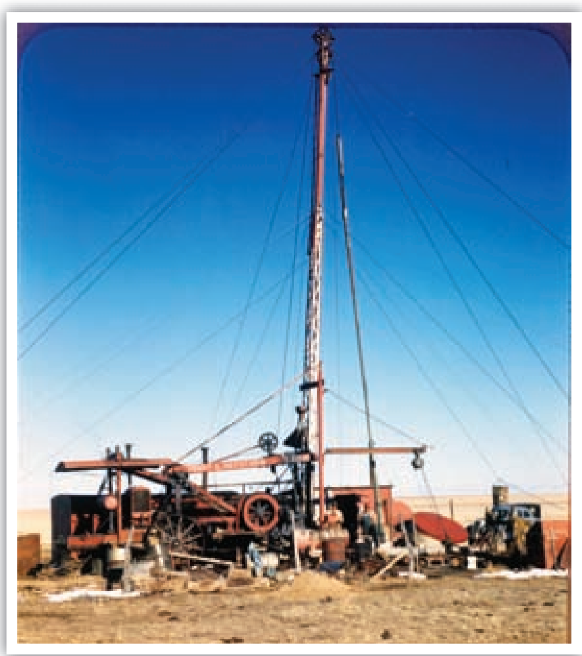
One of Colorado's most significant trans-mountain diversions, the Fryingpan-Arkansas Project, was authorized by the U.S. Congress in 1962. President Kennedy, expressing the federal government's support and announcing the start of construction, gave a short, stirring speech in Pueblo on August 16 that year. James Ogilvie, Bureau of Reclamation engineer and Fryingpan-Arkansas project manager, was there, and his description of the event included: "the Chief Executive speech was short and to the point. Enthusiastic crowds were evidenced...."

Ogilvie captured his perspective of this event and his work on the project in a series of daily diary entries. The set of these neatly typed diaries in the archive's Ogilvie Papers extends from 1957 through 1979, capturing additional work beyond the Fryingpan-Arkansas Project. In addition to his diaries, Ogilvie also saved reports, clippings, maps, and correspondence concerning the project.

Groundwater Data Collection

CSU engineers conducted a number of groundwater studies from the 1940s through the 1970s, mostly on Colorado's eastern plains. Documentation of these studies is compiled in the Groundwater Data Collection. One section of the collection is entirely devoted to the Arkansas Valley and primarily documents the La Junta-Las Animas study conducted at CSU in the 1960s, focusing in particular on groundwater/surface water interaction. The work is documented through reports, data, maps, charts, and drawings. Elsewhere in the collection are data sheets of observation wells, organized by county, as well as publications on the Arkansas Valley.

Additional collections in the Water Resources Archive document the Arkansas River Basin, but to a lesser extent. To keep unique perspectives on this important region from slipping away, the archive is interested in rescuing collections of historical importance. For more information about all of the collections in the Water Resources Archive, as well as how to donate materials, visit http://lib.colostate.edu/archives/water/ or contact the author (970-491-1939; Patricia.Rettig@ColoState.edu).



This March 1948 photo shows a well being drilled 10 miles south of Manzanola on Harriman-Arnold #3 place; rig of H.L. Bechtold, LaJunta. (Image from Groundwater Data Collection, Water Resources Archive, Colorado State University).

The 15th Annual Arkansas River Basin Water Forum (March 31-April 1, 2009)

by Perry Cabot, *Extension Water Resources Specialist, Colorado State University*

Every year, right around the time that the snowpack begins its slow surrender of water to the Arkansas River, Lake Pueblo, and finally the Southern Plains, the Arkansas River Basin Water Forum ("the Forum") commences. First held in 1995, the Forum was initiated to encourage dialogue among those with differing views on how the water of the Arkansas River should be managed.

About 170 stakeholders representing agricultural, municipal, commercial, industrial, and public interests attended this year's Forum, which was held at the CSU-Pueblo Occhiato University Center. The theme—*Water to Fuel our Future*—highlighted the important connection between water consumption and energy production in the Arkansas Basin.

Jennifer Gimbel, director of the Colorado Water Conservation Board, gave the Forum's keynote address, advancing a critical point. "When you are dealing with water, you are dealing with our future," Gimbel noted. "It's going to take choices, and it's going to take trade-offs." Indeed, as the Basin contends with demands for water to serve multiple and competing purposes, such "trade-offs" will require cool heads and compromising attitudes. More importantly, with the Colorado population expected to at least double by 2050, we must consider how to manage the river and its water under tighter constraints.

An ensuing panel discussion on the "Energy-Water Nexus" underscored this urgency. The Forum heard several perspectives on how water affects, and is affected by, renewable energy development, coalbed methane production, bioenergy cropping, and large-scale power generation. Rounding out the first day, the Forum also convened a panel on "Climate Risk and Drought Preparedness" to illustrate the importance of drought mitigation planning by both municipal and agricultural water users. This topic is worthy of regular emphasis in a region where water shortages force us to accept the variability and occasional harsh reality of our climate.

A "Fountain Creek Visioning" panel started off the Forum's second day. Rather than rehashing issues of problematic flooding and water quality, this panel focused on what basin residents can expect as the new Fountain Creek District assumes the responsibility of guiding restoration and enhancement projects for the stream system. Pueblo County Commissioner Jeff Chostner, along with the other panelists, took the audience through the long process that led to the new district's formation.

Invasive species also made the list of important panel topics. As a brief aside, the 1986 classic movie *Aliens* offers a humorous comparison to the tamarisk and zebra mussel saga that has found its way to parts of the basin. In one scene, after a merciless defeat by the territorial and ferocious aliens, Bill Paxton's character "Hudson" nervously declares, "Hey, maybe you haven't been keeping up on current events, but we just got our [rears] kicked, pal!" Okay, the situation admittedly isn't *that* bad, but we definitely have our fair share of unwanted guests here in the Arkansas Basin. The "Invasive Species" panelists highlighted some of the success stories in fighting this pressing problem.

Other activities included a panel that discussed the importance of Lake Pueblo Dam and Reservoir to both the local economy and the river flows. Pueblo City School students also entered pieces in an art contest that provided a number of paintings for participants to enjoy. Lastly, Carl Genova, a long-time board member of the Bessemer Ditch and Southeastern Colorado Water Conservancy District, was given the Bob Appel "Friend of the Arkansas" Award. Genova was recognized for his work on the winter water storage program.

Faculty Profile

José L. Chávez, Assistant Professor, Department of Civil and Environmental Engineering

The effect of water on crop growth and yield first caught my attention when I was about 12 years old. I used to listen to my grandfather comment on his cotton and sugarcane fields production. He told that yields were good one or two years, and two, three or even four years not enough to cover operation costs. The problem was mainly due to cyclical rainfall, i.e., in some years rainfall would be sufficient to satisfy crop water needs, but most of the time there was not enough. After graduation in 1987, I decided to move from the sub-tropical lowlands of eastern Bolivia to the semi-arid northeastern region of Brazil to become educated in irrigation engineering.

In 1992, I graduated as an agricultural engineer and returned to Bolivia, where I became involved in designing pressurized irrigation systems and pumping stations. I eventually became interested in finding efficient technologies for irrigation water management, and I decided to pursue a master's degree in irrigation engineering. I moved to Logan, Utah in 1997 to attend Utah State University (USU), where I was exposed to new developments in irrigation water management.

Irrigation scheduling was based on the estimation of crop water use (evapotranspiration or ET) using weather station data and crop coefficients obtained with weighing lysimeters. The subject was so appealing to me that I wanted to be further involved in ET research. I stayed at USU to pursue a doctoral degree in biological and agricultural engineering. My Ph.D. research involved the improvement of an airborne remote sensing (RS)-based land surface energy balance algorithm, which was used to estimate spatially distributed ET. In addition, I developed a method to properly compare airborne RS ET with ET from eddy covariance (EC) stations. The comparison was achieved through the application of a footprint model (Flux Source Area Model, FSAM) and an integration mechanism.

I graduated in 2005 and began a post-doctoral program in precision irrigation with the Center for Precision Agricultural Systems (CPAS) at Washington State University (WSU). The research at CPAS was aimed towards the remote control and monitoring of continuous move irrigation systems (Linear Moves and Center Pivots). The main objectives were (1) to efficiently apply

variable amounts of water by irrigation zones, and (2) to transfer the site-specific irrigation control system to a Linear Move system/field configuration in a different region of the United States. Research results indicated that it was possible to control and monitor the Linear Move via the Internet. Variable water amounts were precisely applied by location, and the system performed equally well when transferred to a larger Linear Move irrigation system located in the Nesson Valley, North Dakota. After completing my research at WSU, I joined the USDA-ARS Laboratory in Bushland, Texas. There, the research project focused mainly on evaluating crop ET mapping algorithms using space and airborne imagery. The RS-based ET models/sub-models were evaluated using data from four large, monolithic weighing lysimeters and micro-meteorological sensors. In addition, Large Aperture Scintillometer (LAS) stations were used in these spatially distributed ET studies (Figure 1).

ET maps can be used to assess the temporal and spatial distribution of ET and to identify area-specific irrigation water management, soil salinity, soil nutrients, and water logging problems. These maps, along with ground-based information, will allow practical development of new methodologies aimed to improve farmers' irrigation management practices.

At the Bushland ARS, I was also part of a multidisciplinary, multi-institutional research project that involved the evaluation of EC energy balance systems using precision weighing lysimeters. In addition, I developed a research project to model "Surface Aerodynamic Temperature (SAT)" using RS and micro-meteorological inputs. Accurate SAT estimation is needed to more easily map sensible heat fluxes (H) and, therefore, spatial ET rates.

On January 1, 2009, I happily joined the Civil and Environmental Engineering (CEE) Department at Colorado State University (CSU). Here is where I plan to develop a successful career, establish roots (similar to those of alfalfa), and retire. My appointment includes research, teaching and Extension responsibilities. For the research component, I will be installing a Large Aperture Scintillometer (LAS) at the CSU Arkansas Valley Research Center (AVRC) in Rocky Ford, Colorado. In the past couple of years, monolithic weighing lysimeters have been installed at AVRC to precisely determine crop water use and crop coefficients. The large precision weighing lysimeter will serve as reference for evaluating LAS ET measurements. Once evaluated, the LAS system will be used in the verification and improvement of RS-based ET algorithms performance in Colorado.

My main research objectives are to develop an accurate and practical algorithm to assess the spatially distributed actual crop water use, actual crop coefficients, and irrigation systems problems/limitations in order to improve farmers' irrigation management. This new method can potentially be used to save water, soil, nutrients, and energy resources—thus protecting the environment and making irrigated agriculture more sustainable.

I teach two courses: Irrigation Systems Design and Irrigation Systems Management. These courses will incorporate recent technologies and methods. My Extension plan includes publishing research results in peer-reviewed journals, fact sheets, and conference papers, as well as working with county Extension agents in preparing/delivering seminars and workshops to transfer water management techniques.

I am a member of the American Society of Civil Engineers, the American Society of Agricultural Engineers, and the tri-societies "Agronomy Society of America, Crop Science Society of America, and Soil Science Society of America."

My spare time is for my family—bicycling, coaching my sons in soccer, and reading good literature. My family and I enjoy being immersed in a dynamic and progressive society here in Colorado. I am very proud to be part of Colorado's water resources community. I will strive to be a good team player and to help develop useful scientific tools to make irrigated agriculture more sustainable for current and future Coloradans.

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Water Research Awards

Colorado State University (February 15 to April 14, 2009)

Barbarick, Kenneth A, City of Littleton, Cooperative Research Project - Sludge Application to Dryland Wheat Fields - 2009 FY, $107,804

Cotton, William R, NSF - National Science Foundation, Prediction of MCS Hazards and Simulations of Aerosol Influences on Severe Convective Storms, $183,257

Culver, Denise R, Colorado State Water Conservation Board, Identification & Assessment of Important Wetlands in the North Platte River Watershed, $182,000

Culver, Denise R, EPA-Environmental Protection Agency, Survey of Critical Wetlands & Riparian Areas in Gilpin County, CO, $114,310

Doesken, Nolan J, Colorado State Water Conservation Board, Monitoring the Effects of Weather Conditions on Evapotranspiration, $100,818

Doesken, Nolan J, University of Colorado, Subcontract, Climate Support to The Western Water Assessment (WWA), $25,000

Doesken, Nolan J, University of Nebraska, Development and Implementation of a CoCoRaHS Drought Impacts Reporting System for the National Drought Mitigation Center, $43,750

Fausch, Kurt D, NSF - National Science Foundation, The Effects of Trout Invasion on Stream-Riparian Ecosystems: A Global Synthesis for Understanding and Prediction, $6,555

Garcia, Luis, DOI-Bureau of Reclamation, Arkansas River Valley S&T Research Work, $10,000

Gates, Timothy K, Colorado State Water Conservation Board, Data Assessment and Collection in Support of Improved Water Management in the Arkansas River Basin, $599,931

Gates, Timothy K, DOI-Bureau of Reclamation, Identification, Public Awareness, and Solution of Waterlogging and Salinity in the Arkansas River Valley, $50,000

Ham, Jay M, Kansas State University, Modifying Homeowners' Lawn-Irrigation Behavior to Conserve Water and Improve Water Quality in Urbanizing Watersheds, $55,391

Johnson, Brett Michael, Colorado Division of Wildlife, Management of Mercury Bioaccumulation in Colorado Reservoirs, $10,000

Johnson, Jerry J, DOI-USGS-Geological Survey, NIWR Development of Oilseed Crops for Biodiesel Production under Colorado Limited Irrigation Conditions, $12,500

Kampf, Stephanie K, DOI-USGS-Geological Survey, Hydrologic Analysis and Process-Based Modeling for the Upper Cache la Poudre Basin, $10,000

Koski, Anthony J, USGA-US Golf Association/Green Section R, Establishment and Maintenance of Turf-type Saltgrass (Distichlis stricta): Nitrogen Effects, Herbicide Tolerance, and Weed Control Strategies, $9,999

Myrick, Christopher A, University of Washington, Native Trout, $30,328

Qian, Yaling, USGA-US Golf Association/Green Section R, Salinity Management in Effluent Water Irrigated Turfgrass Systems, $27,175

Rathburn, Sara L, DOI-NPS-National Park Service, Establishing Context for River Restoration along Upper Colorado River, $30,783

Reardon, Kenneth F, Virginia Polytechnic Institute, Advancing Genome-Enabled Tools: Guiding Inoculum Design for Sulfate-Reducing Mine Drainage Treatments Systems, $164,470

Roesner, Larry A, Water Environment Research Foundation, Linking Stormwater BMP Systems Performance to Receiving Water Protection to Improve BMP Selection and Design, $134,285

Snyder, Darrel E, DOI-Bureau of Reclamation, Guide to Cyprinid Larvae (Project No. 149), $15,771

Snyder, Darrel E, DOI-NPS-National Park Service, Improve Collections Storage at Larval Fish Laboratory, $28,000

Thornton, Christopher I, Urban Drainage & Flood Control District, PHASE I: Hydraulic Model Study: Type C and D Grate Inlets for Highway Median Storm Drainage, $65,000

Wohl, Ellen E, NSF-GEO-Geosciences, Wood Loading in Headwater Neotropical Forest Streams, $81,804

Yang, Chih Ted, DOD-ARMY-Corps of Engineers, Lewis & Clark Reservoir Sedimentation Study, $234,609

Calendar

May

29-1 **River Rally 2009; Baltimore, Maryland**
This annual event brings together more than 500 river conservationists.
http://www.rivernetwork.org/rn/rally/

June

3-5 **30th Annual Natural Resources Law Center Summer Conference; Boulder, Colorado**
Western Water Law, Policy, and Management: Ripples, Currents, and New Channels for Inquiry
http://www.colorado.edu/law/centers/nrlc/

3-6 **Irrigation District Sustainability—Strategies to Meet the Challenges; Reno, Nevada**
Professionals can exchange ideas and learn from the experiences of others in their field.
http://www.uscid.org/09wdconf.html

14-16 **National Association of Resource Conservation and Development (RC&D) National Conference; Albuquerque, New Mexico**
This meeting features successes of the member Councils, training, and networking opportunities.
http://rcdnet.org/nationalconference.php

14-18 **AWWA Annual Conference and Exposition 2009; San Diego, California**
Covers the latest issues in water treatment, science, regulations, and operations.
http://www.awwa.org/ace09/

29-1 **2009 Summer Specialty Conference: Adaptive Management of Water Resources II; Snowbird, Utah**
Learn more about the basis, theories, and practical aspects of adaptive management.
http://www.awra.org/meetings/SnowBird2009/

July

7-9 **2009 UCOWR/NIWR Annual Conference; Chicago, Illinois**
This year's theme is "Urban Water Management: Issues and Opportunities."
http://www.ucowr.siu.edu/

11-15 **2009 SWCS Annual Conference; Dearborn, Michigan**
Explore current issues in conservation and environmental management science.
http://www.swcs.org/

22-24 **Colorado Water Workshop 34th Annual Meeting; Mt. Crested Butte, Colorado**
Legal, biological, ecological, historical, and economic aspects of non-consumptive use.
http://www.western.edu/water/

August

4-7 **EmCon 2009; Fort Collins, Colorado**
Discuss findings in emerging contaminants in ecosystems and drinking water.
http://www.emcon2009.com/

13 **2009 Rocky Mountain Water Reuse Workshop; Golden, Colorado**
This year's theme is "Purple Mountain Majesties—Water Reuse in the Rockies."
http://www.watereuse.org/sections/colorado

16-20 **StormCon 2009; Anaheim, California**
The world's largest stormwater pollution prevention conference.
http://www.stormcon.com/

16-22 **World Water Week; Stockholm, Sweden**
The leading annual global meeting place for the planet's water issues.
http://www.worldwaterweek.org/

19-20 **2009 Colorado Water Congress Summer Convention; Steamboat Springs, Colorado**
http://www.cowatercongress.org/default.asp

30-2 **Distribution Systems Symposium & Exposition (DSS); Reno, Nevada**
http://www.awwa.org/index.cfm

September

12 **Ag Day 2009; Fort Collins, Colorado**
The 28th Annual Ag Day at Hughes Stadium, hosted by agricultural organizations and associations.
http://agday.agsci.colostate.edu/

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Irrigation of alfalfa with siphons on Roger Maddox Farm near Swink, Colorado. (Image courtesy of William Cotton)