Colorado Water

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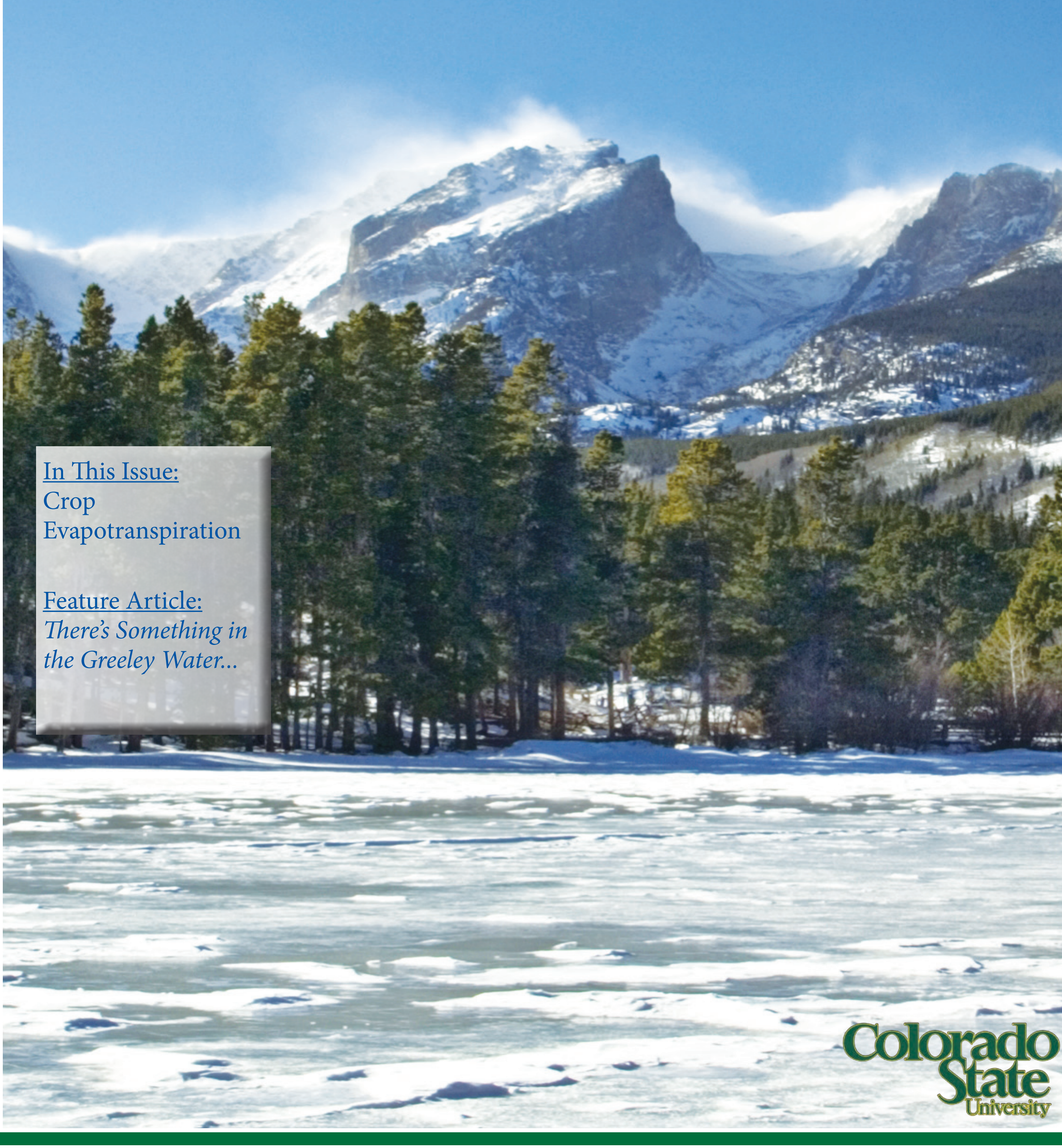

In This Issue:
Crop Evapotranspiration

Feature Article:
There's Something in the Greeley Water...

Colorado State University

Table of Contents

January/February 2008
Volume 25, Issue 1

Highlights:

In Every Issue:

COLORADO WATER is a publication of the Colorado Water Resources Research Institute at Colorado State University. The scope of the newsletter is devoted to enhancing communication between Colorado water users and managers, and faculty at the research universities in the state. This newsletter is financed in part by the U.S. Department of the Interior, Geological Survey, through the Colorado Water Resources Research Institute. The contents of this publication do not necessarily reflect the views and policies of the U.S. Department of the Interior, nor does mention of trade names or commercial products constitute their endorsement by the United States Government.

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Cover Photo: Sprague Lake And Hallett Peak In Winter - Rocky Mountain National Park, Colorado, USA
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Editorial

by Reagan Waskom, Director, Colorado Water Resources Research Institute

Refining our understanding of crop consumptive use

Water use by cultivated crops, rangelands, forests, and riparian vegetation make up the vast majority of consumptive water uses in Colorado. This component of the hydrologic cycle, known as evapotranspiration or ET, includes soil evaporation and the water taken up by plants for growth and cooling purposes. Given the magnitude of ET in the overall water balance (second only to precipitation) it is interesting to note it is still one of the most difficult components to accurately quantify.

In this issue of Colorado Water, you will note that methods used to estimate and directly measure ET are still the subject of intense scientific interest in Colorado, as we continue to refine our knowledge of the water balance. Despite the fact that over a half century has passed since the Blaney-Criddle model was first derived, ET quantification remains an inexact science. Evaporation is driven by energy from the sun, but is influenced by other factors such as humidity, temperature, wind, soil heat and vegetation that vary significantly, both spatially and temporally. Direct measurement of daily ET by weighing lysimeters is considered the most accurate method, but you will see in the article by Abdel Berrada and his colleagues on page 8, that this method still requires careful attention to detail and some good luck. Indirect estimates, using combination equations, models and remote sensing, are subject to even more variability and error, but are critical for quantifying the magnitude of water use on a larger scale.

Reagan Waskom

For those outside the water community, it may appear we are once again guilty of wanting to know more and more about less and less, as we refine ET estimation procedures. The reality is that the administration of intrastate and interstate water hinges upon our consumptive use assumptions. Changing from the Blaney-Criddle to the Penman-Montieth equation may make little difference to an individual irrigator trying to schedule the next water application, but it can make a significant impact on a basin-wide calculations. On page 18 of this issue, Professor Dan Smith summarizes part of a multi-year undertaking to measure consumptive use in high elevation irrigated meadows using compensating lysimeters. His data show that temperature derived monthly crop coefficients reveal some troubling inconsistencies. One of the primary justifications for the installation of the large weighing lysimeter at Rocky Ford was to validate crop coefficients, under Colorado conditions, for use in the Penman-Montieth equation as required by Kansas v. Colorado settlement on the Arkansas River Compact. Professor Niemann's work in the Arkansas Valley on non-beneficial evaporation due to shallow groundwater, described on page 13, is yet another critical component in the understanding of a basin scale water balance.

Application of ET estimation methods on scales larger than the research plot requires long-term, reliable climate data from a reasonably dense monitoring network. State Climatologist, Nolan Doesken and a team of volunteers have worked hard for almost 20 years to keep the COAGMET network functioning in spite of limited funding. As you will read on page 24, Nolan is now trying to examine the impact of rising temperatures on ET trends using the existing weather data network. All of these efforts described in this issue of Colorado Water underscore the need for University researchers and Colorado water managers to work together to install the right monitoring stations, gather the right data, conduct the critical experiments, and then evaluate the findings independently and objectively. The scientific process is not a cookbook recipe; it requires the best of our intelligence, imagination, persistence and creativity to acquire new knowledge which can be used to better manage our water resources.

CWRRI Awards Funding

FY08 Research Projects

CWRRI was fortunate to receive additional funds from the State of Colorado in FY08 to expand the research portfolio. Under Section 104(b) of the Water Resources Research Act, CWRRI is to "plan, conduct, or otherwise arrange for competent research…" that fosters the entry of new scientists into water resources fields, the preliminary exploration of new ideas that address water problems or expand understanding of water and water-related phenomena, and disseminates research results to water managers and the public. The research program is open to faculty in any institution of higher education in Colorado that has "demonstrated capabilities for research, information dissemination, and graduate training … to resolve State and regional water and related land problems."

The general criteria used for proposal evaluation included:
(1) scientific merit
(2) responsiveness to RFP
(3) qualifications of investigators
(4) originality of approach
(5) budget
(6) extent to which Colorado water managers and users are collaborating

A call for proposals went out last July and was responded to by eight high quality requests totaling over $350,000 in requested support. A peer review process and ranking by the CWRRI Advisory Committee resulted in funding 4 projects for FY08. Project titles and investigators and listed below. For more information on any of these projects, contact the PI or Reagan Waskom at CWRRI. Special thanks to the individuals who provided peer reviews of the project proposals.

Developing a GIS Database for Source-Tracking of Human Versus $15,280

Amy Pruden, Colorado State University
Mazdak Arabi, Colorado State University

Hydrologic Analysis and Process-Based Modeling for the Upper Cache la Poudre Basin $35,000

Stephanie Kampf, Colorado State University

Observing and Modeling Non-Beneficial Evaporative Upflux from Shallow Ground Water under Uncultivated Land in an Irrigated River Valley $40,000

Jeffrey D. Niemann, Colorado State University
Timothy K. Gates, Colorado State University
Luis A. Garcia, Colorado State University

Water Reallocation and Bioenergy in the South Platte: A Regional Economic Evaluation $47,981

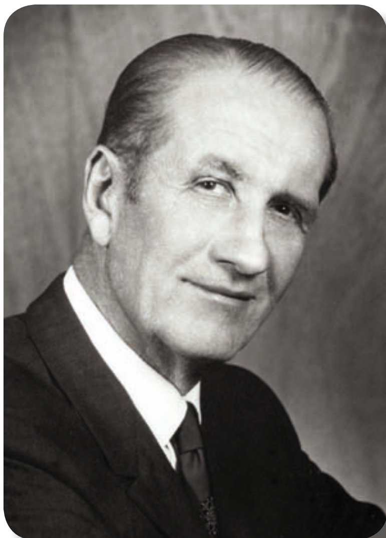
James Pritchett, Colorado State University

FEATURE ARTICLE

There's Something in the Greeley Water: The Remarkable Leadership of Delphus E. Carpenter and William D. Farr

by Daniel Tyler, Colorado State University

We all know good leadership when we experience it, but the ingredients of leadership, or why one approach is more effective than another, are hard to define. Persuasive leaders are increasingly scarce. The more complex society becomes, the harder it is to find individuals with command qualities that appeal to diverse and competing groups. In matters of water, leadership is even more difficult because of the burden placed on stakeholders to defend their litigated rights without acquiescing or compromising what they own with competing interests.



William D. Farr at age 75

Getting people to agree, to move away from proprietary concerns, requires imagination and courage. Napoleon noted that leaders are really dealers in hope. But trust and integrity must be implicit in any leadership style. Norman Schwartzcopf has said that leadership is a combination of strategy and character, and if you must be without one, be without strategy. What people tend to follow is the kind of direction that allows them to believe in the goal without excessive preoccupation over possible obstacles that inevitably surround a plan's implementation. In this vein, the French aviator Antoine de St. Exupery wrote, "If you want to build a ship, don't drum up the men to gather wood, or divide the work and give orders. Instead, teach them to yearn for the vast and endless sea."

Delph Carpenter, born in Greeley in 1877, and William D. (WD) Farr, born in Greeley in 1910, exerted leadership by challenging peers, colleagues, and rivals to look beyond their apprehensions to the possibility of truly meaningful accomplishments. Both men were pioneers in water development. Delph's parents came to the Union Colony of Greeley during the second year of its existence. When their son expressed an interest in water law, father Leroy Carpenter told Delph he would have to write that book himself. Delph's utilization of Article 1, section 10 of the Constitution to justify interstate water treaties was his way of pioneering for the next generation and those to follow.

WD's grandfather, Billy Farr, was also a pioneer. He arrived from Canada as a blacksmith the year Delph was born. A stage coach driver brought him to Greeley, loaning him the cost of a ticket. In 1904, Billy paid his debt by taking the driver to the Paris Exposition. By then, Billy had persuaded the City of Greeley to assume bonded indebtedness to build a forty-mile wood stave pipeline from the Poudre River so the city would have a safe supply of drinking water. Billy's son, Harry, continued to work for larger and more stable water supplies. He was one of the most convincing promoters of the Colorado-Big Thompson Project. Harry's son, WD, pioneered the Windy Gap Project long before Front Range cities had any use for the water, and he helped resolve differences with the West Slope so the Wolford Mountain Project could be built on Muddy Creek.

The Carpenters and Farrs took calculated risks in support of major water projects, because they believed in themselves and in the benefits such projects could bring to their communities and to succeeding generations. Both men had the ability to articulate a vision of an improved future. WD's mantra over a lifetime was, "always a better way."

Both Delph and WD were masters of negotiation. Delph learned the hard way from difficult legal battles when he represented Colorado as the state's interstate streams commissioner. Toughest of all was his fight to preserve to Colorado some water from the Laramie River. Wyoming sued Colorado in 1911 when the Greeley-Poudre Irrigation Company announced plans to divert over 100,000 acre-feet of Laramie River water for new lands in northern Colorado. The case dragged on for eleven years. Most of this time, Delph tried to cajole, threaten, and persuade Wyoming of Colorado's right as basin of origin to unlimited water from a river that began in northern Colorado. But when the Supreme Court denied his claim, awarding Colorado a little over 15,000 acre-feet, he had to conclude that the enormous amount of energy and funds expended on the fight would exhaust the state and its representatives if the same struggle was repeated for every interstate river. He got religion and began to preach the importance of negotiated settlements.

WD's instinct for negotiation emerged early on. Health issues kept him from completing his first semester at the University of Wisconsin. When he returned to Greeley, he spent most of his time with experienced farmers, learning from them how things got done. His willingness to listen, to prepare himself for discussion, to ask questions and to respect others resulted in leadership roles in Rotary, Boy Scouts, various cattle feeding organizations, the National Cattlemen's Association, several banks, and the Northern Colorado Water Conservancy District. Those who negotiated with WD knew he was open, honest and dependable. His power as a leader emanated from this trust and from the fact he knew better than anyone the subject matter being discussed.

Both men were excellent students and lifelong learners. Delph understood the importance of history, of utilizing archival materials and human resources to place difficult problems in proper context. Although the 1922 Colorado River Compact has been criticized for its dependence on erroneous river flow data, Delph availed himself of every chance to seek out and share the best data during negotiations among the seven states.

WD was smart but not arrogant. He knew, as Mark Twain had noted, that "history does not repeat itself — at best, it sometime rhymes." In the words of Jim Witwer, "what he tried to teach us was less specific knowledge than how to think, to plan and execute based upon the best information we have, and to learn from the experience and move further ahead. . . . His view of water policy, and life, combined enthusiasm and the scientific method. He was a great teacher precisely because he was a great student."[1]

The studies of both men extended beyond the nation's boundaries into the history and culture of other countries. Delph sought out spokesmen from Egypt, France, and Switzerland to learn how rivers were managed when they crossed international boundaries. He applied what he assimilated to his work on interstate compacts. WD was one of the first Americans to go to China after that country first opened up to foreigners under Mao Tse-Tung in 1972. He made three trips and marveled at how the Chinese people sustained themselves at a time when capital and technology were scarce. Other trips to Europe, Australia and South America furnished his inquisitive mind with ideas and questions about how American agriculture might be improved. This interest in learning from all people got him into trouble at home when he praised the Chinese at a public lecture after one of his trips to Asia. His minister scolded him for appearing to be "soft on Communism."

More than anything, Delph and WD admired the hard work exhibited by people of other nations. In today's terms, Delph might be considered a "workaholic." He rarely employed assistants to help him with legal briefs, and he took on so many tasks simultaneously, he found himself frequently exhausted. The Parkinsonian symptoms he experienced at the age of 40 worsened over the next thirty years, but he continued to play an active role in water matters even though he had to depend increasingly on his wife. After being unceremoniously removed in 1932 as Colorado's interstate streams commissioner, because he was a Republican in a Democratic state government, Delph retired to his home without a pension or a letter of gratitude from the new administration. However, he was determined to remain mentally active regarding compact negotiations. He answered correspondence through his wife by winking an eyebrow to spell letters in the alphabet when his voice shut down from the sickness.

When I last interviewed WD in the months before he passed away, he frequently held up his gnarled hands to show me how proud he was of the hard work he had known throughout his life. With great pride, he recounted the challenge of feeding sugar or beet pulp and corn by the fork or shovel. Sorting and sacking potatoes into hundred-pound burlap bags was just as demanding. He believed in the dignity of hard physical labor, but his body got beaten up from accidents, strenuous tasks and the many arguments he lost with bucking horses. He also endured intense pain and debilitation as a result of chronic sinus infections caused by allergies. The condition was so severe that doctors had to drill holes in his head to relieve the pressure. The allergic sensitivity remained with him all his life.

> "WD was a great gardener. He made things bloom. He also made humans bloom."

While Delph and WD were similar in many ways, their pursuit of leadership differed significantly. Delph was a trained lawyer. He was taught to seek victories and to adopt winnable positions. Not until he was faced with collapse of Colorado River Compact negotiations in 1921 did he begin to implement a less confrontational style.

He was also more political and had a bigger ego than WD. His diary entry for May 13, 1917, provides a hint of this self-preoccupation. "Perhaps, I have accomplished more than most men at my age, but not so much as many. I was admitted to the bar at 22, elected to the [state] senate at 31, became an interstate water lawyer at 33 and argued one of the greatest cases of western times before the U. S. Supreme Court with favorable mention by the Chief Justice at age 39. I hope I do as well in the years to come."[2] Delph was eager for success and recognition, and though there is little doubt he merited approbation for his work on interstate compacts, his name is scarcely known to those who take pride in the mighty Hoover Dam, an enormous multi-state and national project which would not have been possible without the Colorado River Compact. Delph's accomplishments deserve better.

By contrast, WD never sought recognition and in his lifetime he received all the awards for which a western

[1] *Jim Witwer, "A Remembrance. William Daven Farr: Student of Water and Life." Headwaters (Fall 2007), p. 29.*

[2] *Delph Carpenter diaries, Carpenter Papers, Colorado State University Water Resources Archive, Fort Collins, CO.*

stockman and water guru might possibly qualify in a long and productive life. But he was conspicuously humbled by the appreciation he received As his son, Randy wrote in a recent letter to Eric Wilkinson, "During his later years before [wife] Judy had difficulties of her own, we'd meet for holidays or visits and she would practically have to use a crowbar to get him to divulge yet another accomplishment. Then he would get this 'Oh, shucks. . .' grin and let it out – as if it was as inconsequential as getting a B+ on a spelling paper."[3]

The list of honors is astounding, not only because of its length and diversity of award granting organizations, but because some of those organizations found WD worthy of the same award more than once. From the Boy Scouts to the National Cattlemen's Association, the City of Greeley, several universities, Rotary International, the American Meat Institute and the Colorado Water Congress, WD received acclaim over a fifty-year period. Five of the awards were specifically for leadership. But the one he probably appreciated most was presented by the National Cowboy Museum and Western Heritage Center in Oklahoma City. Four months before he died, bedridden at home, WD dressed in his best Stetson and cowboy shirt and listened on the phone as Chuck Schroeder, executive director, inducted him into the Hall of Great Westerners. This is the museum's highest honor, and it was greatly appreciated by a man affectionately known as "Cowboy."

Even those who knew WD casually recognized the uniqueness of his leadership ability. They saw in him the consummate gentleman, a man deeply interested in the ideas and opinions of others. He validated everyone he met, and he treated people with dignity. His strong sense of duty to family, to community, and to his professional responsibilities produced the great respect required for effective leadership. People trusted him and knew that whatever position he argued, his objective was to improve conditions for those who would live after him.

William D. Farr at age 95

No one I have known in my own lifetime has been as enthusiastic about life and so totally unafraid of change. WD sold the Crystal River Ranch in Carbondale to my father in 1945. He knew that the twenty-mile ditch to the ranch from the Crystal River would always be an Achilles heel for ranch operations, but he painstakingly and optimistically instructed my father on the ranch's potential, as well as its liabilities, and he imparted to all of us his own love of the land and a way of life which he treasured.

WD was astute, perceptive, considerate and humble. He got things done because of his visceral compassion for others, because he was able to turn failure into something positive, and because he could inspire people to look toward a brighter future. As Hank Brown said at the "Celebration" in the Greeley Civic Center, "WD was a great gardener. He made things bloom. He also made humans bloom."[4]

William D. Farr signing the Windy Gap

FEATURE ARTICLE

[3] E-mail, Randy Farr to Eric Wilkinson, General Manager of the Northern Colorado Water Conservancy District, October 29, 2007

[4] Hank Brown, Celebration of Life Service, Greeley, CO, August 23, 2007.

Benefit the Water Community: Make a Donation

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

With a twinkle in his eye, Dick MacRavey talks about being in his "mature youth." He readily reminisces about his accomplishments during 26 years as executive director of the Colorado Water Congress, but he also discusses big plans for his retirement which will capitalize on his youthful energy and accumulated experience.

MacRavey recently took time from his busy schedule to visit the CSU Water Resources Archive, where he made a generous donation of his personal materials. Among the items are books personally inscribed to him by prominent water professionals, including Felix Sparks, former director of the Colorado Water Conservation Board. Also part of the donation are two framed paintings, one of which MacRavey received upon being named the Wayne N. Aspinall Water Leader of the Year by the Water Congress in 1999. Although the donation is small, it is significant, and MacRavey promised there would be more to come.

A Benefit to the Community

Donors like Dick MacRavey understand the importance of saving materials that document Colorado's water history. They recognize that their unique items, which might be the only source of particular information about a certain event or subject, will leave a gap in history if not saved and made available to others. With the significance of water, in all its aspects, to Colorado and the West, the various pieces of its past need to be saved so the present and future can learn from them.

Putting such documentation in an archive not only ensures it will endure long-term, doing so also makes it available to researchers. That availability is a benefit to the entire water community, even if only one person makes use of the materials. When someone uses the material in a public way—a conference presentation, a master's thesis, a television documentary—the information is shared more broadly. The water community then benefits from just one person's research.

So even if 99 percent of the members of the water community never enter the archives, either physically or virtually, they will still benefit from donations of materials. Many in the community are aware of Dan Tyler's biography of Delph Carpenter, Silver Fox of the Rockies. Without the historic materials held by Water Resources Archive and other repositories, Tyler would not have been able to tell that story. If that biography had never been researched, written, and published, there would be far less understanding today of Carpenter's work in the early twentieth century that led to the Colorado River Compact. Indeed, without that book, Russ George, former executive director of the Colorado Department of Natural Resources, may not have conceived the idea of the Interbasin Compact Committee, a visionary move for the state.

This is just one example of how archival materials are crucial to understanding the past, learning from it, and applying the lessons for the present and future. Far more are possible. In fact, Dan Tyler is now working on a biography of W.D. Farr, once again relying on original source material to draw from. One can imagine the possibilities emerging from that work as well.

Make a Donation

The benefits of an individual's research with archival materials can be multiplied dozens, hundreds, thousands of times. Just think how much the community can gain! Then realize that it all begins with donations.

Donation to an archive, while a big decision, is a fairly simple process. If you have or know of some materials that should be permanently stored in an archive and made available for the benefit of the community, please contact the Water Resources Archive. While visits such as Dick MacRavey's are always welcome, an archivist can travel to your location as well. Archivists are trained in evaluating materials for their historic and research value, and it often helps to see the original conditions in which the materials were created and/or stored. Archivists are always glad to talk to potential donors to hear their reminiscences, find out about the materials, and discuss making a donation. Once agreement about a donation has been reached, the archivist can help pack up and transport the materials.

The Water Resources Archive documents all aspects of Colorado water throughout history. Particular subject areas of interest to researchers at the present time include:

- groundwater issues
- ditch companies
- irrigation practices
- the environment
- recreational use of water
- water conservation
- water law

Anyone with significant materials in these areas in particular are encouraged to contact the Archive. Materials types sought include scientific studies and reports, data, correspondence, diaries, photographs, and maps. These are best brought to the attention of the Archive as a set, not as individual items, unless exceptional. While published books, federal government documents, newspapers, magazines, and journals are also helpful to researchers, the Archive leaves collecting those to other library staff—unless the published items are rare or hard to find.

One specific set of published documents the Water Archive would like to have donated is something only spottily available in the state's libraries: the newsletters of the Colorado Water Congress. First published under the title Newsletter in 1958, the publication turned into the tabloid-sized Colorado Water Rights in 1982. The Archive holds the majority of these but is missing a large span of volumes, from 1964 to 1982. If anyone owns these particular volumes and would like to make them available to the community through the Water Resources Archive, please contact us!

During his visit to the Water Archive, Dick MacRavey suggested he might be talking to some of the many water people he knows across the state and encouraging them to donate their historic materials. With the number of people he knows, and given his persuasive skills sharpened during his fifty years in politics, a few words from Dick might go a long way. For the benefit of the community, let's hope so.

For more information about the Water Resources Archive or donating a collection, see the website at http://lib.colostate.edu/archives/water/ or contact the author (970-491-1939 or patricia.rettig@colostate.edu) at any time.

The Lysimeter Project in Rocky Ford: Objectives and Accomplishments

by Abdel Berrada, Lane Simmons, Michael Bartolo, Dale Straw, and Thomas Ley, Colorado State University, Division of Water Resources

Rationale and Objectives

One of the recommendations that came out of the Kansas v. Colorado Arkansas River Compact litigation is for Colorado to use the ASCE (American Society of Civil Engineers) Standardized Penman-Monteith equation to estimate crop consumptive use in the Arkansas River Valley. The Penman-Monteith equation (PME) calculates the evapotranspiration (ET) of a reference crop, which in Colorado is alfalfa, using meteorological data such as maximum and minimum temperature, relative humidity, solar radiation, and wind speed (Allen et al., 1998). The ET of other crops (ETc) is derived from reference ET (ETr) with the equation:

$$ETc = ETr \times Kc$$ (for well-watered crops)

Kc or crop coefficient varies with crop type, growth stage, crop condition (plant density, health, etc.), and soil wetness, among other things. When the crop is water-stressed,

$$ETc = ETr \times Kc \times Ks$$

The coefficient Ks is derived from the water balance (water inputs minus water outputs) in the root zone.

ETr is defined as the evapotranspiration of a non-stressed, well watered alfalfa crop, 50 cm in height, covering the ground fully. In other states, the reference ET is that of a non-stressed grass or similar short crop that is 12 cm in height at full canopy and is usually denoted ETo.

Direct measurement of ET is best achieved with weighing lysimeters. Precision weighing lysimeters measure water loss from a control volume by the change in mass with an accuracy of a few hundredths of a millimeter. Non-weighing lysimeters are more common but they "are not considered suitable for reference ET equation verification and crop coefficient research. They may, however, be very suitable low cost alternatives for studying the effects of varying water salinity levels and high water table conditions on crop ET up and down the Arkansas River Valley." (Ley, 2003).

Fig 1: The inner tank being pushed into the ground to acquire the soil monolith. Photo taken by Dale Straw of DWR.

In the absence of locally generated algorithms for calculating ETr with PME and Kc, the Colorado Division of Water Resources (DWR) has been using estimates from Kimberly, ID and Bushland, TX. However, the crop growing conditions (soil, elevation, climate, etc.) in the Arkansas Valley vary greatly from the prevailing conditions in Kimberly or Bushland. In his findings relating to the Arkansas River Compact compliance litigation initiated by Kansas, Special Master Arthur Littleworth accepted that the method used for calculating crop consumptive use in the Arkansas Valley be changed from Blaney-Criddle to PME. Consequently, Colorado's Attorney General requested that the Colorado Water Conservation Board (CWCB) fund the "design, installation, and operation of weighing lysimeters at the Colorado State University Agricultural Experiment Station at Rocky Ford, Colorado". The requested funds also cover the enhancement of CoAgMet weather stations, the investigation of irrigation water management in the Arkansas Valley, and the review of the changes made to the Hydrological-Institutional (H-I) Model by experts. The H-I Model has been used by the State Engineer's Office (DWR) to determine depletions to usable water flows to Kansas.

Colorado State University (CSU) has a network of twelve automated weather stations along the Arkansas Valley. Temperature, solar radiation, humidity, and wind speed data from these stations will be used to validate ETr and Kc estimates for the whole Valley.

The lysimeter project at the Arkansas Valley Research Center (AVRC) consists of one large weighing lysimeter and one reference lysimeter. The large or test lysimeter was installed in 2006 and the reference lysimeter will be installed in 2008.

The project objectives, according to Thomas Ley of DWR (2003), are to:

1. Evaluate the performance and predictive accuracy of the ASCE Standardized PME for computing alfalfa reference crop ET for the growing conditions in southeastern Colorado,
2. Determine crop coefficients (for use with PME) for the various crops grown in the Arkansas River Valley under well-watered conditions, and,
3. Determine the effects of typical local growing conditions (which may include limited irrigation, high water table conditions and irrigation with water of high salinity contents) on crop water use.

Fig 2: The inner tank plus soil being lowered inside the containment tank. Photo taken by Michael Bartolo.

The latter objective may require additional lysimeters e.g., non-weighing ones to achieve. It is worth noting that the effects of limited irrigation, high water table, and salinity on crop growth and water use in the Arkansas Valley have been studied by CSU scientists for several years using traditional (water balance estimates) and non-traditional (remote sensing) methods. However, the impact of salinity for example on crop water use can be determined more accurately with a weighing lysimeter. Relatively high salt levels have been reported in the soils and waters of the Arkansas Valley (Gates et al., 2006).

The installation of the test lysimeter was completed in the fall of 2006, but some of the meteorological sensors were put in place in 2007. Consequently, it will be two to three years before achieving Objective 1 and several more years before having usable Kc values and formulas for the major crops grown in the Arkansas Valley.

In the remainder of article, we will describe the main characteristics of the test lysimeter and its location and briefly review land preparation, crop establishment, and future plans.

Site Characteristics

The lysimeter is located at the Arkansas Valley Research Center, approximately two miles east of Rocky Ford in Otero County, Colorado (NW1/4 Sec 21, T23S, R 56W). The elevation at the site is approximately 1,274 m, latitude: 38° 2´ 17.30´´, and longitude: 103° 41´ 17.60´´. The soil type is Rocky Ford; coarse-loamy, mixed, superactive, mesic Ardic Argiustoll. Selected soil properties are shown in Tables 1 and 2.

The long-term average annual precipitation at the site is 11.8 inches, with May through August having the highest rainfall. The total average annual snowfall is 23.2 inches. The average minimum temperature is 36.3 °F and the average maximum temperature 70.0 °F. The last spring frost (32.5 °F) occurs on or before May 1 and the first fall frost on or before October 5 in 50% of the years; thus the average length

Table 1. Soil characteristics of the test lysimeter site

Horizon	Depth	Textural Class	pH water(1:1)	CEC (meq/100g)	EGe (dS/m)	Total C g/kg	SAR
Ap	0-23	Clay loam	8.1	17.2	0.82	15.5	1.70
Bt	23-26	Clay	8.0	16.9	0.90	14.8	2.08
Btk	36-100	Loam	8.3	10.0	0.58	9.0	2.46
Bk1	100-170	Loam	8.3	10.9	0.72	9.5	2.40
Bk2	170-230	Clay Loam	8.3	13.5	0.88	10.8	2.18
2C	> 230	Course Sand	8.7	1.5	-	1.7	-

Table 2. Soil bulk density and hydraulic properties (calculated)

Horizon	Depth (cm)	Bulk Density (g/cm3)	Matric Suction in J/kg						Hydraulic Condutivity (cm/hr)
			1500	1000	500	100	33	10	
Ap	0-23	1.36	123	131	144	182	214	254	0.34
Bt	23-36	1.36	124	132	145	182	213	252	0.33
Btk	36-100	1.45	77	84	97	134	167	213	1.25
Bk1	100-170	1.43	82	89	103	141	176	224	1.06
Bk2	170-230	1.35	118	126	141	183	219	266	0.42
2C	> 230	1.86	19	22	26	40	53	73	16.9

of the growing season for warm-season crops like corn is 158 days.

Lysimeter Characteristics

The test lysimeter consists of an inner tank of 10 ft x 10 ft x 8 ft and an outer containment tank. The chamber between the two tanks houses the weighing mechanism, the drainage tanks, data loggers and has standing room for a half-dozen people (Fig. 3). The inner tank was filled with undisturbed soil (soil monolith) from the same field where the lysimeter is located (Fig. 1). Figure 2 shows the tank being lowered into its permanent location. The soil tank moves freely within the outer tank and the two are separated at the top by a fraction of an inch.

The weighing mechanism consists of a mechanical lever scale-load cell combination. The load cells are connected to Campbell Scientific CR-7 data logger which records the weight of the inner tank plus soil every 10 seconds. The readings are given in millivolts per volt (mV/V). A thorough calibration procedure was performed in 2006 to convert the load cell output in mV/V to the weight of water in kilograms.

The standard deviation of the weight measurements (accuracy) was less than 0.02%. The change in total weight of the soil tank represents the amount of consumptive water use (transpiration plus evaporation from the surface of the soil monolith) by the crop. An example of load cell reading is shown in Figure 4.

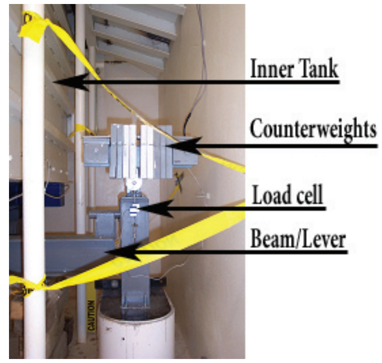
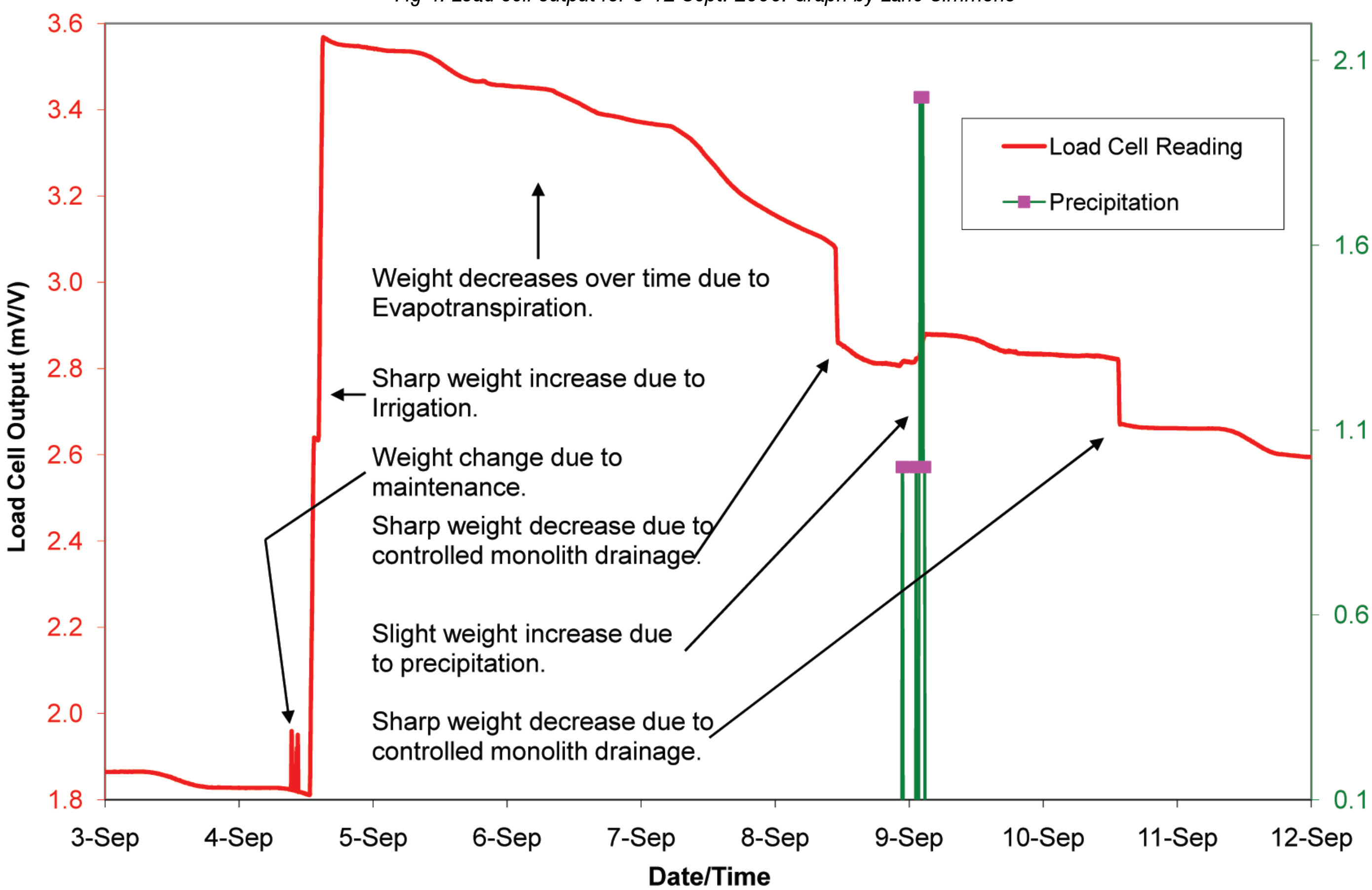


Fig 3: Inside the containment tank (west side). Photo taken by Dale Straw of DWR.

Water that percolates through the soil monolith is collected in two drainage tanks suspended from the scale frame that supports the soil tank, so that there is no overall weight change as water drains into the tanks. One tank collects water from the internal portion of the monolith and the other tank collects water from the perimeter of the monolith.

Fig 4: Load cell output for 3-12 Sept. 2006. Graph by Lane Simmons



Instrumentation

Several instruments are located in, above, or outside the monolith. They are used to measure:

- Precipitation, wind speed and direction, minimum and maximum air temperature, barometric pressure, dew point temperature, relative humidity, and net radiation.
- Incoming (from the sun) and reflected (from the ground or plants) radiation, and incoming and reflected photosynthetic active radiation (PAR)
- Crop canopy temperature
- Soil temperature at various depths and heat flux in or out of root zone
- Soil moisture at 0- to 2.0 m in 20-cm increments with the CPN 503DR neutron probe. A calibration was performed to convert the probe readings into volumetric water content. The calibration procedure and results will be published elsewhere. Comparison of the soil water content inside and outside the soil monolith will be used to adjust the amount of water applied to the monolith and the amount of drainage.

Soil Preparation

Shortly after the installation of the test lysimeter in 2006, the ground around it was flooded to settle the soil. Later, the ground was ripped with a Big Ox chisel plow to alleviate compaction, then plowed, disked, leveled, furrowed, and rolled. The distance between furrows is 30 inches, as is common in the Arkansas Valley. The top eight inches of the monolith were tilled with a rototiller and the beds and furrows were prepared with shovels and spades. There are three full beds in the middle and a half bed against the eastern and western edges of the monolith, and four furrows. They are aligned with the beds and furrows outside the monolith and run north-south.

Fig 5: View of the lysimeter & meteorological instrumentation in late June ‘07. Photo taken by Michael Bartolo.

Fig 6: Water being applied to the soil monolith. Photo taken by Michael Bartolo.

The total area designated for the test lysimeter to ensure a good fetch is 10 acres (520 ft x 840 ft), of which 6 acres were fallowed since 2005 and an adjacent 4 acres was in alfalfa since 2003. It was paramount to get all 10 acres managed uniformly, thus in early spring 2007, the area in alfalfa was sprayed with Roundup and the whole field was planted to oats on 5 April 2007 at 140 lb/acre. The oat crop inside and outside the monolith was irrigated four times and cut for hay on 25 June. Figure 5 shows the lysimeter after the oat was cut.

The hay was baled on 2 July and the bales removed shortly after that. Oat was chosen as the first crop to be planted after the installation of the test lysimeter because it is easy to grow and could be planted and harvested early, allowing enough time for soil preparation and the seeding and establishment of the next crop (alfalfa) before fall dormancy.

In the latter part of July, the soil in the lysimeter field was again ripped, disked, and leveled. Alfalfa variety ‘Genoa’ was seeded on 9 August at 19 lb/acre and the field was then furrowed and rolled. The soil inside the monolith was prepared and seeded by hand. The number and arrangement of beds and furrows was the same as with the oat crop. Two hundred pounds of 11-52-0 per acre were broadcast on top of the hay crop on 6 December.

Alfalfa establishment inside and outside the monolith was good to excellent, with the exception of a couple acres approximately 100 ft west of the lysimeter. In this area, alfalfa stand was spotty due to a heavy infestation of morning glory. The whole field was mowed with a brush hog on 27-28 September above the hay crop to suppress the taller weeds. That is when it became clear that approximately half of the area west of the lysimeter will have to be reseeded in the spring of 2008 to achieve a more uniform stand with the rest of the field. Alfalfa was irrigated on 17 August, 4 September, and 4 October. Water from the irrigation canal was dispensed to each furrow with a siphon.

Irrigation of the Soil Monolith

The monolith was irrigated each time the surrounding area was. The amount of water applied was determined by subtracting the amount that flows (flow x duration) in and out of adjacent furrows, as measured by v-shaped furrow flumes. Water was pumped from the irrigation canal and applied to the monolith through a hose fitted with a flow meter and a valve. The furrows on the monolith were filled with water to simulate normal flood irrigation (Fig. 6).

Future Plans

The reference lysimeter (5 ft x 5 ft x 8 ft) will be installed in 2008 in an adjacent field and seeded to alfalfa. The area of the test lysimeter field that has a poor alfalfa stand will be reseeded in the spring of 2008. Alfalfa in the test lysimeter field will be maintained for at least three more years to calibrate the PME. After that, the field will be planted to corn and other major crops in the Arkansas Valley (corn, wheat, sorghum, onions, etc.) to determine their crop coefficients. It will take at least two years of data per crop to generate reliable Kc estimates. Reference ET will be measured with the reference lysimeter after the results are tested and validated.

The lysimeter project is a joint effort between CWCB, DWR, and CSU. Support has also been provided by USDA-ARS engineers and scientists in Fort Collins, CO and Bushland, TX.

For more information about the lysimeter project at AVRC, please contact Lane Simmons at lane.simmons@colostate.edu or (719) 469-5559.

Emerging Issues in Soil and Water
Gary Peterson and Dwyane Westfall Annual Lecture

April 22, 2008 at 2:00 p.m.

West Ballroom, Lory Student Center, Colorado State University

This public lecture was established at Colorado State University to promote awareness of critical and emerging issues related to soil and water resources. The lecture provides a forum to explore issues, to inspire creative thinking, and to recognize excellence. The lecture is named for Dr. Gary Peterson and Dr. Dwayne Westfall and their dedication to the understanding of soil and water resources in Colorado agroecosystems.

This years lecture will be given by award winning author William Bryant Logan, discussing his book "Dirt: The Ecstatic Skin of the Earth". Join in celebrating the natural resources and discussing how we can work together to use them wisely.

For information contact: Dr. Neil Hansen, 970 491-6804 neil.hansen@colostate.edu

Characterizing Non-Beneficial Evaporative Upflux from Shallow Groundwater under Uncultivated Land in an Irrigated River Valley

by Jeffrey D. Niemann, Assistant Professor Dept. of Civil and Environment Engineering
Nik Hallberg, Graduate Student, Dept. of Civil and Environment Engineering
Timothy Gates, Professor, Dept. of Civil and Environmental Engineering
Colorado State University

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) in southeastern Colorado is no exception to this situation. As early as the 1870's, the Arkansas River was harnessed to irrigate lands in the river's alluvial valley. Now, more than 1000 miles of major canals provide irrigation water to more than 100,000 ha (250,000 acres) of agricultural land stretching from Pueblo to the eastern border of Colorado. This agricultural system is the primary economic driver for southeastern Colorado. Since the 1970's, Front Range municipalities have been buying water rights in the valley. The resulting transfers of water from the Colorado Canal and Rocky Ford Ditch have dried up approximately 78,000 acres of irrigated land. Furthermore, recent litigation surrounding the Arkansas River Compact has produced increasingly strict requirements on farmers to maintain historical flows for downstream users.

Jeffrey Niemann

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). Studies indicate that tamarisk stands may transpire significantly more water than native species, but their consumptive use is expected to depend on the water table depth, soil salinity, and many other factors (Shafroth et al., 2005). Another proposed strategy for conserving water is the application of polyacrylimides (PAM) to canals. PAM is a flocculant that promotes settling of clay particles out of canal water, which forms a lining on the canal bed that can 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 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. Figure 1 shows a roughly 50 mile segment of the LARV above John Martin Reservoir. In this figure, colored areas indicate land that falls within the command of the irrigation systems. Green areas were planted during the growing season of 2003. Yellow and brown areas identify naturally-vegetated and fallow lands, respectively. Approximately 50% of the land area was uncultivated during the growing season of 2003. This percentage is expected to vary between years, depending on the amount of available water, and to vary seasonally with much larger areas of uncultivated land occurring in the winter. Preliminary estimates of ET from uncropped areas in a portion of the region shown in Figure 1 during 1999-2001 are on average about 52,600 acre-ft per year (Burkhalter and Gates, 2005).

Much uncertainty persists regarding the effectiveness of proposed water conservation strategies, and 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. From studies in the literature, it is known that the ET depends on the proximity of the water table to the ground surface, and various functions have been proposed to represent this dependence including a power function (Gardner, 1958), an exponential function (Ripple et al., 1972), and a linear function (Banta, 2000). It is also known that the upflux from the ground water depends on the density and type of vegetation (Weeks and Sorey, 1973; Grismer and Gates, 1988; Jorenush and Sepaskhah, 2003). Furthermore, soil texture, salinity, salt crusting, surface cracking and transport of water vapor in the soil near the surface may play a role in determining this upflux (Grismer and Gates, 1988; Jorenush and Sepaskhah, 2003; Gowing et al., 2006). However, it is still not well-understood how all of these factors combine to control field-scale ET rates from uncultivated lands in a semi-arid environment. For example, Cooper et al. (2006) found that the reduction in ET due to a drawdown of the water table was over-predicted by 65-155% by two available models at one particular arid location. They hypothesized that the error in that case was due to long-term changes in vegetation cover as the water table dropped.

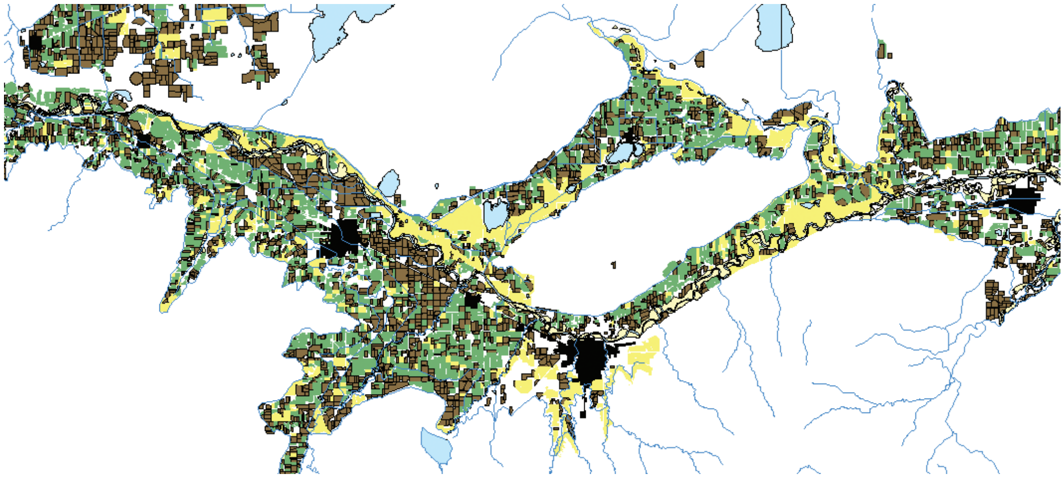


Fig 1: A portion of the agricultural lands in the LARV upstream from John Martin Reservoir. Green areas are cropped, yellow areas are naturally-vegetated, and brown areas are fallow. Data are derived from NDVI processing of five LandSat5 images taken in 2003. (Visit the CWRRI website for color version)

The overarching objective of this project is to quantify the controls on non-beneficial consumptive use of water from uncultivated lands in an intensively irrigated valley. In particular, we seek to determine: (1) the portion of total ET from uncultivated lands that comes from groundwater upflux and (2) the sensitivity of the non-beneficial ET to the water table depth. An improved understanding of the evaporative upflux from fallow fields and naturally-vegetated lands in the Arkansas Valley is expected to directly benefit the assessment of water conservation strategies in the valley. Such assessments necessarily rely on a calibrated regional model, such as MODFLOW-MT3DMS (Banta, 2000; Burkhalter and Gates, 2006), to forecast the changes in the hydrologic system that would result from proposed interventions. Such models typically calculate ground water upflux using an empirical function that depends on the water table depth DWT and reference crop evapotranspiration (ET0), which plays a central role in determining the sensitivity of ET losses to changes in DWT. An improved understanding of evaporative upflux is also expected to benefit soil salinity and water quality assessments. For example, Burkhalter and Gates (2006) used their model to estimate that a 30% reduction in ground water recharge from fields and a 50% reduction in seepage losses from canals would increase DWT by about 0.8 m in the upstream study region. The deeper water table is associated with an estimated 390 mg/l decrease in the soil salinity, which is expected to improve crop productivity. Moreover, reducing excess recharge and thereby lowering the water table may reduce the hydraulic gradient toward the river and diminish salt loads to the river by as much as 20 to 40% (Burkhalter and Gates, 2006). Such assessments are expected to be sensitive to the modeled relationship between ET losses and water table depth.

Approach

Our strategy focused on making detailed measurements at two uncultivated field sites in the LARV. ET was estimated using a remote sensing method, and potential explanatory variables, such as DWT, were measured in the field using a variety of techniques as described below. The two field sites were selected to represent different land-use conditions found in the valley (Figure 2). One of these sites is a retired field north of the town of Swink and close to the Arkansas

Fig 2: (left) Researcher downloading data from a raingage at the Swink field site and (right) Researcher downloading water table depth measurements at the Manzanola site.

River. The field is no longer cropped because it lies in a conservation easement that aims to reduce agricultural losses from floods. Because the site lies within the alluvial valley, it has very little topographic relief. The other 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.

Both ET and vegetation greenness at the two field sites were estimated from remote-sensing. Elhaddad and Garcia (2006) used thermal infrared and visible band information from the Landsat5 satellite in an energy balance approach to estimate ET in the LARV. These estimates were calibrated using weather station observations and are expected to have an accuracy of 10-20% (Elhaddad and Garcia, 2006). This approach provides ET estimates on a 30 m grid once every 16 days if cloud cover is not present (Figure 3). The remote sensing algorithm also produces the normalized difference vegetation index (NDVI), which measures the greenness of the vegetation. NDVI is related to the photosynthesis and transpiration of plants (Sellers, 1985), so it is expected characterize the extent to which the vegetation is actively transpiring water.

Nik Hallberg

Both field sites were extensively instrumented to quantify potential influences on the space-time variation of ET. Multiple monitoring wells were drilled using a GiddingsTM truck-mounted drill rig that was available from the USDA Natural Resources Conservation Service. 33 wells were drilled on a 60 m grid at the Swink site, and 22 wells were drilled on an irregular, approximately 45 m grid at the Manzanola site. Hobo® Water Level Loggers were placed at the base of most wells to continuously measure the water level above the sensor (accuracy of +/- 2.1 cm). 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. ET_o was also computed using data from a CoAgMet weather station at Rocky Ford, which is located about 5 mi from the Swink site and 15 miles from the Manzanola site.

On each date that the satellite passed and the sky was clear, measurements were made in each field of potential explanatory variables. Spot measurements of DWT were made at all wells using an electric tape. Gravimetric soil moisture was measured near all wells using soil samples

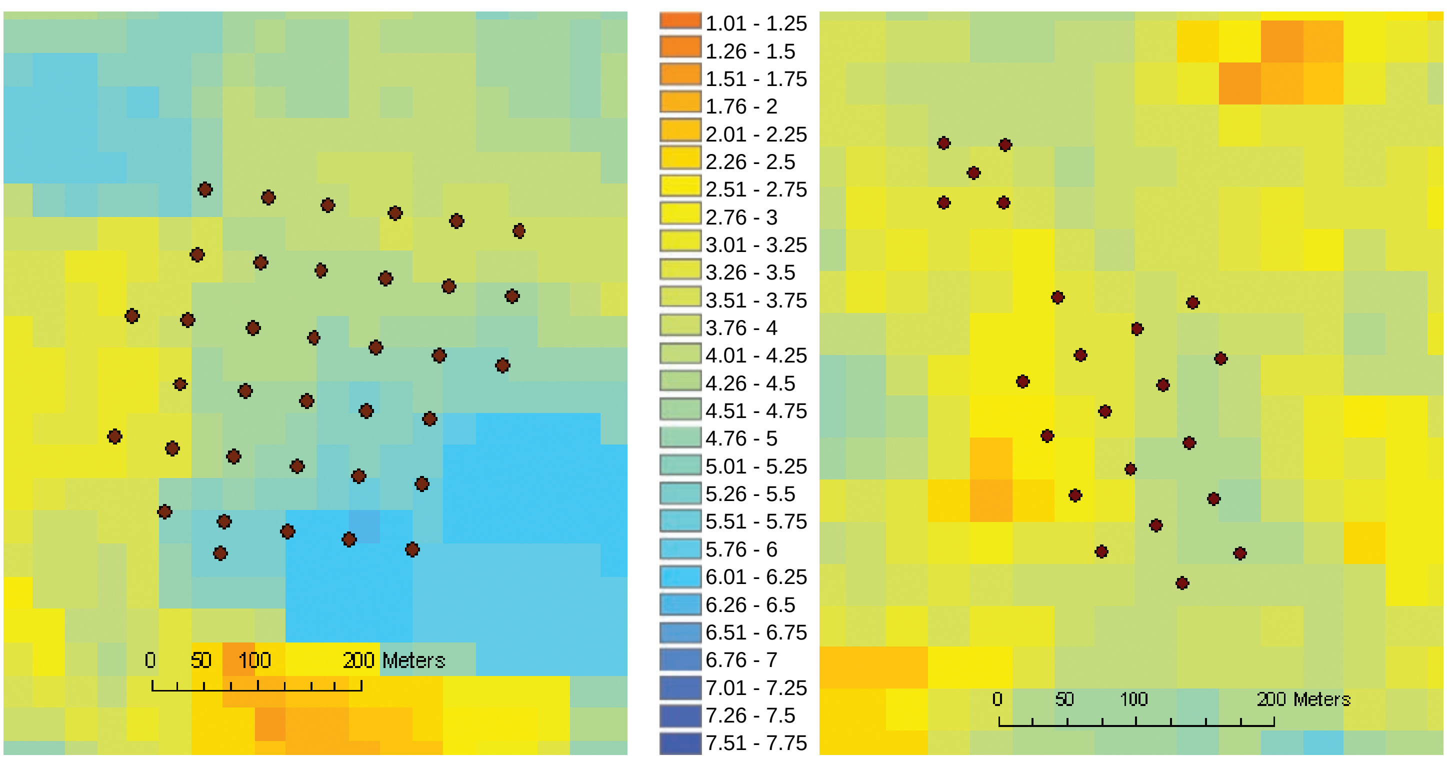


Fig 3: Spatial patterns of ET (mm/day) on 6/15/07 at the (left) Swink and (right) Manzanola field sites as estimated from the remote sensing algorithm. Dots indicate the locations of monitoring wells. (Visit the CWRRI website for color version)

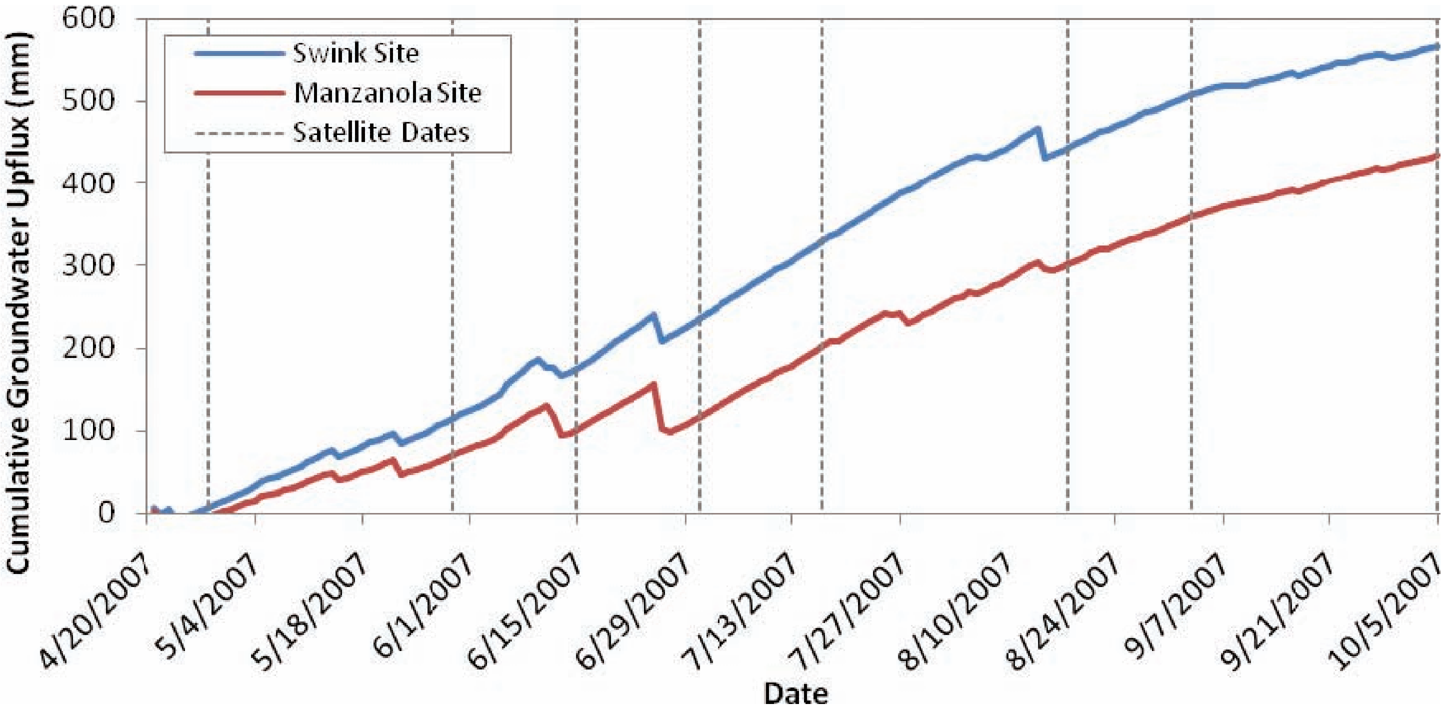


Fig 4: Estimated cumulative groundwater upflux in support of ET (mm) for the Swink and Manzanola field sites. Vertical lines indicate dates on which ET is estimated from remote sensing.

collected with an Oakfield probe at a 1 ft depth. Samples at 2 ft, 3 ft, and 4 ft depths were collected near 4 wells at each site using a soil auger. Soil salinity was estimated using a calibrated GeonicsTM EM-38 electromagnetic induction probe.

Analysis and Key Results

The contribution of groundwater upflux to the total ET was estimated using a water balance approach. First, the ET efficiency (ET / ET_o) for each field was estimated on each clear date that the satellite passed. The ET efficiency was then linearly interpolated between observation dates and multiplied by the continuous record of ET_o from the CoAgMet station to estimate the actual ET on each day during the growing season. 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 study period. The maximum possible contribution by changes in soil water storage was estimated by assuming that the soil began saturated and then fully dried over the course of the study period. This maximum possible contribution was found to be insignificant in comparison to the total ET during the study period. It is assumed that all precipitation became ET (i.e. no groundwater recharge occurred). Thus, the cumulative groundwater upflux during the study period can be estimated as the cumulative ET minus the recorded precipitation depths. These results are shown in Figure 4. Reference crop ET is on average 5.2-7.7 mm/day during the growing season. Actual ET for the two sites is estimated to be about 4.9 mm/day at Swink and 4.0 mm/day at Manzanola based on the remote sensing measurements. Based on the results in Figure 3, the groundwater upflux to ET is on average 3.4 mm/day at Swink and 2.6 mm/day at Manzanola, which is 65-70% of the actual ET. These estimates suggest that the non-beneficial consumptive use of water at both sites is primarily supplied from upflux from the shallow water tables at both sites.

We have also examined how much of the variability in ET can be explained by variations in the groundwater depth and other site characteristics. This issue was primarily investigated through a series of linear and nonlinear stepwise correlation analyses. In particular, the correlation analysis attempts to explain variations in ET / ET_o as linear or specified nonlinear functions of the potential explanatory variables. The stepwise approach incrementally adds variables to the regression equation and by evaluating whether the variance explained by each additional variable is statistically significant. At the Swink site, DWT is relatively uniform, varying less than 1.5 m between all the wells and all times. As a result, the variations of ET / ET_o within this field are not significantly influenced by the variations in DWT. Instead, vegetation as described by NDVI is the most important variable in explaining the variations in ET / ET_o (Figure 5a). The Pearson correlation coefficient between ET / ET_o and NDVI is 0.60 when grouping the observations from all dates at the Swink site. In contrast, the Manzanola site exhibits a larger range of DWT, varying from nearly 0 m to more than 2.5 m. At this site, the most important variable in explaining the variation in ET / ET_o is DWT (Figure 5b).

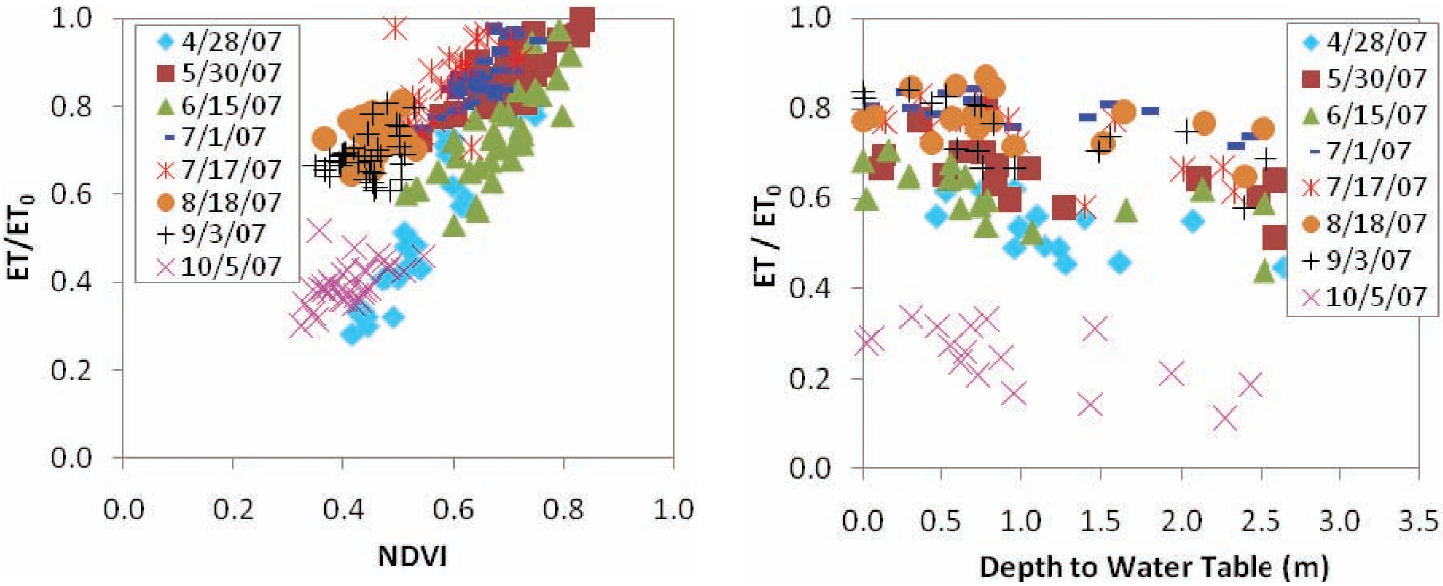


Fig 5: (left) The observed relationship between the evaporative efficiency (ET / ET0) and NDVI at the Swink field site, and (right) the observed relationship between evaporative efficiency and DWT at the Manzanola field site. (Visit the CWRRI website for color version)

When observations from all dates are included in the regression analysis, the correlation coefficient between ET / ET_o and DWT is -0.42, indicating that a larger water table depth tends to result in a smaller evapotranspiration efficiency.

Key Conclusions

Although monitoring and data analysis are ongoing, these preliminary results demonstrate that groundwater upflux was the dominant contributor to ET at both field sites during the growing season of 2007. This confirms that non-beneficial ET is closely linked to the presence of a shallow water table under the uncultivated lands in the LARV. Groundwater upflux is expected to be an important contributor to ET at uncultivated sites in the LARV where the water table is relatively close to the ground surface, but the quantitative contribution of groundwater upflux is expected to depend on the local soil and vegetation characteristics. Fluctuations in ET were shown to depend on fluctuations in the depth to the water at one of the two study sites. This site (the Manzanola site) exhibited a wider range in water table depths due to the topographic variability at the site. The relationship identified at this site still contains much unexplained scatter, but it hints that observable reductions in ET could be achieved if the water table is lowered by 1 to 2 m. Much more research is needed to clarify this relationship. In particular, the spatial variations of ET observed here may not be analogous to the temporal changes in ET that would result from lowering the water table. In particular, the vegetation patterns have likely adapted to the spatial variations in water table depth within these sites. If the water table was 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.

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Consumptive Irrigation Water Use Intermountain Meadows of Colorado

by Dan H. Smith, Department of Soil and Crop Sciences, Colorado State University

Irrigated mountain meadows are widely distributed throughout the intermountain west. In Colorado and Wyoming these meadows typically are continuously flood-irrigated using surface water supplies from adjacent streams. Irrigation commences in early May, when the beginning of spring runoff begins, and continues until just prior to the time when pastures are harvested for hay (usually late July to mid-August). After the hay is removed, a second cycle of irrigation occurs in some meadows if late-season streamflows are adequate.

Irrigated meadows account for more than 95% of total water use in the upper reaches of many basins in Colorado. Because of rapid population growth along the Front Range of eastern Colorado, water used to irrigate meadows became the target of municipalities in the latter part of the 1900's. This trend continues to the present, especially in South Platte River basin. In other intermountain basins, increased water demand for population growth and instream flows has sustained water transfers from meadows. Before these transfers can occur, engineering assessments of the magnitude of consumptive water use must be completed, so accurate estimates of depletions associated with irrigation of mountain meadows are essential.

In 1998, the Upper Gunnison Water Conservancy District provided CSU with part of the funding required to conduct field studies to refine methods that would accurately account for consumptive water use of irrigated meadows in the basin. In addition to their local importance, these estimates over wider regions were of interest because of their role in certifying Colorado's status relative to various interstate water compact agreements.

Current models used to estimate consumptive water use in irrigated mountain meadows are generally derived from temperature-based Blaney-Criddle methods (Blaney and Criddle, 1962). This is a reasonable strategy because the climatic data necessary for more sophisticated methods of computing evapotranspiration (i.e., Penman combination methods) are not available. The Blaney-Criddle approach involves computation of consumptive use over relatively extended periods (15 days or more) using average daily temperature (average of minimum and maximum), a daylength function, and a crop coefficient. The function is expressed as follows:

$$u = kf$$

where:

u = consumptive use of a given crop for a given month (inches)

k = empirical monthly crop coefficient

f = monthly consumptive use factor, measured as $(t \times p) / 100$

with:

t = mean monthly air temperature (°F)

p = monthly percentage of daytime hours in the year

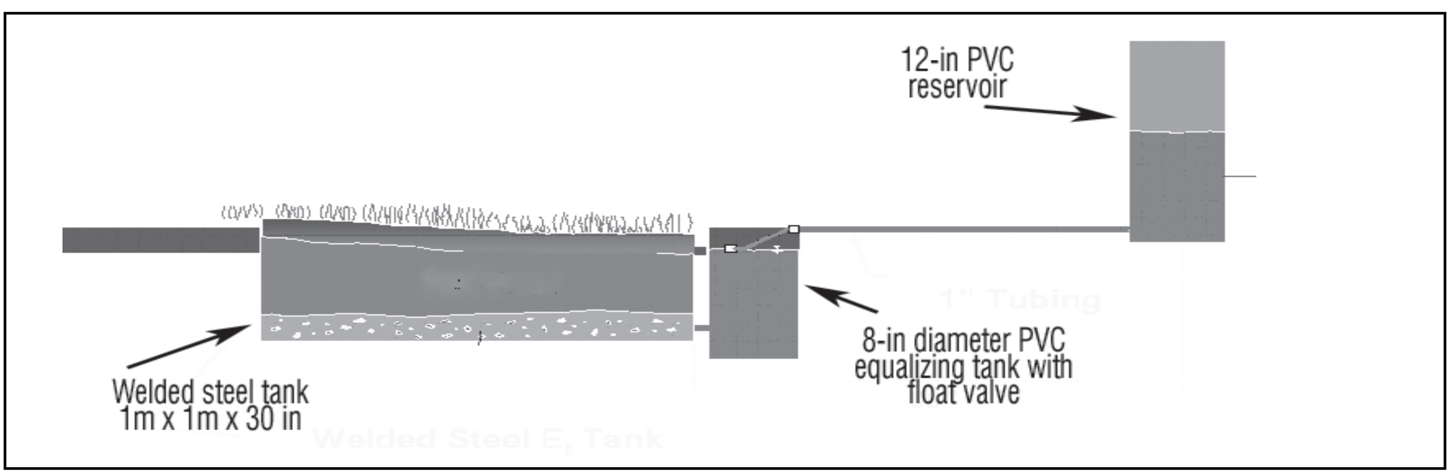


Fig 1: Schematic drawing of compensating lysimeters. The lysimeter is filled in layers with a gravel base covered by soil excavated from site and topped by sod removed from the site. Water table level within the lysimeter is maintained by positioning of a float valve within an equalizing tank. The reservoir tank supplies water to the lysimeter to replenish the volume of water consumed by evapotranspiration. Consumptive water use over an interval of time is determined by measuring the decline in water level within the reservoir.

In their original article, Blaney and Criddle presented suggested monthly crop coefficients for various crops, including grass pastures, for many different regions of the US and selected sites worldwide. These projections were based on data available at the time. The authors acknowledged, however, that these coefficients included both crop and meteorological effects. As a result, use of the originally published monthly crop coefficients often produces significant variation between computed consumptive use values and those obtained from lysimeter measurements. These errors are known to be especially high in semi-arid, high-altitude environments (Doorenbos and Pruitt, 1977).

The general approach to resolving the problem of inaccuracies in monthly crop coefficients is to conduct lysimeter assessments of actual evapotranspiration that allow for the computation of locally calibrated crop coefficients. As background, we identified three previous calibration studies conducted in Colorado mountain meadow environments. Kruse and Haise (1974) performed lysimeter studies at a single site on Ohio Creek in the Gunnison basin during three different years and at two sites in South Park (near Garo, CO in the upper South Platte River basin) over three growing seasons. Additional South Park investigations were conducted by Walter et al. (1990) using multiple lysimeter sites. Following this work, Carlson et al. (1991) carried out lysimeter calibration studies at two sites in the upper Colorado River basin in Grand County.

Approach

In response to local needs in the upper Gunnison River basin we conducted studies to determine appropriate temperature-based methods of estimating consumptive water use. Field verification of these methods included direct measures of actual evapotranspiration (consumptive water use) using compensating lysimeters under fully irrigated conditions. The work was conducted over five consecutive growing seasons (1999 to 2003). Sites were selected in meadows of each of the major hay-producing subbasins within the Gunnison River basin, including meadows located adjacent to the Slate River, the East River, Ohio Creek, Quartz Creek, upper and lower Tomichi Creek, and the main stem of the Gunnison River above the town of Gunnison. Schematic illustrations and photographic images taken during lysimeter installation are presented in Figures 1 and 2, respectively. Temperatures and precipitation were monitored continuously at each of the sites.

Fig 2: Compensating lysimeters consisted of rectangular steel tanks installed in meadows after excavation of sod and soil. These photos illustrate the installation of the lysimeter (left) and a functioning lysimeter with accompanying weather-monitoring equipment during the growing season (right).

Lysimeter construction, installation, and maintenance and data collection procedures were essentially the same as those used for the previously referenced calibration studies. At the beginning of each season water was added to the lysimeters, float tanks, and reservoirs, and the lysimeters were allowed to adjust internally until the water table within the lysimeter achieved a depth designed to mimic the depth that would be observed in the surrounding meadow under irrigated conditions. Once this condition was reached, water-use observations were begun. Our goal was to initiate measurements at each site by the time irrigation in the surrounding meadow began. This was usually on May 1; however, the lysimeters at the eight monitoring sites used in 1999 were installed just prior to the beginning of the growing season, so recorded observations during the first year did not begin until June 1. Monthly observations of consumptive use from each lysimeter were compiled and used to calculate monthly crop coefficient values.

Results and Analysis

There was no evidence of significant variation in monthly average temperatures or consumptive water use among sites, so the results for this study are expressed as basin-wide averages. These are presented in Table 1 along with those from the previously cited calibration studies.

Comparisons among the coefficients revealed both interesting trends and troubling inconsistencies. Our k values were most similar to those recommended by Walter et al. (1990). However, the coefficients generated from our studies were remarkably dissimilar to those from all the previous calibration studies in the upper Gunnison basin (Kruse and Haise, 1974), South Park (Walters et al., 1990), and the upper Colorado (Carlson et al., 1991). Another striking trend observed in the results from each of the studies was the considerable variability in monthly coefficients from year-to-year. In many instances, the greatest discrepancies, either among the averages from different studies or among years within the same study, were observed in the coefficients for May, June, and July, the months of highest water use. Thus, potential errors in estimates of seasonal water use could be magnified by selection of the least accurate coefficients for these months. Because all of the coefficients presented in Table 1 were generated from actual water use data, it follows that our conventional methods for determining locally applicable crop coefficients fail to account for one or more variables affecting water use. This is not surprising since temperature is the only variable available to estimate crop consumptive water use, which is known to be a function of temperature and other variables (radiation, wind, and humidity) affecting surface energy balance.

After noting the magnitude of the variability in monthly Blaney-Criddle crop coefficients, we focused on the temperature variables that could potentially account for this deviation, the monthly average of daily maximum and minimum temperatures (T_{avg}) and the monthly average in the difference between the daily maximum and minimum temperatures (T_{diff}). We conducted correlation analyses to determine the nature and significance of any potential relationships between monthly crop coefficients and the temperature variables. For this exercise, we used results from our studies (averages over all sites for each individual year) and those from the previously cited calibration studies (Kruse and Haise, 1974; Walter et al., 1990; Carlson et al., 1991). In all instances, data from each individual month were pooled and analyzed separately.

The results of the correlation analyses are reported in Table 2. For three of the five months, the difference in the maximum and minimum daily temperature (T_{diff}) was more closely correlated with the Blaney-Criddle crop coefficient than the average daily temperature (T_{avg}). More importantly, T_{diff} and monthly k values were highly correlated during May and June, two of the three months that account for most of the

Table 1

Average and range in monthly Blaney-Criddle crop coefficient (k) values for the current study and from other calibration studies conducted in Colorado. Also presented are monthly k values recommended for mountain meadows by Walter et al. (1990).

		k values	
Study / Region	**Month**	**Average**	**Range**
Current Upper Gunnison	May	1.29	1.12-1.48
	June	1.42	1.25-1.55
	July	1.13	0.94-1.25
	August	0.83	0.68-0.96
	September	0.86	0.71-0.95
Kruse and Haise Gunnison	May	1.19	1.17-1.20
	June	1.01	0.91-1.10
	July	0.95	0.87-1.02
	August	0.81	0.77-0.86
	September	0.79	
Kruse and Haise South Park	May	1.01	0.82-1.20
	June	1.16	0.91-1.37
	July	0.98	0.84-1.13
	August	0.73	0.69-0.77
	September	0.89	0.71-1.07
Walter et al. South Park	May	1.38	1.12-1.65
	June	1.36	1.18-1.74
	July	1.33	1.06-1.62
	August	1.10	0.63-1.33
	September	1.24	0.99-1.54
Carlson et al. Upper Colorado	May	1.08	0.98-1.21
	June	1.12	1.00-1.33
	July	1.09	0.90-1.20
	August	0.88	0.77-0.97
	September	0.97	0.85-1.04
Recommended values (Walter et al.)	May	1.18	
	June	1.40	
	July	1.22	
	August	0.81	
	September	0.86	

Table 2

Correlation coefficients (r) and the significance of the relationships (P) between the monthly Blaney-Criddle crop coefficient (k) and either average daily temperature (T_{avg}) or the average daily difference in the maximum and minimum temperature (T_{diff}).

	k vs T_{avg}		k vs T_{diff}	
Month	**r**	**P***	**r**	**P**
May	0.28	0.235	0.63	0.0030
June	0.18	0.419	0.58	0.0048
July	0.57	0.006	0.52	0.0131
August	0.49	0.022	0.71	0.0002
September	0.44	0.058	0.41	0.0812

**P value indicates the probability that the correlation observed could have occurred by chance alone without there being any significant relationship between the two variables.*

Table 3

Regression equations for estimating monthly Blaney-Criddle crop coefficients (k) from the average daily difference in the maximum and minimum temperature (T_{diff}).

Month	Prediction Equation
May	$k = -0.231 + 0.045\ (T_{diff})$
June	$k = 0.085 + 0.035\ (T_{diff})$
July	$k = 0.216 + 0.028\ (T_{diff})$
August	$k = -0.674 + 0.046\ (T_{diff})$
September	$k = 0.172 + 0.023\ (T_{diff})$

irrigation water use in mountain meadows. Conversely, T_{avg} was poorly correlated with monthly crop coefficient values during May and June. Overall, these results demonstrated that monthly T_{diff} values were better predictors of monthly Blaney-Criddle crop coefficients than T_{avg}. For the months of May, June, and August T_{diff} versus k value relationships are relatively "robust," with T_{diff} accounting for up to 50% of the year-to-year variation in monthly crop coefficients. For the remaining months, the Tdiff variable is still an adequate predictor of k values.

In retrospect, the superiority of T_{diff} over T_{avg} in producing more accurate estimates of monthly crop coefficients is not surprising. The only weather variable used in computing the consumptive-use factor (the f-value) Blaney-Criddle formula is T_{avg}. Use of this variable to compute a correction factor (the crop coefficient) for consumptive use represents dual use of a single variable. The difference in the maximum and minimum daily temperature is a temperature variable that is distinctly different from T_{avg}. The variable T_{diff}, originally used by Hargreaves and Samani (1985), provides reasonably accurate estimates of solar irradiance. In most cropping situations, solar radiation is the dominant source of energy driving evaporation and transpiration, the two factors that account for consumptive water use.

Correlation analysis was conducted separately for each month of the season because cropping and management factors vary over time during the growing season. Least-squares linear regression techniques were then used to determine the optimum predictive relationship between T_{diff} and monthly crop coefficients. The specific regression formulas generated through this process are presented in Table 3.

The database used to develop the predictive equations in Table 3 encompassed a relatively wide range of elevations and climatic conditions within intermountain meadows of central and northern Colorado. We anticipate that these equations can be used to adjust monthly Blaney-Criddle crop coefficients to account for year-to-year variation in environmental conditions for sites or areas that have similar climates or for variation among sites that differ in long-term climatic conditions. The key question, however, is whether the approach of using the variable T_{diff} to adjust crop coefficients is superior to the use of average values of monthly crop coefficients derived from local calibration studies conducted over multiple years. We have not yet performed the analyses required to answer this question definitively.

2008 CWC 50th Annual Convention
January 23-25, 2008 at the Hyatt Regency Denver Tech Center

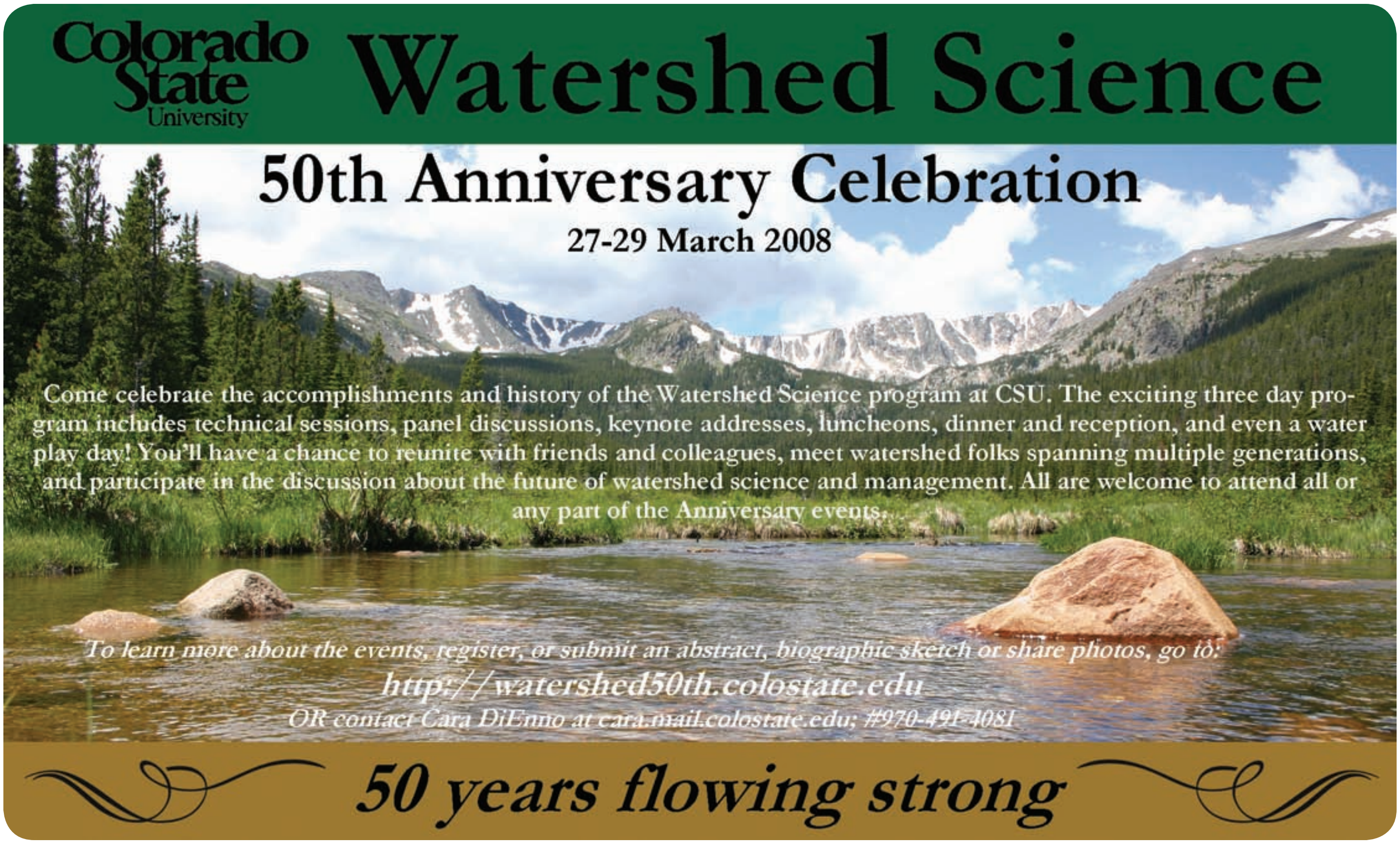
This convention will start off with An Audience Dialogue with State Legislators and State Water Legislation on the Horizon for 2008 with Representative Kathleen Curry, and Senator Jim Isgar.

If you are interested in attending this convention, please visit http://cowatercongress.org/ to register.

If you are interested in sponsorship or exhibit booth space, please contact Mary Stirling at (303) 837-0812 or cwc@cowatercongress.org

Hyatt Regency Denver Tech Center
7800 East Tufts Avenue
Denver, CO 80237
(303) 779-1234

Conference topics include:
- Water Planning in an Uncertain Future
- Colorado State Engineer
- Endangered Species Recovery Programs
- New Approaches To Water Management
- Water Science
- Water Law
- Water Engineering and Management
- Wild and Scenic Rivers
- Colorado Water Conservation Board
- Water and Energy
- Water Planning and Finance
- New Concepts in Water Management
- Water Studies
- Water Engineering and Management



The 6th Annual DARCA Convention: Acequias in Colorado February 21-22, 2008 at the Sangre de Cristo Parish Center, San Luis Colorado

The convention will again provide a wealth of information on a broad array of issues relevant to Colorado's water providers. The first day of the convention will focus on land and water issues in the Rio Grande Basin including the importance of acequias in Colorado and New Mexico. Congressman John T. Salazar will be the keynote speaker and representatives from the Lower Arkansas Valley Water Conservancy District will discuss their efforts in organizing the Super Ditch in the Arkansas Valley.

On the second day, Jim Csabay from the St. Mary River Irrigation District in Alberta, Canada will tell about how to creatively deal with water shortages in times of drought.

DARCA

Ditch and Reservoir Company Alliance

DARCA will also present Flow Measurement for Ditch Companies, the pre-convention workshop on February 20 from 9:00 a.m. to 4:00 p.m. at the Fort Garland Museum in Fort Garland, Colorado.

The Ditch & Reservoir Company Alliance, a nonprofit organization, established in 2001, is dedicated to serving the needs of mutual ditch and reservoir companies, irrigation districts and lateral companies.

For information regarding convention registration as well as sponsorship or exhibitor opportunities please visit www.darca.org or contact the event coordinator, Max McKenzie, at 303 875-2809.

Detecting Trends in Evapotranspiration in Colorado

by W. Austin Clifford, Colorado Climate Center and
Nolan J. Doesken, Colorado State Climatologist

Abstract

There is increasing evidence that temperatures throughout parts of Colorado and most of the Western U.S. have warmed detectably in the past 20 years and may continue to rise. What this means for Colorado's water resources is uncertain since increased temperatures could be associated with either more or less precipitation, or seasonal changes in the distribution of precipitation. Since precipitation is inherently highly variable in both time and space, it may require many decades to confidently assess systematic changes. The less studied and possibly more answerable question is "What does this mean for evaporation and transpiration rates and consumptive use of Colorado's precious and limited water supplies?" In particular, are we capable, with existing weather data, to detect local and regional differences, year-to-year variations and potential long-term changes in ET and consumptive use?

In the first year of this exploratory study, data from the Colorado Agricultural Meteorological Network (CoAgMet) (www.coagmet.com) were closely examined to determine if they are able to accurately detect spatial and temporal variations in evapotranspiration (ET). CoAgMet is the only statewide network of weather observing sites that measure all of the standard climate elements that directly affect ET rates: temperature, humidity, wind movement, solar radiation, and precipitation. Using the Penman-Monteith model for computing alfalfa reference ET, results show that average May-Sept. ET is highest in the Arkansas River basin where the average seasonal reference ET is 51 inches. and lowest is the North Central region where the seasonal average is 41 inches. At any given station, the difference in cumulative ET from a low ET year to a high ET year is about 7 inches. The highest reference ET values were noted in 2002, Colorado's extreme drought year. 1994 was also very high. Low ET rates were observed 1995-1999. Overall, there is an apparent upward trend in reference ET, but with only 16 years of data these preliminary results are not statistically significant. Comparisons with data from Northern Colorado Water Conservancy District (NCWCD) showed that CoAgMet ET estimates correlate well with data from NCWCD's well-maintained weather station network, but CoAgMet shows systematically higher ET rates and more station to station variability. In summary, CoAgMet has the

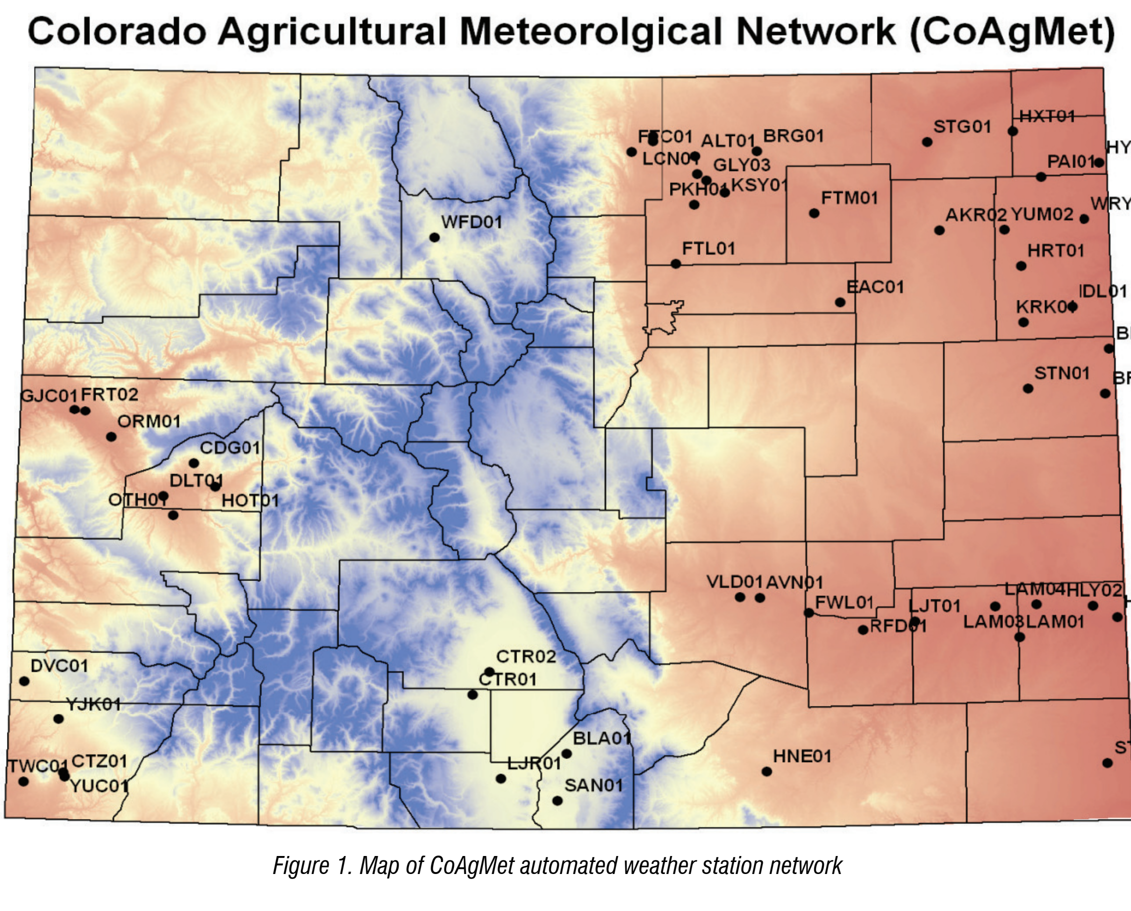


Figure 1. Map of CoAgMet automated weather station network

potential to provide critical information for water resource assessments and decision support. However, periods of missing data, infrequent instrument calibration and potentially unrepresentative locations for some weather stations have compromised CoAgMet data quality for long-term ET applications. Improvements in station maintenance and exposure are encouraged so that the CoAgMet network can be an even more valuable part of Colorado water management and planning for the future.

Introduction

In 1989, two unrelated agricultural research programs in Colorado, both collecting detailed weather data, decided to informally share resources and combine efforts to improve and expand access to timely agricultural weather data (Doesken et al., 1998). This resulted in the establishment of the Colorado Agricultural Meteorological Network (CoAgMet) – a system of automated weather stations that measure and report temperature, humidity, wind speed, direction, solar radiation, precipitation and soil temperatures (examples of stations are shown in Figures 5-6). The majority of the stations are located in areas of intensive irrigated agriculture (Figure 2). These weather stations continuously monitor the weather elements that directly influence the water used by plants – temperature, humidity, wind, sunshine and precipitation. CoAgMet has grown to include 60 active stations. Several new stations were added in 2003-05 in the lower Arkansas River Basin in Colorado as a direct consequence of litigation of the Arkansas River interstate compact with Kansas. The network has never been well funded but is managed as a loose federation of motivated organizations with a shared interest in weather data serving Colorado's diverse agricultural needs.

Colorado water courts have long accepted estimates of consumptive use based upon the Blaney-Criddle (1950) model. The Penman-Monteith model is quickly becoming the accepted standard method, but to be effective long-term detailed meteorological data must be readily available.

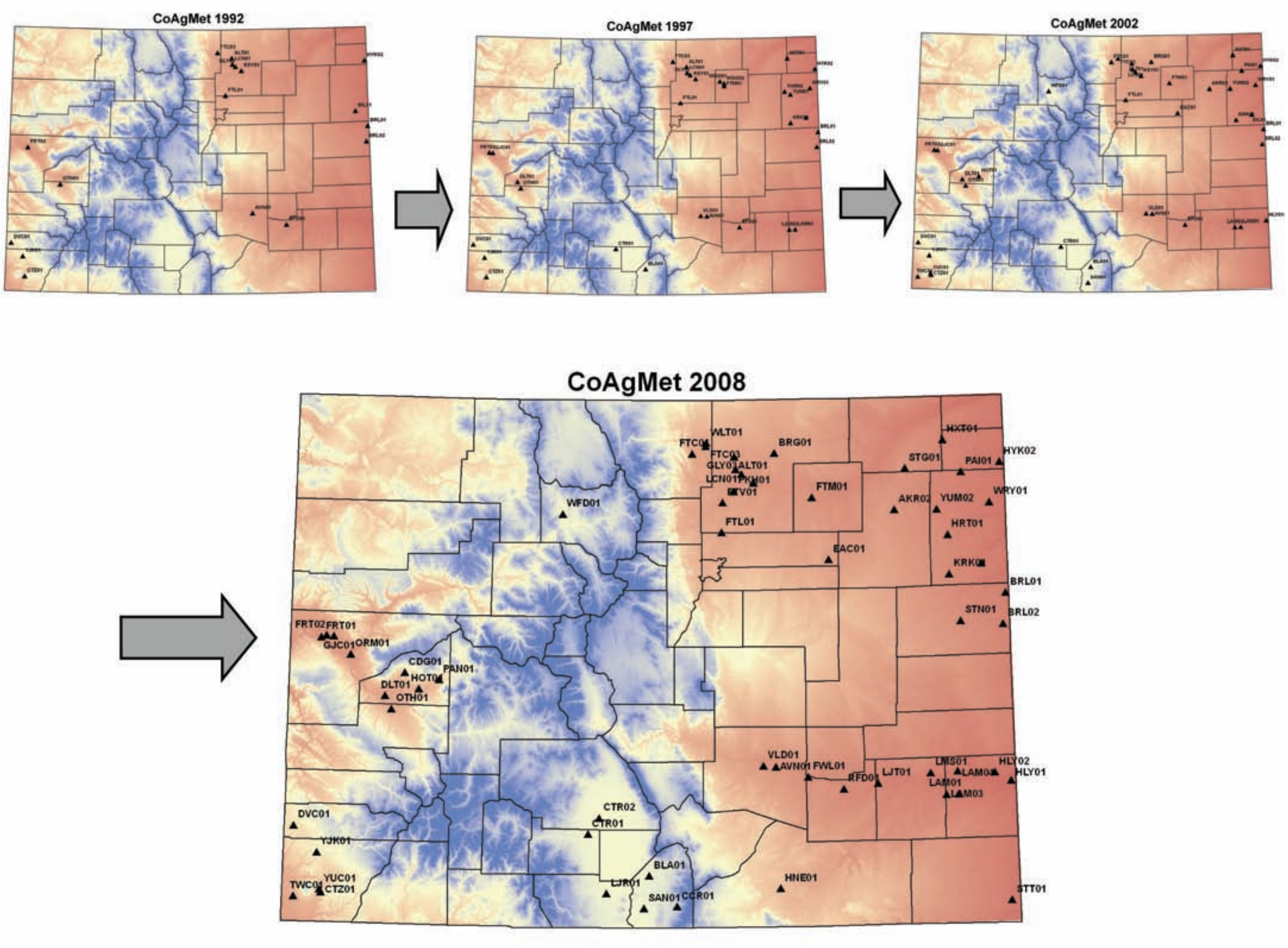


Figure 2. History of CoAgMet (1992-2008)

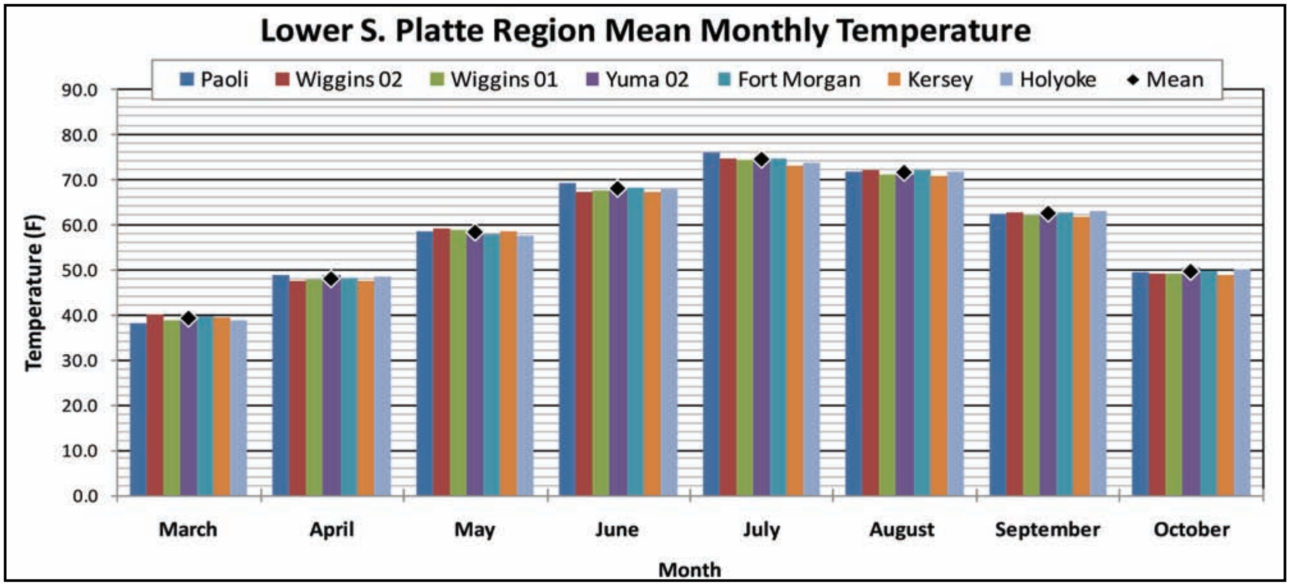


Figure 3. Lower S. Platte Region Mean Monthly Temperature

Methods

After completing the network-wide data quality assessment and comparison, then the Penman-Monteith seasonal cumulative ET was calculated for all stations from the available daily data sets. The growing season was defined as the period from 1 May to 30 September.

Mean cumulative July ET values were compared separately. This aided in determining which stations may have unrepresentative siting. It should be noted the CoAgMet Network has traditionally used the Kimberly-Penman (1982) model for estimating ET. Since the initiation of this study, Penman-Monteith estimates are now co-generated by CoAgMet.

Relatively large differences in monthly and seasonal ET values were noted among stations in each region. To help explain these variations, station locations, elevation and proximity to irrigated land were assessed. Photographs of the CoAgMet stations were examined, and interviews were conducted with CoAgMet collaborators familiar with each station.

Results

Many CoAgMet weather stations are missing significant amounts of data, as seen in Figure 4. There are no stations with serial complete data since 1992. Overall, data are more than 90% complete for many stations. The data quality between regions has varied in the past. The San Luis Valley region overall had the most data gaps, and the North Central Region typically had the most complete data. The Lower S. Platte and the Arkansas River Valley Basin showed

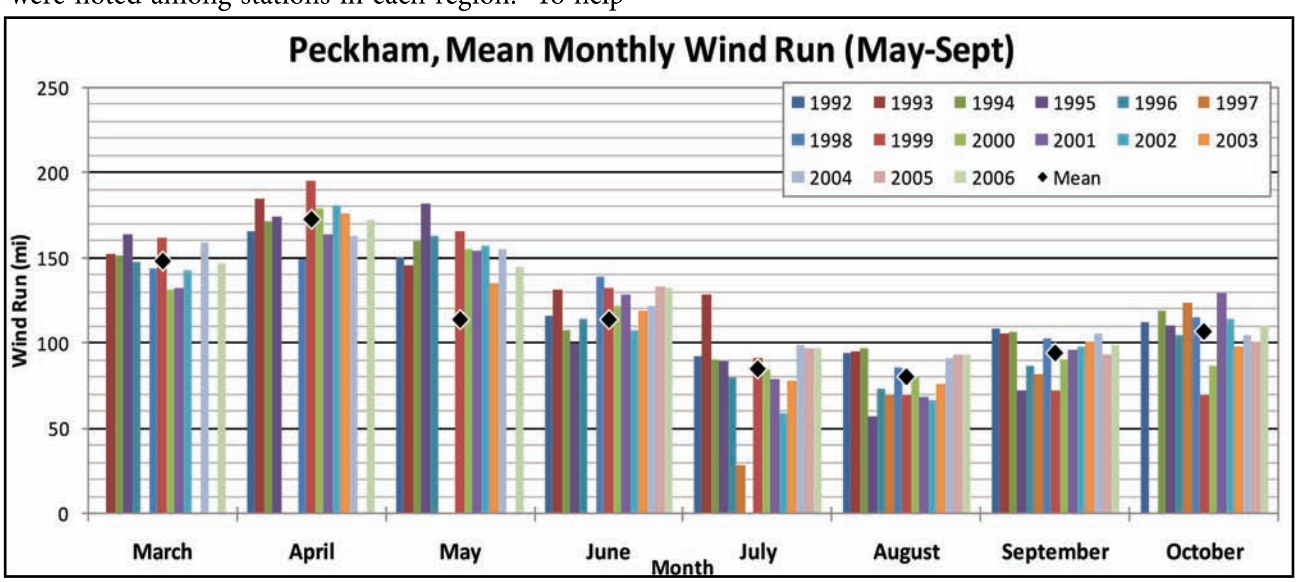


Figure 4. Mean Annual Monthly Wind Run (May-Sept) for Peckham

reasonably complete and consistent data. Unfortunately, for this study, some of the best data in the Arkansas River Valley was measured by stations relatively new to the network, so long time series of high quality data were not yet available based on a large aggregate of stations.

Due to the voluntary nature of CoAgMet and its' ad hoc history, station siting has not been uniform. Some sites are located over or adjacent to clipped grass or alfalfa, while others are in unirrigated areas. Some sites may not fully represent weather conditions observed over irrigated fields so may not be ideal or appropriate for ET applications. Some stations are on the fringe of irrigated areas and some are in dryland areas. Their meteorological data are still valuable for many applications, but the exact local siting affects how suitable each station is for representing ET rates for adjacent cropland. We will be providing a more complete assessment in year two of this project based both on site documentation and computed ET rates.

Conclusions

Close scrutiny of weather data and computed reference ET estimates for seven agricultural regions of Colorado have been completed for the period 1992-2007 using weather data from the Colorado Agricultural Meteorological network (CoAgMet). May-September alfalfa reference ET was shown to be highest in the Arkansas River basin (51 inches) and lowest is the North Central region (41 inches). Year to year variations in computed reference ET are not large (generally less than 15% of the long-term average). At any given station, the difference in cumulative ET from a low ET year to a high ET year is about 7 inches. The highest reference ET values were noted in 2002, Colorado's extreme drought year. ET was also very high in 1994 was also very high. Low ET rates were observed 1995-1999. Overall, there is an apparent upward trend in reference ET, but with only 16 years of data these preliminary results are not statistically significant. Comparisons with data from Northern Colorado Water Conservancy District (NCWCD) showed that CoAgMet ET estimates correlate well with data from NCWCD's well-maintained weather station network, but CoAgMet shows systematically higher ET rates and more station to station variability.

This study shows that CoAgMet has the potential to provide critical weather information to assess year to year variations in reference ET necessary for irrigation scheduling, water resource assessments and decision support. However, periods of missing data, infrequent instrument calibration and potentially unrepresentative locations for some weather stations have compromised CoAgMet data quality for long-term ET applications. Improvements in station maintenance and exposure are encouraged so that the CoAgMet network can become an even more valuable part of Colorado water management and planning for the future.

Figure 5. CoAgMet volunteer Dr. Harold Duke services Dove Creek. Due to the lack of underlying vegetations, sites like this may not be ideal for ET applications

Figure 6. Fort Collins AERC is an example of a clipped grass environment

Future Plans

One more year of work remains under this CWRRI funded project. In 2008, correlation statistics will be developed to provide quality estimates for missing data from stations within each region. CoAgMet station siting will be further assessed. The CoAgMet website will be annotated so that users know which stations are appropriate for reference ET use. Missing data will then be filled in from previous years to create serially complete time series for many stations. This will give a much needed increase in available data for long-term trend analysis. Time series will then be recomputed and evaluated. Further statistical analysis will be completed, including a step-wise regression sensitivity analysis to better understand which weather variables have the greatest impact on computed reference ET here in Colorado. Beginning in early 2008, results from this study will be presented to the CoAgMet advisory team. Efforts to provide reliable funding for CoAgMet and to assure proper instrument siting and consistent maintenance must be given high priority.

For entire report, including site data, please visit http://www.cwrri.colostate.edu/2007_CoAg_Report.pdf

Colorado Water Workshop

Pete Lavigne, Director 970-943-3162 fax 970-943-3380 plavigne@western.edu

Call for Papers, Posters and Presentations!
Water Workshop May 14-16, 2008

Our theme for 2008 is **Mining, Energy and Water in the West**. We'll be looking at the water quality and supply issues around the revival of mining and energy production in the region including coal bed methane production in Colorado, Utah, Wyoming and elsewhere; coal mining in Colorado, Arizona and other areas; reopening and/or new uranium and molybdenum mining; water related effects of the ethanol boom; and other topics you suggest related to mining, energy development and water.

We'll also have updates on other Colorado issues including the 1177 process and possibly the Black Canyon litigation.

Send your proposals now! ***Abstract deadline January 10, 2008.***

Send to ***water@western.edu***

Pete Lavigne, Director
Colorado Water Workshop
Western State College
Gunnison, CO 81231

Phone: 970-943-3162
Fax: 970-943-3380
E-mail: **water@western.edu**
www.western.edu/water

Colorado Water Workshop 2007 Photograhs

(top) A CWW Presentation, (left) Pat Mulroy, Pamela Hyde and Jack Schmidt at the 2007 Water Workshop, (right) Ferrell Secakuku former Chairman, Hopi Tribe.

CSU Research Colloquium
Global Water: From Conflict to Sustainability
Tuesday, March 25th, 2008
Hilton Hotel, Fort Collins, Colorado

2005-2015 is the decade designated by United Nations as the International Decade for Action: "Water for Life." 2008 or the "International Year for Sanitation" coincides with many of the issues we are facing today in Colorado including: poor water quality and salinization, wastewater treatment, aging sewer systems, and antiquated policy & institutional frameworks. Historically, international work in water resources has long been a focus at Colorado State University. Today, international water research and development continues and is spread across campus ranging from Engineering, Natural Resources and Agriculture to Sociology, Environmental Health, Business and Biological Sciences.

Environmental and human induced climate changes are effecting natural water regimes world-wide. The Global Water Colloquium aims to present the impact these changes have on decreasing water quality and increasing water scarcity visible across spatial and temporal scales in the hope that the university community will engage in open discussions and collaborative solutions. Many such solutions in the form of technological advances in hydrology and hydraulics will be presented during the 28th Annual Geophysical Union - Hydrology Days being held directly after the Global Water Research Colloquium on March 26-28. Warner College of Natural Resources will be hosting a three day event to celebrate 50 years of the Watershed Science Program beginning March 27th.

The colloquium is designed to benefit investigators with research activities that could be applied to water resources at a local, regional, national and international level as well as researchers with established water resources research programs. Individuals, private consultants, public administrators, managers, policy makers, and those interested in learning more about international research activities in water resources would also benefit from the research colloquium.

The Global Water: From Conflict to Sustainability Colloquium is hosted by the Office of the Vice President for Research. For updates on all these events please visit the Vice President for Research Web site. http://www.vpr.colostate.edu

Contact
Faith Sternlieb
CWRRI Research Associate
faith.sternlieb@research.colostate.edu
(970) 491-6328

FY08 Student Water Research Grant Program

Request for Proposals

The Colorado Water Resources Research Institute is pleased to announce a request for proposals for the FY08 Student Water Research Program.

Program Description

This program is intended to encourage and support graduate and undergraduate student research in disciplines relevant to water resources issues and to assist Colorado institutions of higher education in developing student research expertise and capabilities. It is intended to help students initiate research projects or to supplement existing student projects in water resources research. Proposals must have a faculty sponsor and students must be enrolled full-time in a degree program at one of Colorado's nine public universities (ASC, CSM, CSU, CU, FLC, MSC, MSCD, UNC, or WSC).

Funding

Budgets may include, but are not limited to, expenditures for student salaries, supplies, and travel. Funds will not be approved for faculty salaries. Each award is limited to a maximum of $5,000. Awards may be effective as early as April 1, 2008 and research projects should be completed by March 31, 2009. For these research grants, only direct costs are allowed. Facilities & Administrative (F&A) costs may be shown as institutional cost share. Institutions are encouraged to participate in project costs although cost sharing is not required.

Eligibility

Students must be enrolled full-time in a degree program at one of the nine Colorado public universities. Proposals must have a faculty sponsor from the applicant's institution. The faculty sponsor is responsible for ensuring that the proposal has been processed according to their university's proposal submission policies and procedures.

Deliverables

Upon completion of the research project, recipients will be required to submit a final project report, which will include a narrative on research activities and results. **Projects must be completed and results reported by March 31, 2009.** Students may be asked to present an oral report on their work to the CWRRI Advisory Board.

Submission Process

All proposals must be submitted online. Please visit http://www.cwrri.colostate.edu for submission site.

Proposal Deadline

February 29, 2008 at 5:00pm MT

Expected Award/Start Date

Start Date: April 1, 2008

End Date: March 31, 2009

Announcement of Awards

The student applicant and faculty sponsor will be notified as to the status of their application by March 31, 2008 via email.

Program Contact Information

For questions concerning the program, please contact:

Dr. Reagan Waskom, Director
reagan.waskom@colostate.edu

Nancy Grice, Assistant to the Director
nancy.grice@colostate.edu

Phone: 970-491-6308

Fax: 970-491-1636

Web: http://www.cwrri.colostate.edu

FACULTY PROFILE

Allan Andales

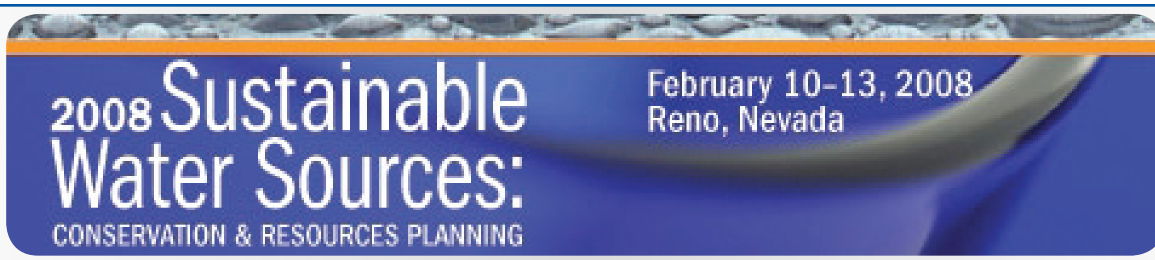
Colorado State University, Department of Soil and Crops Sciences

Allan Andales joined the Department of Soil and Crop Sciences in August, 2007 as an Assistant Professor. He has Agricultural Engineering (Soil and Water emphasis) degrees from the University of the Philippines (BS) and Iowa State University (MS and PhD). He has worked as an Assistant Professor of Agricultural Engineering at the University of the Philippines at Los Baños, as a postdoctoral fellow working on irrigation of pecan trees at New Mexico State University, and as a Soil Scientist with USDA-Agricultural Research Service-Agricultural Systems Research Unit in Fort Collins, Colorado. His primary research activities with USDA focused on computer modeling of agricultural systems (cropland and rangeland) and related field measurements to characterize the systems. Allan has 13 years of experience in developing and using computer simulation models for field applications ranging from water balance calculations to analyses of cropping systems.

Allan has research, teaching, and extension responsibilities in the areas of irrigation and water science. His interests are in quantifying the effects of alternative irrigation and water management strategies on crop production and the environment. Research findings will be used to develop best management practices for conserving water in agricultural fields and urban landscapes in Colorado. Both water quantity and water quality aspects of irrigation will be considered. Computer simulation models of soil-plant-atmosphere systems will be used to extend site-specific research findings to other locations, management practices, or climate scenarios. Courses on irrigation principles and management will be taught. In addition, opportunities for outreach and collaboration with water managers and users will be sought to address water issues and test new ideas.

Allan and his wife Jane have two sons: David (age 11) and Daniel (age 8). He enjoys involvement in church ministries, biking, gardening, walking or hiking with the family, and playing the guitar.

Allan can be contacted at allan.andales@colostate.edu



Join water industry professionals from around the world to discuss Conservation and Water Resources issues as water utilities search for sustainable solutions and seek to integrate resources management into their long-term planning. This year's technical program will specialize in climate change impacts on sustainable water sources.

Who Should Attend

The Water Sources Conference is geared toward professionals involved in all aspects of water resources and conservation. Businesses represented include:

* Water resource planners and engineers
* Conservation professionals
* Municipal water utilities
* Wastewater utilities
* Industry consultants
* Local, state, and federal governmental agencies
* Water utility investors
* Educators
* Distributors of equipment and supplies
* Private industrial systems
* Agricultural interests
* Research labs
* Utility managers
* Water quality specialists
* Public affairs managers
* Special interests such as golf courses, aquifer storage, & recovery

Registration is now available. Visit http://www.awwa.org/Conferences

RESEARCH AWARDS

Research Awards

Colorado State University, Fort Collins, Colorado
Awards for September 2007 to December 2007

Ballweber,Jeffery A, Agriculture & Resource Economics-Mississippi State University--Southeast Regional-Small Public Water Systems Technical Assistance Center: Strategic Planning, **$27,279**

Bright,Alan D, Human Dimension of Natural Resources-USDA-CSREES-Coop State Rsrch Edu & Ext--Public Values & Attitudes Toward Agricultural Water Use in the West, **$170,000**

Davis,Jessica G, Soil & Crop Sciences-University of Nebraska--A National Learning Center for Animal Agriculture Water Quality Issues, **$7,500**

Gates,Timothy K, Civil Engineering-Lower AR Valley Water Conservancy Dist.--Monitoring and Modeling Toward Optimal Management of the Lower Arkansas River, **$35,000**

Hawkins,John A, Fish, Wildlife & Conservation Biology-DOI-Bureau of Reclamation--Yampa River Nonnative Fish Control: Translocation of Northern Pike from the Yampa River, **$22,065**

Kelly,Eugene F, Soil & Crop Sciences-USDA-USFS-Rocky Mtn. Rsrch Station - CO--Monitoring Forest Recovery and Watershed Protection in Beetle-Killed and Salvage-Logged Rocky Mountain Forests, **$33,300**

Kummerow,Christian D, Atmospheric Science-DOC-NOAA-Natl Oceanic & Atmospheric Admn--Development of an Improved Climate Rainfall Dataset from SSM/I, **$104,739**

Kummerow,Christian D, Atmospheric Science-NASA - Natl Aeronautics & Space Admin.--The Role of Warm Rain Systems in the Tropics, **$24,000**

Loftis,Jim C, Civil Engineering-DOI-NPS-National Park Service--Status and Trends of Impaired, Threatened, & Outstanding National/State Resource Waters, **$174,338**

Loftis,Jim C, Civil Engineering-DOI-NPS-National Park Service--Clean Water Act Impairments and Use Designations for National Park System Water Resources, **$50,000**

Niemann,Jeffrey D, Civil Engineering-DOI-Bureau of Reclamation--Implementing a Framework to Assess Uncertainty in Hydraulic and Hydrologic Models, **$49,996**

Oad,Ramchand, Civil Engineering-New Mexico Interstate Stream Commission--Decision Support Systems for Efficient Irrigation Management in the Middle Rio Grande, **$160,893**

Paustian,Keith H, Soil & Crop Sciences-USDA-ARS-Agricultural Research Service--Land Use Change and Carbon and Water Dynamics in Conservation Reserve Program Lands, **$2,000**

Stephens,Graeme L, Atmospheric Science-NASA-Goddard—CloudSat, **$455,400**

Swift,Curtis E, Extension- DOI-Bureau of Reclamation--Irrigation Audit Project for the Grand Valley of Western Colorado, **$5,000**

Thornton, Christopher I, Civil Engineering-Nebraska Public Power District--Physical Model Study of the Sutherland Reservoir Outlet Works and Stilling Basin, **$137,200**

Thornton,Christopher I, Civil Engineering-Ayres Associates--NCHRP Project 24-26: Effects of Debris on Bridge-Pier Scour, **$19,232**

Thornton,Christopher I, Civil Engineering-DOI-Bureau of Reclamation--Alpha Weir Field Reconnaissance, **$12,507**

Tranel,Jeffrey E, CSU Extension-Colorado Department of Natural Resources--Colorado Water for the 21st Century: Educating the Public, **$20,294**

Vonderhaar,Thomas H, Atmospheric Science-DOC-NOAA-Natl Oceanic & Atmospheric Admn--IPCC Studies for Climate Observations, **$50,000**

Wilkins-Wells,John Reese, Forest Rangeland & Water Stewardship-DOI-Bureau of Reclamation--Social Factors Affecting the Transfer of Modern Water Management Technologies and Water Banking/Marketing Mechanism, **$5,000**

Wohl,Ellen E, Geosciences-USDA-USFS-Forest Research--Assessing Channel Changes & Bank Stability Downstream from Hog Park Reservoir, Medicine Bow National Forest, **$24,587**

Yang,Chih Ted, Civil Engineering-DOD-ARMY-Corps of Engineers--Lewis & Clark Reservoir Sedimentation Study, **$224,043**

Calendar

2008

January 23	**Real Estate Law for Ditch Companies Workshop.** Denver, CO. For more information and to register visit http://www.darca.org
January 23-25	**CWC 50th Annual Convention**. Denver, CO. More information available at http://www.cowatercongress.org
February 3-7	**USDA-CSREES National Water Conference**. Sparks, NV. For conference information and registration visit http://www.soil.ncsu.edu/swetc/waterconf/2008/home08.htm
February 9	**Water Tables: From Water Fights to Water Rights**. Fort Collins, CO. More information available at http://lib.colostate.edu/archives/water/
February 10-13	**AWWA 2008 Sustainable Water Sources: Conservation & Resources Planning**. Reno, NV. For registration and more information visit http://www.awwa.org/conferences
February 20	**Flow Measurement for Ditch Companies Workshop**. Alamosa, CO. More information available at http://www.darca.org
February 20-22	**6th Annual DARCA Convention: Acequias in Colorado**. San Luis, CO. For more information and to register visit http://www.darca.org
March 5-6	**The 18th High Altitude Revegetation Workshop**. Fort Collins, CO. For more information please call (303) 422-2440 or (303) 279-8532.
March 10	**Directors & Officers Training for Ditch Companies Workshop**. Las Animas, CO. More information and registration available at http://www.darca.org
March 20	**GIS I for Ditch Companies Workshop**. Fort Collins, CO. More information and registration available at http://www.darca.org
March 21	**GIS II for Ditch Companies Workshop**. Fort Collins, CO. For more information visit http://www.darca.org
March 25	**Global Water Colloquium.** Fort Collins, CO. For more information visit http://www.vpr.colostate.edu
March 26-28	**Hydrology Days 2008**. Fort Collins, CO. More information available at http://hydrologydays.colostate.edu/
March 27-29	**50th Annual Celebration of Watershed Sceince.** Fort Collins, CO. For more information visit http://watershed50th.colostate.edu
April 14	**Ditch Hazards Awareness & Safety Workshop**. Grand Junction, CO. More information available at http://www.darca.org
April 22	**Emerging Issues in Soil and Water**. Fort Collins, CO. For more information contact Neil Hansen at 970 491-6804 or neil.hansen@colostate.edu
May 14-16	**33rd Colorado Water Workshop: Mining, Energy and Water in the West**. Gunnison, CO. For more information please visit http://www.western.edu/water
May 28-31	**USCID Water Management Conference: Urbanization of Irrigated Land & Water Transfers**. Scottsdale, AZ. For more information visit http://www.uscid.org
July 22-24	**UCOWR/NIWR 2008 Conference.** Durham, NC. For more information visit http://www.ucowr.siu.edu/
August 20-23	**CWC Summer Convention 2008.** Vail Marriott Mountain Resort. For more information visit http://www.cowatercongress.org

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