

Colorado Water

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Front Cover: The Gunnison River and an orchard in Dominguez Canyon between Delta and Grand Junction Colorado.

Photo by Bill Cotton

This Page: Aerial view of the lower Arkansas River basin. Photo by Bill Cotton

Editorial

by Reagan Waskom, Director, Colorado Water Institute

Agriculture has been humanity's single biggest industry for the past 10,000 years, as post ice age social units transitioned from hunter-gatherers to pastoralists and cultivators of crops. Past civilizations were all built on the foundation of adequate and reasonably stable supplies of food and water. Civilizations that did not sustain these amenities failed. The industrial revolution and the development of modern machinery rapidly transformed agriculture from a labor-intensive endeavor that most of humanity was involved with, to an industry in which two percent of the population now grows food for the other 98 percent (at least in the developed world). The post-World War II green revolution is credited with greatly boosting crop production worldwide, particularly in the developing world, and often underappreciated was the companion "blue revolution" of rapid irrigation development.

Currently, about 40 percent of the world's crops are grown on the 15 percent of cultivated lands that are irrigated. Irrigation greatly reduces the risk of crop failure, thereby stabilizing food supplies. We live in a global marketplace, where commodity production in one region can affect prices on the other side of the globe. Meanwhile, surface water supplies have been fully appropriated, and groundwater aquifers have been over-subscribed in many arid and semiarid regions across the world. Agriculture consumes an estimated 70 of water used globally—this figure exceeds 75 percent in Colorado and much of the West. Continued population growth and increasing standards of living portend a bright future for agriculture. But pressure is mounting in water-short areas to use irrigation water more efficiently and to conserve agricultural water for transfer to other uses.

Ag water conservation techniques have their limits, however. The simple fact is that plants use a great deal of water to meet evapotranspiration demands, and primary productivity is tightly linked to transpiration. Due to the mechanism plants use to capture and fix carbon, it is highly unlikely that plant breeders will uncouple this fundamental relationship—I certainly would not bet the farm on it. Agricultural water management and conservation have been studied at Colorado State University for well over 100 years and are the focus of this edition of Colorado Water newsletter. Our wheat breeding program, as just one example, has made significant strides in developing high yielding varieties



capable of withstanding moderate drought stress. CSU and USDA-ARS irrigation research have led to the development of many approaches for increasing the efficiency of irrigation, but the question remains whether we can conserve significant quantities of agricultural water that can be made available for transfer to municipal, industrial, and environmental uses. Further, can we do this while meeting world food supply needs and sustaining producer profitability? These are questions worth asking, as the future of western agriculture may hinge on the answer.

This agricultural water conundrum does not exist in isolation, nor can it be resolved as an agricultural issue alone—it is society's issue and must be approached comprehensively. We need the intelligent foresight to provide leadership for resolving an issue not yet widely perceived by the public as pressing. To sustain irrigated agriculture in the West, we will need a new approach that includes consideration of urban growth, energy, environment, climate, and consumption trends that the marketplace will not sort out for the benefit of society as a whole. It's a tall order to work through this much complexity, particularly as our experience is mainly in single sector approaches. Some part of this will be resolved through technological innovation, but no real progress will be achieved without changed minds that do not accept the inevitability of unbridled population growth and unsustainable consumption of natural resources. The benefits will accrue mainly to future generations, but certainly past generations have done as much for us.

Adaptations to Drought

Evidence From Agricultural Producer Survey

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*Aerial view of the Colorado beef feedlot west of Lamar, Colorado.
Photo by Bill Cotton*

- Surveys were sent to Colorado farmers and ranchers to determine their operations' response to financial stress caused by drought (measuring production losses, drought mitigation strategies, future plans, and demographic/financial information).
- Several trends were noted, including a decrease in crop production, increase in debt, sales of land and livestock, and use of mitigation strategies.

Colorado's ongoing drought is significant in its geographic reach and economic impacts. For farms and ranches, the drought shrinks yields and total crop production, deteriorates pasture condition, reduces cow condition,

and leads to difficulty in locating critical feed inputs. These production losses generally reduce revenues, although declining receipts may be partially offset by higher prices.

Yet, the drought's impacts to the farm or ranch business are not contained within a single season. Much like reservoir levels that are drawn down and may take years to replenish, the impact of a drought can reduce a farm or ranch's equity position, making it difficult to service debt or take advantage of future investment opportunities. Equity erosion may take years to rebuild.

In this article, recent drought survey responses are described in order to characterize the potential longer term impacts of drought. Emphasis is placed on production losses and producers' mitigating actions. While it is difficult to forecast the length of the recovery period for Colorado farmers and ranchers, their adaptations and changing production activities in 2012 do indicate the

severity and persistence of financial stress.

An Economic Drought Morphology for Colorado

The economic severity of a drought depends importantly on several factors such as:

- The initial soil moisture, snowpack, and reservoir storage conditions. Generally speaking, if a drought follows a wet or normal year, the economic impacts to the entire state's agricultural economy are less severe than if the beginning conditions are characterized by water shortage.
- The timing of the drought's onset. If a drought begins in late fall and extends into the winter, farmers may choose to adjust planting decisions and ranchers may evaluate forage alternatives and replacement decisions. However, if drought becomes severe later in the calendar year, agriculture

producers lose flexibility in mitigation strategies. For spring grain crop producers, many inputs such as fertilizer, seed, and chemical are purchased early in the season. These costs are sunk should a drought occur sometime after planting, and below average revenues are often insufficient to recover these costs. Likewise, a ranch's forage alternatives are reduced as the grazing season progresses, so a late drought may induce the purchase of more expensive hay stocks from greater distances.

- A widespread drought is costly for purchasers of feedstuffs and farm products, but sellers of farm commodities may actually receive some offsetting benefits. Simply put, the greater the geographic reach of the drought, the more that national markets are influenced, and the subsequent reduced supply of farm commodities drives higher prices. Higher prices can partially offset production losses for the seller of farm commodities. Yet, the price increases represent cost shocks to purchasers of farm commodities (such as feedlots and millers) who have fewer alternatives for ag products and may have to ship inputs greater distances.
- The duration and severity of the drought also influences the resiliency of farm and ranch businesses. When droughts extend over multiple seasons, economic impacts are likely to be more severe not only because of aggregate impacts, but also because of an inability to service debt or obtain access to credit.

Localized drought is a consistent climate feature in Colorado, but the last few years are notable. Drought began in southeastern Colorado in the fall of 2010 and resulted in

more than \$100 million of lost revenues and related shortfalls to allied industries (Goemans et al, 2012). As indicated by Figure 1, the drought was particularly intense in the southern part of the state in the fall of 2010 through the winter of 2011, and then the drought extended to the entire state during the summer of 2012. Statewide water storage and snowpack were better than average during the winter of 2011/2012 meaning that irrigated crop producers suffered less severe disruption of operations compared to

dryland producers and ranch owners who had no such stores of available moisture.

The drought's national reach was (and to a lesser extent still is) extensive—more than two-thirds of cropping acres in the United States were affected by drought in the summer of 2012. The resulting high prices partially offset revenue losses for producers of certain commodities, but also dramatically increased the costs of purchasing feed and forage supplies. The national drought was

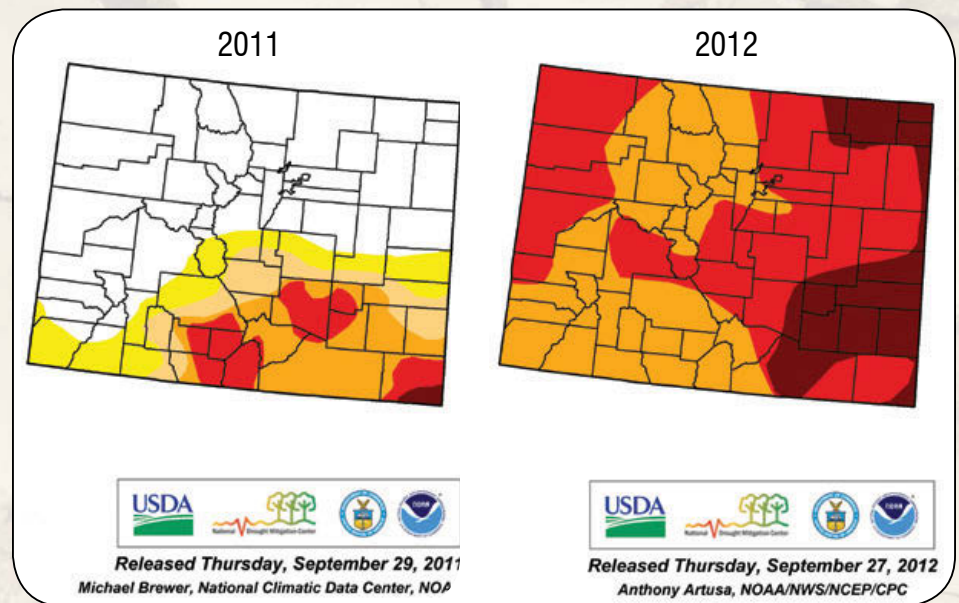


Figure 1. National Climate Data Center Depiction of the 2011 and 2012 Drought Severity in Colorado

Table 1. Survey Respondents Reported Production Losses for Selected Irrigated and Dryland Crops

Irrigated Crop Yields and Harvested Acres					
	Wheat	Milo	Millet	Sunflower	Corn
<i>Actual vs. Expected Yield</i>	-30%	-69%	-75%	-55%	-87%
<i>Harvested vs. Planted Ac. For Respondents</i>	-6%	-63%	-45%	-44%	-68%

Dryland Crop Yields and Harvested Acres				
	Corn Grain	Corn Silage	Wheat	Dry Beans
<i>Actual vs. Expected Yield</i>	-28%	-34%	-29%	-21%
<i>Harvested vs. Planted Ac. For Respondents</i>	-19%	-17%	-6%	-0%

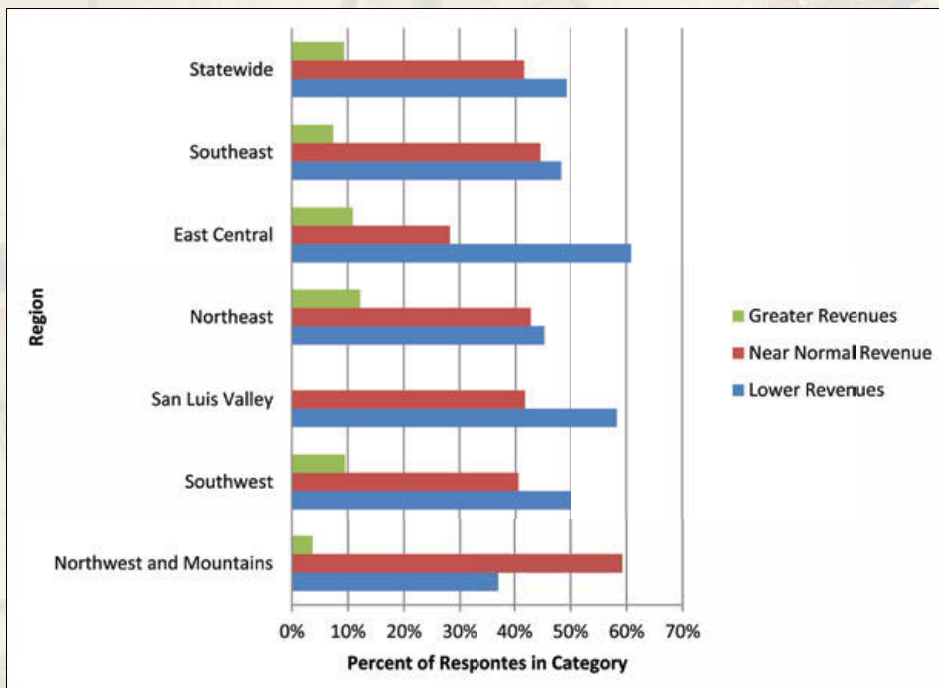


Figure 2. Respondents' Revenues Compared to a Normal Year by Colorado Region

largely unexpected (Hoerling et al., 2013) leaving few mitigation opportunities for producers. An exception is the southern Great Plains that had experienced drought in the immediate previous years, but adaption in this region largely pre-dated 2012.

Colorado Farm and Ranch Responses to Drought

For individual operations, how significant are the short and long term impacts of the 2012 drought? Some evidence can be taken from a statewide, online survey of producers completed in March 2013. Responding agriculture producers completed a questionnaire that examines production losses, drought mitigation strategies, future plans, and demographic/financial information. In sum, 550 Colorado producers completed a portion, if not all, of the survey with 75 percent reporting their operations were impacted by drought. The following describes some of those responses with particular emphasis

on production losses and mitigation actions.

Production Impacts

As indicated in Table 1, production losses were pervasive among survey respondents whether enterprises included irrigated or dryland cropping. Interesting was the relatively small portion of dryland wheat abandoned acres (six percent), largely because fewer acres were planted in Fall 2011 due to little soil moisture in southeastern Colorado.

Production losses were partially offset by higher prices, crop insurance, and stored irrigation water, so that some producers received near normal or above average revenues (Figure 2). Irrigated cropping fared better than dryland cropping, and the most severe revenue decreases appear to be from the east-central part of Colorado.

Cow-calf producers also suffered losses (Table 2), especially due to increased costs of feeding. Respondents indicate increased culling rates and a decreased herd size as they respond to drought.

Table 2. Respondents' Production Metrics for Cow-Calf Production

Production Metric	Change from Typical Conditions
Number of Cows	-48%
Culling Rate	21%
Cow Condition at Present	-18%
Weaning Percentage	-1%
Average Weaning Weight	-16%
Average Cost per Cow	+40%

Mitigation Strategies for Drought

More aggressive culling is an example of a disruptive drought mitigation strategy. The selling of assets, such as breeding livestock, can be very disruptive to the agricultural operation because it reduces revenue generated in subsequent years, and asset replacement requires significant capital investment in the future. For these reasons, asset sales can signal significant financial stress for the farm or ranch operation.

More generally, a hierarchy of mitigation strategies exists, ranging from the least to most disruptive for the operation:

- **Managing Cash Flow:** Agriculture producers will seek to increase household income by generating more revenue from the existing asset base and reducing expenses. From a business perspective, farm and ranch managers critically evaluate whether a production input will "pay its way" by matching revenues and expenses. The exceptions are longer term assets whose revenues may extend beyond the current accounting cycle. Examples of managing cash flow include performing soil tests so

that nutrient application is more precisely matched to crop needs, custom farming for others, and reduced household expenses.

- **Managing Debt:** A drought can reduce cash flow to the operation, and for the leveraged producer, reduced cash flows may result in inability to service debt. If debt service is a problem, debt management strategies include refinancing existing loans for longer terms, paying only interest on term notes, pledging more collateral as security, cross-collateralization, and amortizing an operating note from a single year to multiple year payback. These strategies are less desirable than adjusting managing cash flow because they influence the farm/ranch's ability to service and acquire future investment capital. In addition, the strategies may improve cash flow in the short term, but increase the overall cost of financing assets in the long term via increased total interest expense.
- **Managing Assets:** Assets are converted to cash for the operation by sale or may be used more intensively to increase revenues. Initially, farm and ranch managers sell short term assets (e.g., grain inventories) or place calves in a feedlot early in order to reduce expenses and increase revenues to the operation. These actions may be poorly timed, but are less disruptive than leasing assets or more intensive use of assets (e.g., custom farming with own equipment) that hastens the depreciation of assets. The most disruptive asset strategy is to sell noncurrent assets such as breeding livestock and land.

Survey results indicate that Colorado producers are using a mix of these

mitigation strategies in response to drought, but are generally focused on managing cash flow and managing debt. As indicated in Table 3, respondents sought to reduce family expenses first (59 percent of respondents) while relatively few took advantage of federal drought assistance (18 percent of respondents), even though more than four out of five were aware that federal assistance was available. Perhaps the participation can be explained by a lack of eligibility, a shortfall of federal funds, or an unwillingness to complete the sign up process. Respondents were also asked to indicate if they would adopt a practice if the drought continues. A smaller proportion selected reducing family living expenses (41 percent) as a strategy, likely because it is difficult to cut expenses that have already been reduced. An increasing percentage will adopt custom farming, seek off farm employment, and obtain federal assistance.

Respondents are managing debt to mitigate drought impacts. The most popular debt management is rolling an operating note into the next year

(17 percent) followed by paying the interest only for a scheduled debt payment (15 percent) or putting up more collateral (nine percent). If the drought persists, more operations will seek all debt management strategies.

It is clear that survey respondents are depopulating their cow herds with more aggressive culling in order to cope with drought. Among survey respondents, 41 percent indicate they have sold breeding livestock, and 29 percent indicate they will do so if the drought continues. Relatively few have sold land in response to drought (two percent) but more will consider doing so if the drought continues (nine percent).

Based on survey responses, farm and ranch operations are experiencing financial stress due to the drought, but the hierarchy of strategies represented in Tables 3 through 5 suggests that the most intense stress is borne by those who are culling breeding livestock. If the drought persists, financial stress will likely increase, but respondents do not anticipate drastic changes to current efforts.

Table 3. Respondents' Approaches and Participation Rates for Managing Cash Flow

	<i>In response to drought our operation ...</i>	<i>If the drought continues our operation will ...</i>
<i>Custom Farm(ed)</i>	12%	14%
<i>Sought/ Seek Off-Farm Employment</i>	25%	26%
<i>Reduce(d) Family Expense</i>	59%	40%
<i>Sought/ Seek Federal Assistance</i>	18%	25%

Table 4. Respondents' Approaches and Participation Rates for Managing Debt

	<i>In response to drought our operation ...</i>	<i>If the drought continues our operation will ...</i>
<i>Paid/ Will Pay Interest Only</i>	15%	16%
<i>Put Up More Collateral</i>	9%	11%
<i>Roll Operating Note Into Next Year</i>	17%	18%

Table 5. Respondents' Approaches and Participation Rates for Managing Assets

	<i>In response to drought our operation ...</i>	<i>If the drought continues our operation will ...</i>
<i>Sold/ Will Sell Breeding Livestock</i>	41%	29%
<i>Sold/ Will Sell Equipment</i>	13%	19%
<i>Sold/ Will Sell Land</i>	2%	9%

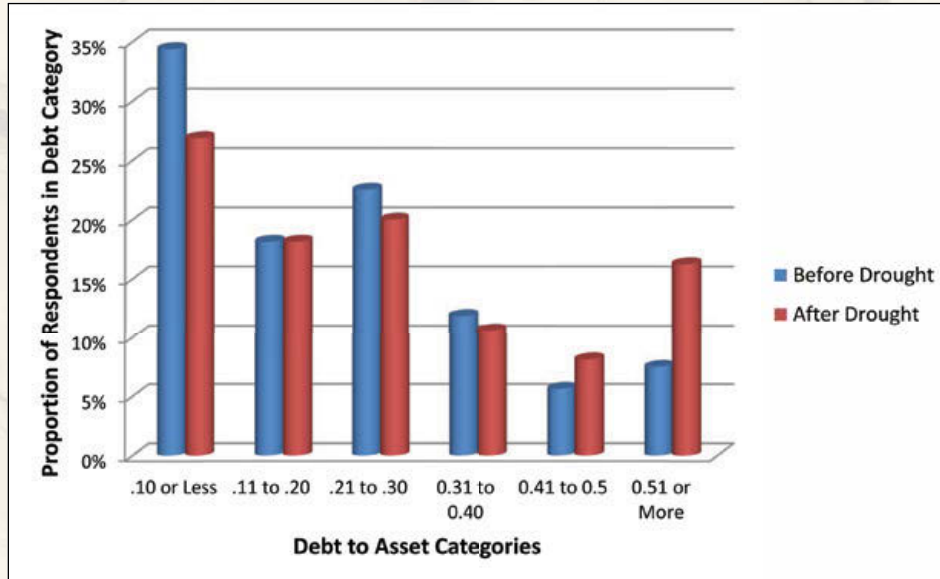


Figure 3. Respondents' Percentage of Assets Financed by Debt Before and After the Drought

One caveat applies to the previous statement. Survey respondents are predicting slight changes if drought continues, but these same respondents are adding debt to the operation. As illustrated in the “Before Drought” and “After Drought” debt to asset percentages in Figure 3, the proportion of operations with very little debt has decreased substantially, and those in the highest debt category—50 percent or more of assets financed with debt—has increased significantly. If the drought continues through 2013, more drastic management practices may be adopted than those suggested by survey respondents. ●

Authors gratefully acknowledge funding from the Colorado Water Conservation Board and the Colorado of Agriculture Department.

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CWCB's Efforts to Facilitate Alternative Water Transfer Methods in Colorado

Todd Doherty, Water Resources Administrator, City of Boulder

- CWCB alternative transfer efforts have recently included Alternative Agriculture Water Transfer Methods Grant Program (ATM grant program) pilot projects, passage of HB 13-1248 (allows for 10 pilot project in 10 years), and support of basin-scale planning efforts.

The Statewide Water Supply Initiative (SWSI) 2010 estimated that by 2050, the State of Colorado may lose 500,000 to 700,000 acres of currently irrigated farmland. These losses are predicted due to a number of reasons, including urbanization, inadequate augmentation water supplies for out-of-priority well pumping, enrollment of lands in conservation programs, declining aquifers, and compact compliance. Additional irrigated acres are anticipated to be lost due to planned agricultural-to-municipal water transfers and transfers to meet the future water supply gap. In the South Platte Basin, there are currently 830,000 acres of irrigated lands, and an estimated 300,000 to 425,000 irrigated acres will be lost by 2050 under status quo conditions. The administration, the CWCB, the Interbasin Compact Committee, the basin roundtables have all voiced concerns over significant losses of irrigated agriculture and have supported the effort to promote alternatives to this option. If the State

of Colorado can make alternative water transfers such as rotational fallowing and interruptible supply agreements commonplace, then these losses in irrigated acres could be significantly reduced while still providing the municipalities needed water and helping sustain agriculture.

Recognizing the need to promote alternatives, in 2007 the CWCB initiated a grant program, the Alternative Agricultural Water Transfer Methods Grant Program (ATM grant program). To date, the ATM grant program has provided funding for over 20 projects totaling over \$3.5 million (for a summary of the projects and synthesis of the findings, please see the CWCB report, *Alternative Agricultural Water Transfer Methods Grant Program Summary and Status Update*, November 2012). Some projects have moved toward conceptual implementation of ATMs, while others have been of a research nature. Through these studies and projects as well as discussion through various task force meetings, subcommittee meetings, and other forum, several key barriers to ATMs have been identified:

- High transaction costs associated with alternative transfers compared to permanent “buy and dry” transfers
- Water rights administration issues

Aerial views of drought affected Colorado farm lands, 16 miles SE of Ft. Morgan, Colorado on Saturday, July 21, 2012.
USDA photo by Lance Cheung

Table 1. CWCB Alternative Agricultural Water Transfer Methods Grant Program pilot projects

Name of Project	Sponsor
Use of ATMs to Increase Supplies for Conejos Basin Agricultural, Municipal and Environmental Purposes	Conejos Water Conservancy District
Implementation of Deficit Irrigation Regimes: Demonstration and Outreach	Colorado State University
Poudre Basin Water Sharing Working Group Efforts Leading to Agreements South Platte Basin	Colorado Water Institute (CSU)
FLEX Water Market--Education and Implementation Phase	Ducks Unlimited
Compact Water Bank Feasibility Study	Colorado River District
Northeast Colorado Water Cooperative Implementation Project	Lower South Platte River WCD

- Need for municipalities to have a permanent and reliable water supply
- Infrastructure needs and water quality issues

Solutions to some of the barriers to implementation have been recommended through the findings of the ATM grant projects, but more work is needed to fully realize the goals of the grant program. Certain barriers to implementation, such as infrastructure needs and water quality, have received limited attention. The CWCB has recognized that the ATM program should shift more to an application and integration phase that will more fully integrate the findings of the past projects to achieve the dual objectives of overcoming the barriers to implementation and establishing realistically implementable ATM projects.

The CWCB has recognized that while there may be tools developed for ATMs that are applicable within a basin or even statewide, it may be difficult to create a template applicable for all needs. Considering that

each municipal water provider has their unique demands, supplies, and infrastructure system and each irrigation district or ditch company have unique water rights, by-laws and location, ATM projects will likely be implemented through separate agreements between municipal providers and irrigators. To help facilitate these water sharing agreements, the CWCB has indicated a desire to focus on the facilitation of agreements between irrigators and municipal water providers through demonstration and pilot projects. In May 2013, the CWCB approved six additional projects that are directed at implementing specific water sharing projects throughout the state. It will be exciting to follow these projects over the course of the next several years as they all have the potential to become successful ATM projects (Table 1).

Aside from the ATM grant program, the CWCB has been helping to facilitate agricultural transfers through several other initiatives. One of those is the passage of HB 13-1248, which authorizes the Colorado Water Conservation Board to administer a pilot program consisting of up to 10 pilot projects, each up to 10 years

in duration, in the Arkansas, South Platte, Colorado, and Rio Grande basins to demonstrate the practice of following agricultural irrigation land and leasing the associated water rights for temporary municipal use. The legislation calls for the CWCB, in consultation with the State Engineer, to establish criteria and guidelines for the pilot projects' application, selection, and approval process. Below are some considerations for the CWCB that may be included in the criteria and guidelines which are expected to be developed and finalized by early 2014 to allow for pilot projects to be considered by the CWCB during the 2014 growing season.

- Ensuring non-injury to other water users
- Demonstrating the practice of following agricultural irrigation land and leasing the associated water rights for temporary municipal use
- Demonstration of how the operation of the project will not expand the historical use of the water right, change the historical return flow patterns, or otherwise cause material injury to other vested water rights or impair compliance with interstate compacts
- Provide insights for the selection of particular ditch system (i.e. priority, location, exchange capacity, by-laws), and economic factors such as willingness to pay or lease
- Demonstrating new tools and/or methods for determining historic consumptive use and non-injury to other water rights

Another effort supported by the CWCB is the coupling of conservation easements with interruptible water supply

agreements. The concept includes the use of conservation easements on irrigated agricultural land to both preserve long-term agricultural irrigation and provide secure long-term water supplies to a municipality. An agricultural-municipal conservation easement would perpetually preserve the irrigated land and give the municipality a secure, legally enforceable permanent source of additional water supplies—addressing one of the key barriers to ATM implementation listed above. In late 2012, the CWCB granted the Lower Arkansas Water Conservation District funds to demonstrate this concept and as well as provide a concrete example of the legal and technical details of such a transaction. It is expected that the completion of the easement transaction would contain example or model language for an Ag-municipal conservation easement, including an enforceable municipal interest in the use of water rights under defined terms

and conditions in, for example, three years out of 10—leaving the water in irrigation seven years out of 10.

To date, the Alternative Agricultural Water Transfer Methods Grant Program has provided funding for over 20 projects totaling over \$3.5 million.

Lastly, basin roundtables have recognized the need to focus on basin level planning and look for ways to increase the flexibility within the system through alternative transfers, cooperative agreements, drought plans, and additional infrastructure while respecting Colorado water law and individual property rights. Through the update to the Statewide Water Supply Initiative (SWSI), the CWCB will support the development of basin implementation plans

with the goal of developing projects and methods to meet municipal, industrial, agricultural, environmental, and recreational needs. It is envisioned that these plans will examine hydrologic operations and basin constraints and opportunities to help basins proactively meet water needs, with currently planned projects, re-prioritized projects, and new projects, operational agreements, flow protections, or other methods, including ATM projects.

While there is still much work needed to establish alternative water transfers as a significant water resource management tool for water managers, huge strides has been made thus far. The CWCB has shown great leadership in supporting this program and advancing this effort. With the latest ATM projects underway, HB13-1248, and basin implementation planning, the next few years will show even more progress. ●

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A Mobile Irrigation Scheduling Tool for Colorado

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A key component of irrigation water management (IWM) is proper irrigation scheduling, which involves applying the correct amounts of irrigation water at the right times. A number of states have developed irrigation scheduling software to assist farm managers. These software packages range in complexity from standalone spreadsheets or programs to more sophisticated Web-based applications.

- CSU specialists began in 2011 a four-year USDA-NIFA project to develop, pilot, and disseminate a mobile tool for improved irrigation water management.
- The tool uses online weather databases, user-inputted crop data, and environmental modeling tools and calculations to estimate daily soil moisture content.
- The tool is currently being presented to stakeholders and water users and being tested by potential users.

A common feature of these irrigation schedulers is the use of soil water balance calculations to determine irrigation requirements and timing. Stand-alone tools often require manual input of water balance components such as precipitation and crop water use; while Web-based applications have the capabilities of field mapping, accessing soils databases, and automatic downloading of precipitation and calculated crop water use from online weather networks. Advanced features include irrigation optimization across multiple fields, including economic analyses. Currently available irrigation schedulers are not designed to interact (input and output) with handheld devices such as smartphones. Some situations may also require access to irrigation advisories in field locations without network connectivity. Irrigation companies have begun providing irrigation equipment monitoring via smartphones, but irrigation scheduling advice is not routinely provided.

over-irrigation leads to losses of water and agricultural chemicals via surface runoff or deep percolation; and under-irrigation leads to crop water stress and yield reductions. In Colorado, the recent confluence of weather monitoring technology, cloud computing capabilities, and drought conditions have increased the interest in an online irrigation scheduling tool.

Mobile Irrigation Water Management System

In 2011, Colorado State University (CSU) initiated a four-year project funded by USDA-National Institute of Food and Agriculture (NIFA) to develop, pilot, and disseminate a scalable device-independent mobile system for improved IWM. The system leverages three key technologies available at CSU: (1) the Colorado Agricultural Meteorological Network (CoAgMet) of 60+ automatic weather stations around Colorado (<http://ccc.atmos.colostate.edu/~coagmet/>); (2) the environmental Risk Assessment and Management System (eRAMS) that provides a web-based geographic information system (GIS) and environmental modeling tools; and (3) the Cloud Services Innovation Platform (CSIP) developed in collaboration with USDA to handle calculations (water balance calculations for example) for multiple users over a network or across the Internet. A functional prototype of the IWM tool has been developed and is currently being tested on several irrigated fields.

The online tool can be accessed in eRAMS (www.eramsinfo.com)

In a survey of Colorado irrigators, it was found that a majority of irrigators (89 percent) still rely on imprecise methods of irrigation scheduling such as using past experience or relying on crop appearance. These methods, which are not based on actual consumptive water use or soil water content, can result in significant over- or under-irrigation. Consequently,

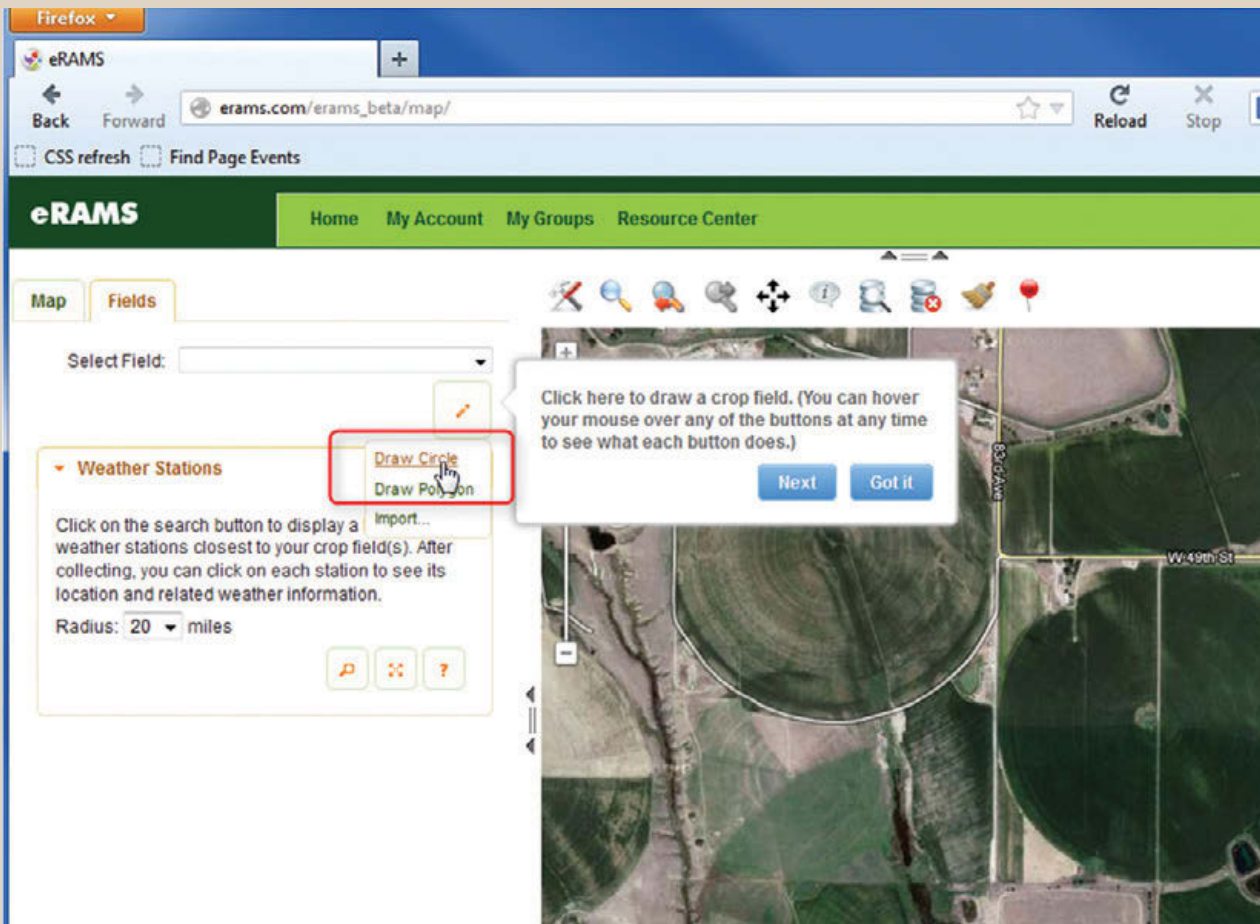
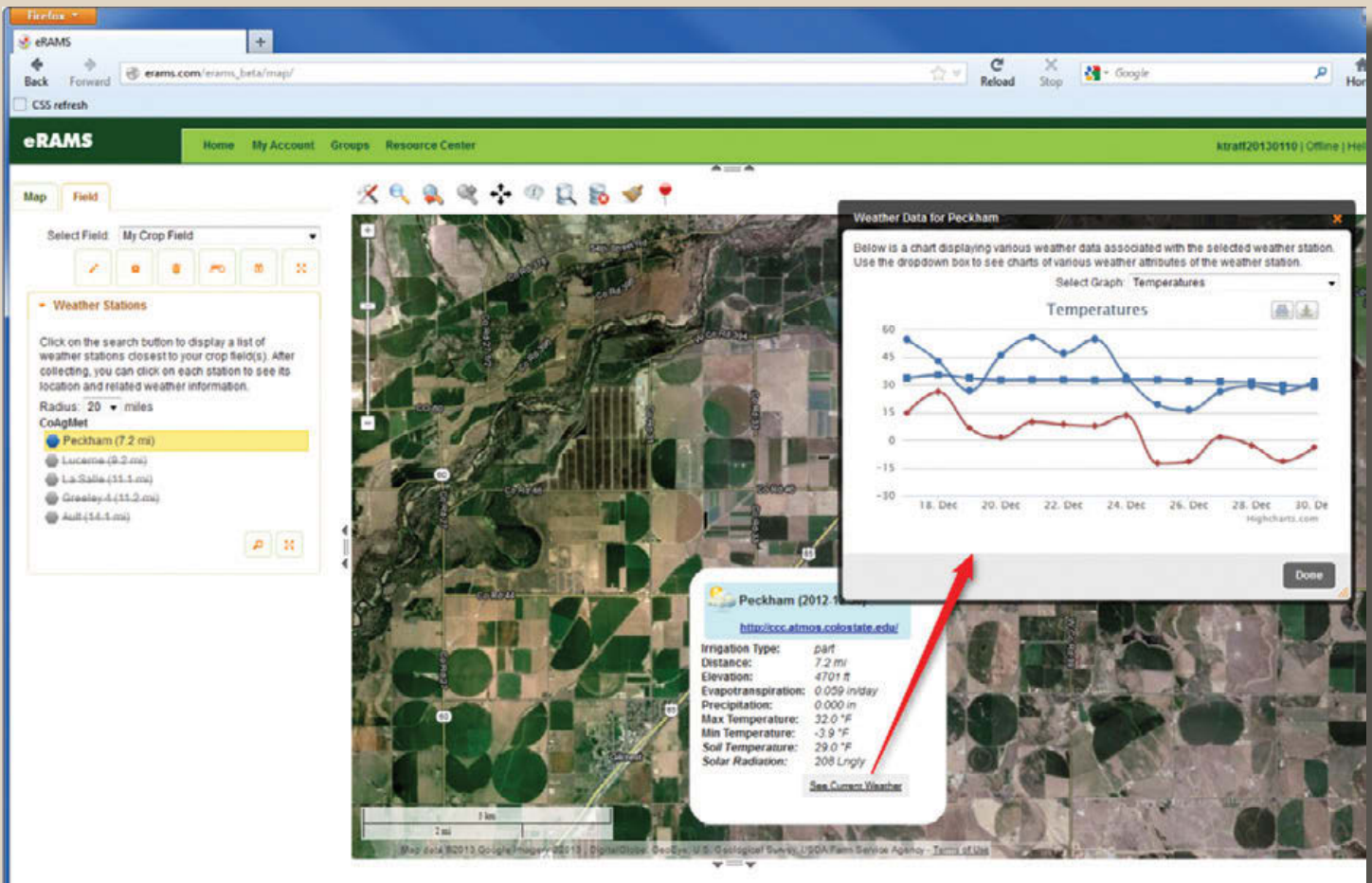


Figure 1. (Left) View of the online irrigation scheduler showing tools for drawing field boundaries on a map.

Figure 2. (Below) Online irrigation scheduler showing nearby weather stations and charts of recent weather data.



using a Web browser and an Internet connection. It is still in beta version, and is not yet being widely distributed until it is fully tested. The tool has capabilities for locating a specific field on an aerial map and drawing field boundaries (Figure 1). Once the field boundaries are drawn, the tool extracts soil properties of the field from the USDA-Natural Resources Conservation Service (NRCS) Soil Survey Geographic (SSURGO) database. The water holding capacity of the soil in the field is the primary piece of information used by the tool for estimating soil moisture.

The tool will locate the online weather stations closest to the selected field, according to a user-specified search radius. Nearby weather stations are displayed on

the map, and the user can select the weather station(s) that will be used to estimate precipitation and crop consumptive water use (evapotranspiration) on the selected field. Charts of recent weather data can also be viewed (Figure 2).

A functional prototype of the irrigation water management tool has been developed and is currently being tested.

To completely set up a field for irrigation scheduling, the user also has to input the following information.

- Crop information: type, emergence or green-up date, managed root depth
- Irrigation system information: type, application efficiency, capacity, typical irrigation frequency
- Soil information: initial soil moisture content at emergence or green-up

Once a crop type is selected, default values of crop coefficients (used to estimate crop water use from weather data) are provided. The crop coefficients incorporate the effects of crop development on water use. Advanced users can modify the default values to better represent their crop variety.

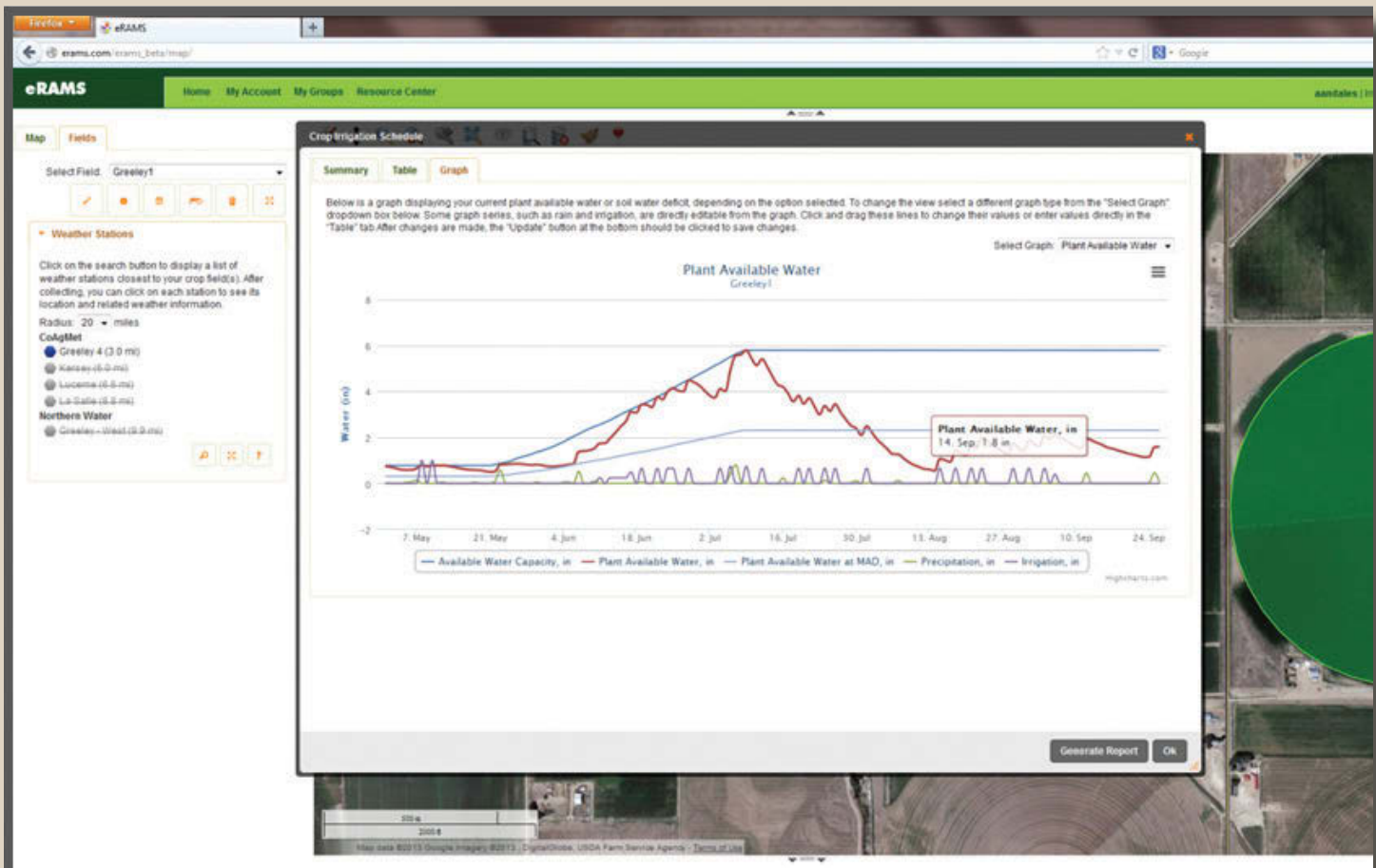


Figure 3. Example graph showing plant available water in the root zone (red line; inches of water) in relation to available water capacity of the soil (top blue line) and management allowed depletion (MAD, light blue line). Irrigation is recommended when the red line approaches or falls below the MAD.

After the user provides all the field information, the tool can begin estimating the daily soil moisture content of the managed root zone. Gross amounts of irrigation applied to the field must be inputted whenever irrigations occur. The tool automatically downloads daily weather data from the pre-selected station, up to the most current data. The tool accounts for daily additions (effective precipitation or irrigation with estimated losses by runoff or deep percolation) and subtractions (consumptive water use or deep percolation) of water in the managed root zone. The tool has a simple root growth model that estimates rooting depth as the crop develops. Crop water use is subtracted from the appropriate soil layers, corresponding to the estimated root distribution in the soil profile.

The daily water balance of the root zone can be viewed in tabular or graphical form (Figure 3). The following is an example of irrigation advice provided by the tool.

Summary Information for 2012-07-02

Your crop used **0.8** inches of water since the last irrigation

Your field is currently **1.2** inches below field capacity (soil water deficit is **-1.2** inches)

1.8 inches of water are still available to your crop before stress level (MAD) is reached

Weather forecasts estimate your crop will use an additional **1.9** inches in the next **6** days.

Based on current information about your crop field, we recommend that **1.0** inch of water be applied to your field within the next **4** days.

Mobile App for Smartphones

A prototype iPhone® app has also been developed to synchronize information with eRAMS and give mobile access to a field's water status. A water gauge or "bucket" diagram is used to show the amount of water available to the crop and the recommended amount of irrigation (Figure 4). Options for inputting actual gross irrigation or locally measured precipitation are also available. Yesterday's weather can also be viewed for the pre-selected weather station.

Currently the app is not yet communicating with eRAMS, but programming work to accomplish this will be completed this year.

Once the iPhone app is completed, an Android® version of the app will also be developed.

Demonstrations of the Irrigation Scheduler

The online IWM tool was demonstrated at the winter conference of the Rocky Mountain Agribusiness Association (16 January 2013; approximately 50 attendees), at a stakeholder group meeting at CSU (8 April 2013; 10 attendees representing producers, crop consultants, and agencies), and at the Upper Arkansas Valley Water Conservancy District (26 April 2013; 10 attendees). The interest and feedback from these demos was very positive. The stakeholder group has provided valuable suggestions to

improve the functionality of the tool. Western Sugar Cooperative has shown a keen interest in using the IWM tool, and testing is currently underway on four sugar beet fields in Northeast Colorado.

Acknowledgements

This project is funded by the USDA-National Institute of Food and Agriculture. Computer programming was done by Kyle Traff, Dave Patterson, and Andrew Bartlett. Olaf David provided expertise on CSIP. Erik Wardle and Andrew Bartlett are coordinating the demonstration and field-testing of the IWM tool. Funding was provided by Western Sugar Cooperative to test the IWM tool on sugar beet fields. ●

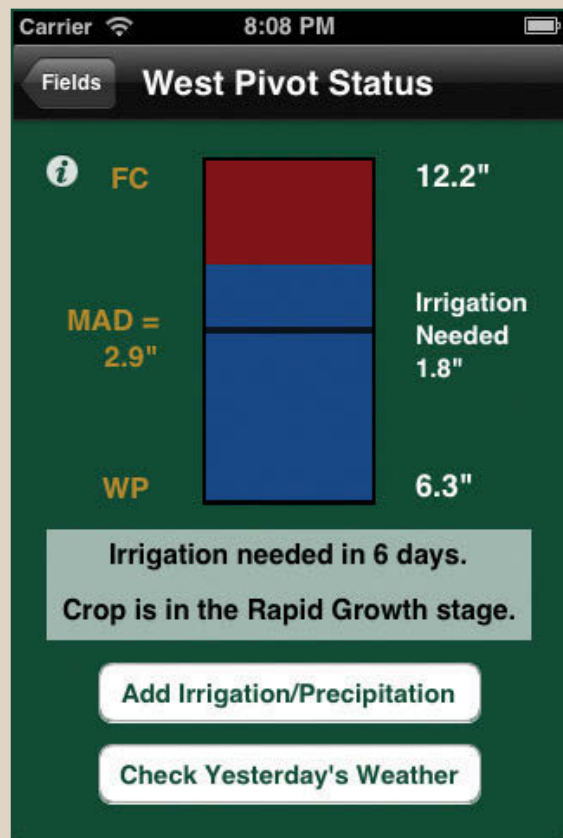


Figure 4. Prototype iPhone® app showing a "water bucket" representation of soil moisture status of a field. Field capacity (FC) and wilting point (WP) show the upper and lower limits of plant available water (inches of water) in the root zone, respectively. The red bar shows the estimated amount of depletion relative to management allowed depletion (MAD).

Determining Corn Water Use with Thermal and Weather Data

José L. Chávez, *Civil and Environmental Engineering, Colorado State University*

- The crop water stress index (CWSI) method was applied to a corn field in eastern Colorado, divided into varying levels of irrigation.
- Using airborne and handheld temperature readings, the CWSI method was found to closely predict actual water use.

Introduction

In the Western United States as well as in other semiarid regions of the world, intensifying competition for limited water supplies between urban, industrial, and agricultural uses continues to exert profound pressures on the agricultural sector. In the Western U.S., agriculture currently accounts for about 70 percent of consumptive water use (or evapotranspiration, ET), and its water rights are increasingly being transferred to municipal and industrial uses. Farmers in Colorado are allowed to transfer the portion of ET not used. Therefore there is a need to closely monitor actual crop water use so farmers and irrigation districts know how much water the crop uses and thus how much water was not used (the portion that may be approved for water rights' leasing or transfer).

Some researchers have investigated methods to capture crop water use and stress. Among numerous methods that have been developed in the past, there is the "Crop Water Stress Index" (CWSI) approach. This method was developed to be used with hand held infra-red thermometers (IRT), to obtain canopy temperature (T_c), pointed in an oblique view and looking at the vegetation leaves only. However, to cover large irrigation areas, it is more practical to use sensors

mounted on an aircraft. This application means that the thermal camera will be looking straight down (nadir) from the plane to the corn canopy. If the CWSI method could be used with nadir looking IRTs (ground-based), then airborne and spaceborne platforms with thermal bands/cameras might be used to obtain surface temperature (T_s) and then derive corn water stress indices and actual corn water use amounts (throughout the season) covering large areas.

In this study, the CWSI dT method was applied in eastern Colorado on data acquired over a corn field in 2011, using nadir looking IRTs and airborne multispectral imagery.

Application of the CWSI Method

The CWSI method was applied during the 2011 corn growing season on a field located near Greeley, Colorado. The corn field area was 400 m long by 135 m wide (1312 ft by 443 ft). The field was divided into three blocks, each 400 by 45 m (1312 ft by 148 ft), each block with a different irrigation water amount. The amounts determined were: full irrigation (plot 2) to cover the corn full water demand, deficit irrigation (plot 3, only two full irrigations), and reduced irrigation (plot 1, half the amount of the full irrigation). The field was surface irrigated through gated pipes and furrows. The water supply was a deep well with a capacity of $129 \text{ m}^3 \text{ h}^{-1}$ (568 gpm).

The CWSI method relies on the temperature difference (dT) between the vegetation canopy and the air ($T_c - T_a$), and on upper and lower limits of this difference in temperatures. The lower limit occurs under the vegetation non-water-stressed conditions when the crop has sufficient water available in the soil root zone and the transpiration process is only limited by weather conditions. The





Photo by Andreas Krappweis

upper limit, in contrast, occurs when the vegetation is not transpiring because of soil water limitations (most commonly); however, other types of constraints as high soil salinity concentration, toxicity, or even soil root zone waterlogging or high watertable can affect the ability of the plant to use existing water in the soil profile. The lower dT limit depends on the atmospheric water vapor pressure deficit (VPD, kPa) while the upper dT limit depends on the vapor pressure gradient (VPG).

To compute the vapor pressure deficit one needs readings of air temperature and relative humidity. Weather stations as the ones that are part of the Colorado Agricultural Meteorological Network (CoAgMet) provide such data. One should be careful to use data from a weather station that is close to the field of interest, in a similar micro-climate, and under similar water management. In the case of our application of the CWSI method, each irrigation level plot was equipped with a Vaisala HMP45C sensor, installed at a height of approximately 2.7 m (8.9 ft) above the ground, to measure air temperature and relative humidity. Surface temperature (including corn canopy and some soil background) was measured with an Apogee SI-111 infra-red thermometer. The IRTs were installed at a height of 2.8 m (9.2 ft). Data were sampled every three seconds, and five minute averages were recorded by an on-site datalogger.

Once the corn water stress index was computed, the next computation was the actual corn water use, or ET. This computation employs the stress index and the so called potential (no stress) crop (corn in our case) ET rate. Potential corn ET values were calculated by multiplying alfalfa reference ET (ET_r) by tabulated basal corn crop coefficients (K_{cb}). Daily ET_r values were computed using weather data from CoAgMet, using the standardized ASCE Penman-Monteith equation. The weather station was located approximately 1 km (0.63 miles) from the field site.

Evaluation

Estimated corn actual water use (ET_a), from the CWSI method, was evaluated using ET values derived from a soil water balance (SWB) based on measured volumetric soil water content (VSWC in percent) over the crop root depth 0 to 1.2 m (0 to 4 ft). The SWC was measured with a portable Mini Trase time domain reflectometer, on the shallow first 15 cm (6 inches). The subsequent readings were taken in the middle of 0.30 m (1 ft) thick soil layers. Soil water content at these layers was measured with a neutron probe soil moisture gauge (CPN 503DR Hydroprobe). Readings of VSWC were taken before and after irrigation and rainfall events. The SWB was applied between wetting events (to avoid accounting for precipitation/rainfall amounts, deep percolation, and runoff) and about two days after the occurrence of the event when the soil water content approximately reached field capacity. Since the resulting ET corresponds to a period of days, the ET was called “cumulative” measured actual ET. Measured cumulative ET was the reference for the evaluation of the CWSI-based actual ET values.

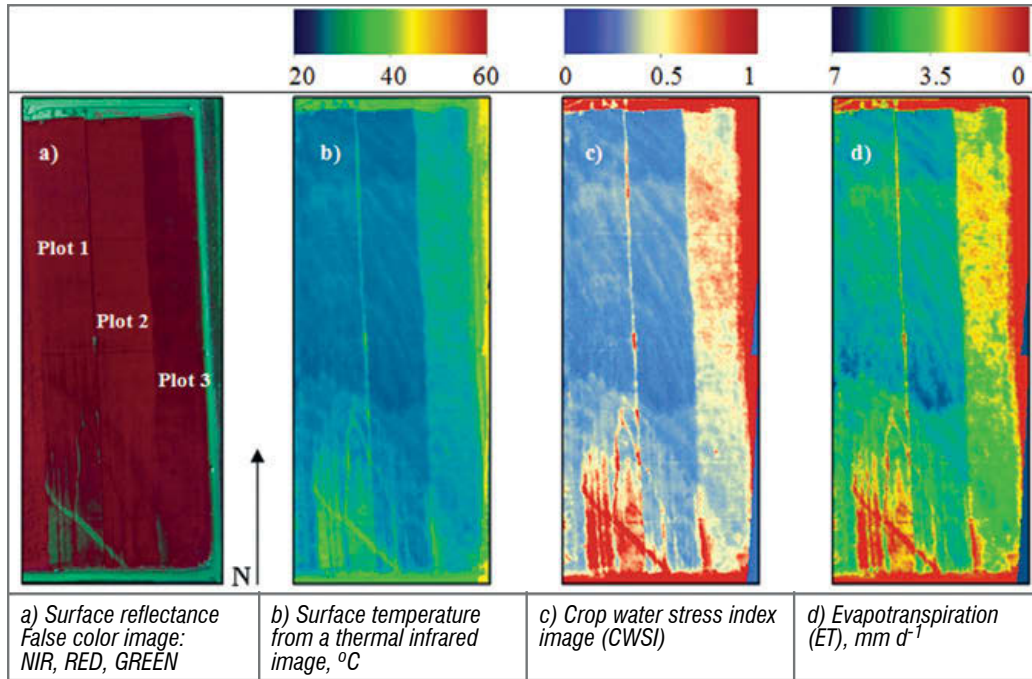
Remote Sensing Data

Airborne images were acquired during different campaigns/days using a digital multispectral airborne remote sensing system. This system consisted of digital cameras with wavelengths similar to those of satellite Landsat 5 Thematic Mapper bands 2 (green), 3 (red), and 4 (near infra-red, NIR) to measure surface reflectance, and 6 (thermal) to measure surface temperature. The aircraft overpasses occurred just before solar noon. Flight elevation was about 450 m above ground level, resulting in very high pixel “spatial” resolution (0.5 m or 1.65 ft).

Results and Discussion

The CWSI derived corn water use resulted in slightly lower ET values than those derived from the soil water content

Figure 1. Maps of corn surface reflectance (a), temperature (b), CWSI (c), and ET (d). Image taken on 12 August 2011 at 11:35 a.m. (M.S.T.). Field 400 m long by 135 m wide (1312 ft by 443 ft).



sensors. This good performance of the method occurred when the surface, air temperature, and air relative humidity data were obtained earlier in the day (9-10 a.m.). Surface temperature readings taken later in the day resulted in larger discrepancies between estimated and measured crop water stress and use. This larger error meant that the level of stress was overestimated and therefore the amount of water used by the plant underestimated.

Observing the remote sensing image taken on August 12, 2011 (Figure 1), it can be seen that the northern half portion of plot 1 and 2 had similar surface reflectance and temperature, CWSI, and ET rates. For plot 1 the average actual corn ET was 5.1 and for plot 2 it was 5.6 mm d⁻¹, or 0.2 and 0.22 inches per day, respectively.

In general, the CWSI method seems to be accurate enough to be used with ground-based and airborne-based remote sensing images (same bandwidth for the thermal band) to infer on spatially variable crop ET. Using the CWSI method to infer on

corn water stress and consumption may be a viable method to conserve water by improving site specific management of irrigation by mapping CWSI and actual ET using remote sensing images during the crop growing season.

Using an airborne (aircraft or unmanned aerial vehicle) remote sensing system to obtain surface radiometric temperature during early times of the day is feasible, since most arid and semi-arid regions do not develop clouds during this period of the day.

Conclusion

Applying the Crop Water Stress Index method, using remotely sensed surface radiometric temperature to monitor and estimate actual water use, seems to be very feasible for corn fields in eastern Colorado.

Actual corn evapotranspiration values derived using the CWSI method were compared to corresponding values obtained using soil water content sensors and the soil water balance method. Results from the comparison

indicated that, in general, errors in the estimation of actual corn ET were low for surface temperature, air temperature, and relative humidity data acquired between 9-10 a.m.

These results are encouraging for the use of the CWSI method to estimate the consumptive crop water use of a stressed crop and thus determine the portion of potential (maximum) ET not used by the crop and therefore available for water rights lease or transfer in Colorado.

Furthermore, applying the CWSI method to map ET with high resolution airborne imagery (0.5 m spatial pixel resolution) has the capability to be used to define the irrigation management zone and therefore be employed within a decision support system and a precision or variable rate irrigation system (e.g., center pivot or lateral move) as a tool to optimize irrigation scheduling and calculations of water amounts (depths) to improve the spatial soil water retention and water availability and uptake by crops. Consequently, the system/method has the potential to optimize crop yields while protecting the soil and water resources.

Acknowledgements

The author is grateful to the following institutions and individuals for the support received and for their involvement, one way or another, in studies related to the application of the CWSI method: Colorado Water Conservation Board, Parker Water & Sanitation District, Regensis Management Group, Northern Water, USDA ARS, Saleh Taghvaeian, Tom Trout, Bill Sanford, Neil Hansen, Jordan Varble, Jonathan King, and a number of technicians. ●

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What to Do When There's Not Enough Water

Tom Trout, Research Leader, USDA-Agricultural Research Service, Water Management Research Unit

- USDA Agriculture Research Service (ARS) projects to maximize crop productivity per unit of water used include limited irrigation research.
- At a farm in Greeley, ARS studied the effects of limited irrigation on corn, winter wheat, sunflower, and other crops. Results include recommendations for reducing consumptive use and reducing water cost compared to crop value.

Table 1. Total water requirements (irrigation plus precipitation), yields, and water productivity of four crops grown near Greeley.

Crop	Total Water Requirements	Average Maximum Yield	Water Productivity
Corn	23 inches	210 bu/ac	500 lb (9 bu)per ac-in
Winter Wheat	19 inches	95 bu/ac	290 lb (5 bu)per ac-in
Sunflower	19 inches	3500 lb/ac	185 lb per ac-in
Pinto Beans	14 inches	2500 lb/ac	180 lb per ac-in

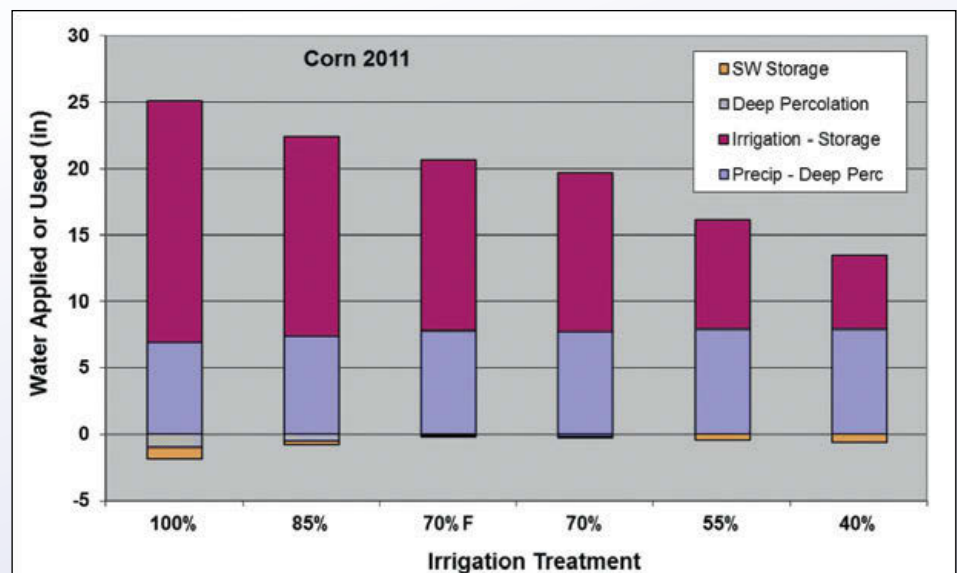


Figure 1. Seasonal water balance for the 2011 corn crop showing precipitation, irrigation, and seasonal soil water storage changes. Treatments are designated as the targeted percentage of crop water use relative to the fully-irrigated treatment. Bars below zero represent additions to soil water storage or deep percolation losses.

According to the Statewide Water Supply Initiative (SWSI) 2010 report, there will be an increasing gap between water supply and demand in Colorado. The study predicts that, as our population grows, agriculture's share of the supply will decline, and over a half million acres of irrigated agricultural land may be dried up. Drying up productive Ag land will hurt rural economies and decrease our ability to meet growing global food needs.

Water will be the important limiting resource of this century—not only in Colorado, but across the western U.S. and in most semi-arid regions of the world. Where we used to evaluate our productivity in terms of land area (bu/ac) or energy inputs (bu/kW-h), we will instead be working to maximize

our production per unit of water used (bu/ac-in).

The USDA Agricultural Research Service (ARS) is working jointly with Colorado State University to develop ways to maximize agricultural productivity per unit of water used through a variety of projects. The goal is to sustain productive irrigated agriculture in the face of declining water supplies. Projects include breeding crops that can survive and be productive under limited water conditions, promoting conservation tillage to increase the collection and storage of rainfall and reduce soil evaporation, developing crop rotations that can be more productive with limited water,

scheduling irrigation to get the most from a limited water supply, and studying farmers' responses to an increased value of their water supply. In collaboration with a private firm, we are developing guidelines that can allow producers to lease water to cities while maintaining a productive agricultural operation with limited irrigation.

The goal of the ARS research is to increase the water productivity of irrigated cropping systems in the Great Plains. The field research is carried out at the Limited Irrigation Research Farm, northeast of Greeley. The farm is ideally suited to limited water studies because of productive, medium-textured soils, low annual

rainfall, and a flexible water supply. We began limited irrigation research at the farm in 2008 with a four crop rotation of wheat, corn, sunflower (for oil), and pinto beans. We applied six levels of irrigation to each crop for four years to determine the yield that could be produced with each amount of water. Irrigation was applied through a drip system so we could accurately and uniformly apply water to each field plot. Strip tillage maintained residue cover and reduced evaporation water losses. We measured precipitation, soil water content, and reference evapotranspiration to accurately schedule irrigations and estimate crop water use. The goal was to determine how crop growth and yield varies with water used.

Table 1 shows the water required to get maximum yields for each crop. Corn required the most water because it is a long season crop with relatively high water requirements. However, it is also the most productive crop per unit of water at nine bushels per acre grain yield per inch of water used. Winter wheat required fewer irrigations and used less water, since much of its growth occurs before the midsummer heat. However, its productivity for the amount of crop water used was about half that of corn. Sunflower has a shorter season than corn and used a little less water, but produced much less yield. Pinto bean has an even shorter season and lower water use, and about the same yield per unit water as sunflower. Even though yields and water productivity for sunflower and beans are lower, their prices and production costs might make them a good economical option. A grower must evaluate water productivity in terms of net profits per unit of water for his prices and costs.

The water requirements listed in the table reflect the amount of water used by the crop (consumptive use, CU; or

evapotranspiration, ET). If irrigation were 100 percent efficient, this would be equal to the amount of seasonal rainfall and irrigation water applied. Full irrigation is almost never 100 percent efficient, even with uniform irrigation systems and accurate scheduling. With a well-watered crop, a rain following irrigation will usually result in water lost to drainage or runoff. The gap between water applied and used by the crop increases with less efficient irrigation.

Figure 1 represents the water balance for the six levels of irrigation (from 100 percent down to 40 percent of crop water requirements) for the corn crop in 2011. In 2011, we received eight inches of seasonal precipitation (blue bars), and applied 19 inches of irrigation (red bars) on the fully irrigated corn, and only six inches of irrigation on the most stressed corn. For the full irrigation, about one inch was lost to drainage (deep percolation), and one inch was left in soil storage at the end of the season, resulting in 25 inches of crop consumptive use. For the most stressed treatment, no water was lost to deep percolation, but a late season rain on the senesced crop left one

extra inch of water in the soil at the end of the season, resulting in 13 inches of consumptive use. In this least irrigated treatment, a 70 percent reduction in irrigation resulted in a 50 percent reduction in consumptive use.

Figure 2 shows the yield response to water, otherwise known as the water production function, for corn in each year of the study. The left set of curves, showing the yield response to irrigation water applied, varies because precipitation amount and timing varies from year to year. The curves also become flat near maximum yield because of the inefficiencies inherent with full irrigation. These curves show that you can reduce water applied by 50 percent and still achieve 70 percent of maximum yields. Water productivity gains, in terms of applied water with deficit irrigation, can be even larger when less efficient methods of irrigation (such as surface irrigation) are used and in areas with higher rainfall.

The right set of curves shows yields with increasing amounts of crop water use (ET). There is less year-to-year scatter because ET does not vary much from year to year. The

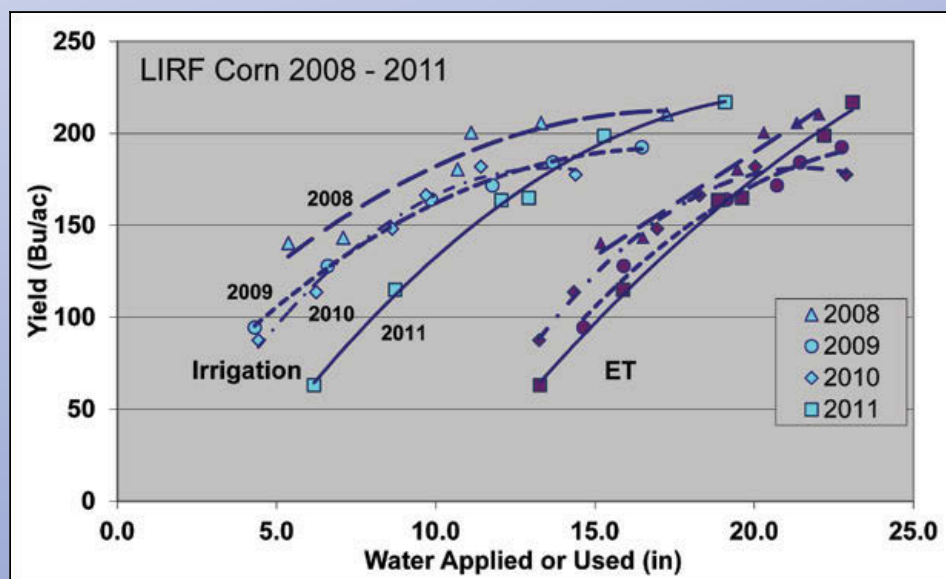


Figure 2. Water production functions for 2008 - 2011 corn at the USDA-ARS Limited Irrigation Research Farm. Yields are plotted relative to both irrigation amount and crop evapotranspiration (Blue symbols are yield vs. irrigation water applied; purple symbols are yield vs. water used as ET).



Figure 3. High Boy reflectance tractor measuring corn canopy reflectance and temperature to determine the level of stress and water use.

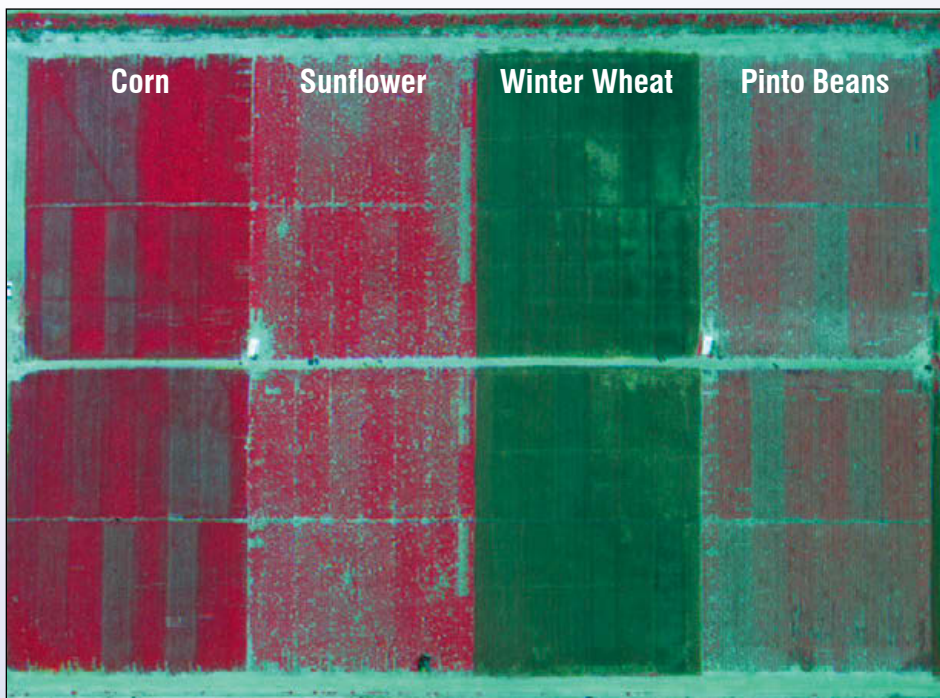


Figure 4. Aerial false color image of the limited irrigation field. Varying stress levels are reflected in the amount of green canopy (red color) and the canopy temperature. The wheat is mature in this August 4, 2010 photo.

lines are also straighter because corn, like many crops, is fairly efficient at adding yield for each extra amount of ET. A 50 percent reduction in ET results in more than a 50 percent reduction in yield because the corn requires about 10 inches of ET before it begins to produce grain yield.

Water production functions such as these are the basic information

needed to evaluate the costs and benefits of deficit irrigation. By applying these relationships to a grower's cost of production and prices, a decision can be made how to best allocate limited water supplies to get the most income. A critical part of that evaluation will be whether the farmer desires to reduce the amount and cost of water applied (due to

pumping costs or restrictions), or to reduce the amount of water consumed (such as for leasing water).

In 2012, the ARS limited water research was refocused on developing a better understanding of crop response to water stress, with the goal of improving crop productivity with limited water. We reduced the number of crops in rotation to two (corn and sunflower) and began applying water at specific growth periods to determine how to best allocate limited water to minimize yield declines. We closely monitor the crop physiological responses to stress, both above and below ground. At the same time, we take many plant and soil measurements that might be useful for a farmer to use to schedule deficit irrigation. One of the promising technologies is to use crop canopy temperature, measured from the ground, the air, or space, to indicate both the degree of stress, and the reduction in ET.

So, what should a farmer do when facing water shortages? First, do everything possible to collect and conserve winter moisture and summer rainfall, including reduced tillage and residue management to leave as much residue as possible on the soil surface to reduce soil evaporation. Second, irrigate as uniformly as possible and schedule irrigations carefully. This is much easier with pressurized irrigation systems. Then, if the water supply is limited, reducing irrigation by up to 50 percent is likely a good option, as long as the crop is given adequate water at critical periods such as during tassling or flowering.

However, if the goal is to reduce consumptive use, deficit irrigation may not be a good option, and profitability would likely be higher by cropping and fully irrigating only part of the area and fallowing or producing dryland crops on the remaining area. ●



Aerial view of the Highline Canal as it heads towards Grand Junction from Palisade. Photo by Bill Cotton

Effect of Fallow Periods on Yield and Nutrient Availability for Corn Cropping Systems in the Lower Arkansas River Valley

Extension

Perry Cabot, Extension Water Resources Specialist, Colorado State University

Introduction

The basic approach to what is referred to as “fallowing-leasing” in the context of Colorado House bill 13-1248 is that a holder of water rights water rights may enter into an agreement with a prospective water user to lease the use of the water right for a period agreed upon by both parties. More specifically, the “fallowing-leasing” approach was designed as an alternative to permanent agricultural dry-up and to provide structure for agricultural water rights holders to lease water for temporary municipal use.

In 2008, Colorado State University was approached by interests in the Lower Arkansas River Valley to establish two sites that would represent demonstrations of “fallowing-leasing” sites. The project activities focused on quantifying changes in yield, soil nutrient levels, and profitability that resulted on irrigated fields when they were brought back into production after various periods of fallowing. The project consisted of two sites, each

comprised of eight acres arrayed into two-acre subplots which were cropped or fallowed according to a temporal schedule intended to represent a three-year period of fallowing-leasing. The purpose of using a three-year period was to adhere to guidelines (C.R.S. §37-92-309) which allowed the temporary transfer of water for up to three years out of 10 under the terms of interruptible water supply agreements approved by the State Engineer. In our demonstration, therefore, all plots were fallowed during the first year except for the “control plot,” which was planted in continuous corn during the entire project. In each successive year, another two-acre subplot was returned to crop production. The project has now been fulfilled through four cropping seasons. Of the four subplots, three were fallowed in 2009, two in 2010, one in 2011, and finally all four subplots were planted back to corn in 2012. See Figure 1a below for a graphical depiction of the cropping sequence.

Project Results

The most evident and obvious result of fallowing previously irrigated cropland is that without a dryland cover crop or a significant investment in herbicides, weeds common to this region such as Kochia (*Kochia scoparia*), Pigweed (*Amaranthus retroflexus*), Bindweed (*Convolvulus arvensis*), Bull Nettle (*Cnidoscolus texanus*), Purslane (*Portulaca oleracea*), and Spurge (*Chamaesyce maculate*) will dominate fallow sites under fallow conditions. See Figures 2a and 2b for fallow sites, as compared with cropped fields. Aside from the general concerns regarding weed propagation, the weed issue introduces a consideration that farmers must take into account when practicing fallowing-leasing. In arid climates, weed control is imperative in order to reduce the likelihood of non-beneficial consumptive use of stored soil moisture or, in some cases, groundwater. Additionally, weeds will tend to “mine” valuable nutrients from the soil, a portion of which may even have originated from

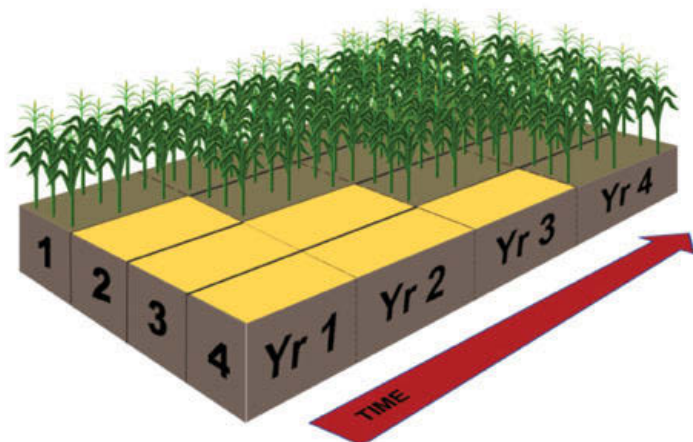


Figure 1a. Original demonstration layout in space and time for fallowing project using corn as the index crop for Highline and Holbrook canal sites

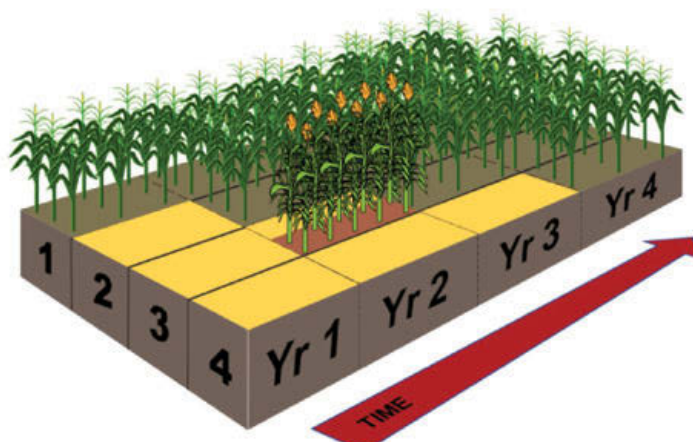


Figure 1b. Modification of demonstration site in order to incorporate dryland farming of forage sorghum on one acre of Year 2 fallow plot



Figure 2a. Demonstration site with index corn crop (above) and fallow plot (below) overrun with Kochia despite spraying with Roundup and Banvel at \$20.50/acre



Figure 2b. Demonstration site with index corn crop (right) and fallow plot (left) bare with Kochia weeds emerging in 2011

Another aspect of the project involved the evaluation of nutrient levels and nutrient carryover during the successive years of the demonstration. Perhaps the most interesting finding is that yearly soil measurements suggest retention of nitrogen (N) on fallowed fields. Levels of N remained fairly consistent one year later after the single addition of 128 lb N/acre and 92 lb N/acre, respectively, at the Highline Canal and Holbrook Canal sites in Year 1 (2009). Soil N levels were obtained from samples taken during the spring

generally exhibited increased or high N levels. The cause of increasing N levels was most likely due to mineralization of organic N already present in the soil, coupled with aggressive weed control that presented the utilization of soil N. It should be noted, however, that in one plot at the Highline Canal site N levels diminished significantly following the 2011 fallow period. It is believed that the significant loss of soil N was due to poor weed control by the farmer (See Figures 3 and 4).

Corn yields following the fallow period were compared with yields on the index plot for each respective year. At the Holbrook Canal site in 2010, for example, corn grain yield was 224 bushels/acre on the continuous corn index plot, somewhat less than 242 bushels/acre on the plot that had been fallowed in the previous year. The increase in yield over the index plot was somewhat surprising, but reasonable due to the available moisture and carryover of N. A small modification of one of the demonstration sites in 2010 allowed us to document a favorable yield of forage sorghum (17.4 T/ac) on a dryland basis (Figure 1b). Forage sorghum may offer an alternative cropping system for fields that are entered into leasing arrangements. In 2011 at this site, corn grain yield was 196 bushels/acre on the continuous corn index plot, larger than 138 bushels/acre on the plot that had been fallowed for the previous two years. The decrease in yield was not surprising after two years of fallow, but

fertilizer applications initiated by the farmer before the decision to enter a fallowing agreement was made. On the other hand, weed control can be an expensive and time-consuming practice. The farmer must consider the value of lost nutrients and water against the cost of herbicide under any fallowing scenario.

season before the fallowed plots were planted back to corn (See Figures 3a and 3b), but before these plots were fertilized with recommended N additions. On these sites, N levels were low or diminished after uptake by corn during the previous year. Other the other hand, plots where corn had not been planted during the previous year

noteworthy in that the plot had not been fertilized with since Year 1 (2009) of the demonstration. Due to the drought and the junior water right that supplies irrigation water to this site, the 2012 cropping season was so damaging to the corn plots that they were headed for complete failure, and therefore the decision was made to harvest early for silage. Interestingly, none of the plots yielded much differently in terms of silage.

At the Highline Canal site, results were similar. In 2010, corn grain yield was 206 bushels/acre on the continuous corn index plot, very comparable to the 203 bushels/acre on the plot that had been fallowed in the previous year. In 2011, corn grain yield was 196 bushels/acre on the continuous corn index plot, significantly larger than 150

bushels/acre on the plot that had been fallowed for the previous two years. Again, the decrease in yield was not surprising after two years of fallow, but noteworthy in that the plot had also not been fertilized with since Year 1 (2009) of the demonstration. Data are still forthcoming from the 2012 yields at this site. Though it was able to be harvested for corn grain, due to the senior water right supplying irrigation water to this site, the yields were extremely low and very significantly affected by the drought.

Concluding Thoughts

The practice of fallowing-leasing holds great promise as an alternative to permanent dry-up of agricultural land. The entities entering into these lease arrangements are doing so with

the knowledge that the fallowed land will at some point be returned to full production. This multi-year planning strategy, which now includes something akin to “water farming,” should prioritize the protection of soil resource. In areas such as the Lower Arkansas River Valley, soil resources must be carefully protected, due to the high propensity for wind erosion and weed invasion. Proper protection of the soil will keep sustained agriculture in practice in this area, which relies heavily on farming to support the rural economies of Southern Colorado.

This project owes special thanks to Jim Valliant, Mike Bartolo, Jeff Tranel, and Caleb Erkman, all of whom have assisted on various aspects of this project. ●

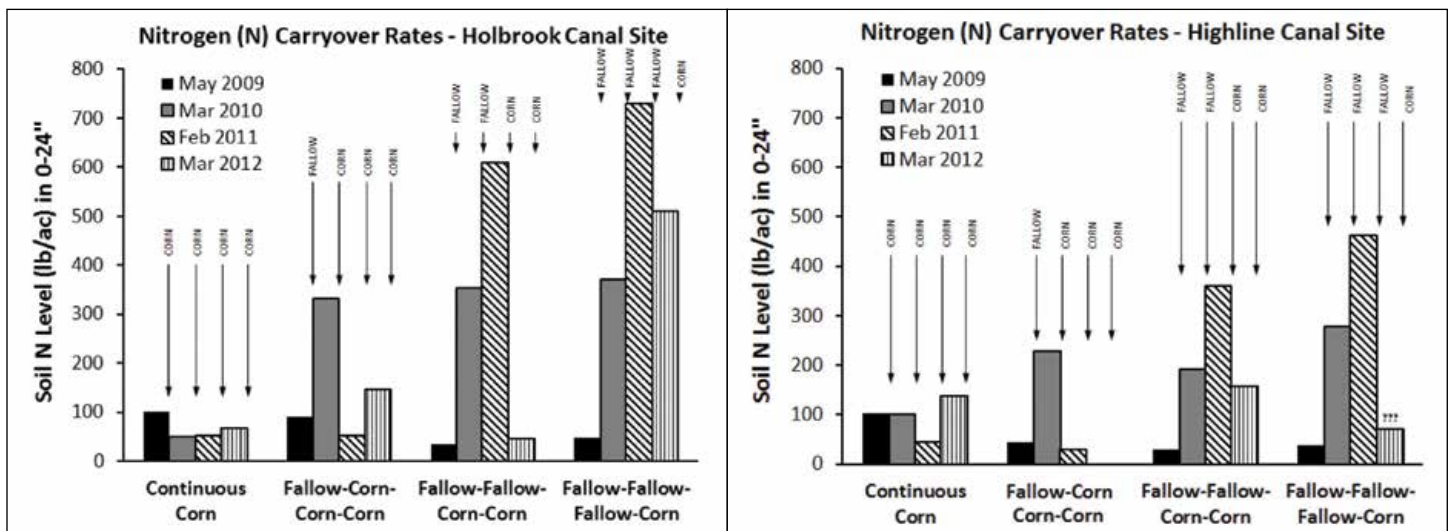


Figure 3. Nitrogen (N) levels at Holbrook Canal (a) and Highline Canal (b) sites from samples obtained during the spring season, before sites were planted to corn

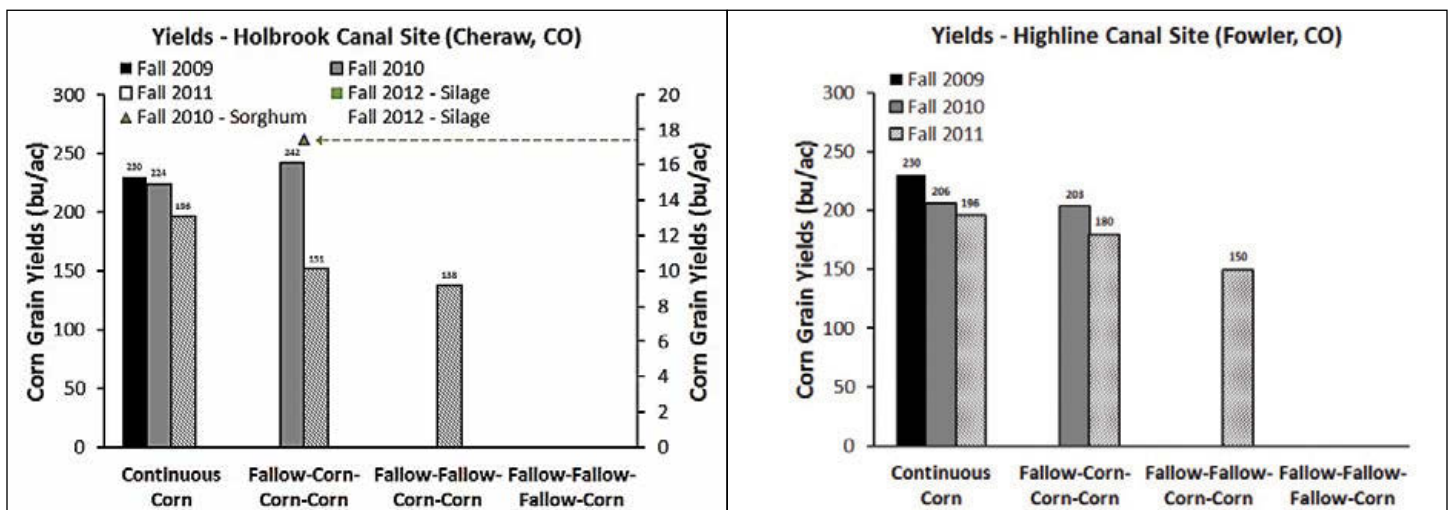


Figure 4. Yields from the Holbrook Canal (a) and Highline Canal (b) sites in years where plots were planted to corn

Nitrogen Response of Irrigated Sunflowers

Joel P. Schneekloth, *Regional Water Resource Specialist,*
Colorado State University

*Photo by
Messycupcakes
Photography*

Introduction

Research in the area of nitrogen response of irrigated sunflowers is limited. Much of the work has been done in rainfed production where yield potential of the crop may be limited due to water stress during the growing season. Zubillaga et al. (2002) found that yield of rainfed sunflowers increased with the addition of fertilizer. The yield of sunflower increased to the maximum amount of N applied (138 kg/ha). Yield content generally decreased with the addition of nitrogen, which resulted in similar total oil

production for all nitrogen rates. This work was done in a highly productive region with precipitation during the growing season being greater than 450 mm. Within these regions and precipitation patterns, nitrogen may be leached and unavailable to the plant, which may be different than that of the High Plains where precipitation is generally limited. Mathers and Stewart (1982) found increasing yields of sunflower with smaller amounts of nitrogen applied and then a small decline in yields with additional fertilizer. Oil content of sunflowers also decreased with the

addition of nitrogen. This was done with very limited amounts of water to prevent observed wilting of the crop. This limited amount of water may have limited the yield potential of sunflowers, which would mask the response of nitrogen. Vigil (2000) observed no yield response of sunflowers to nitrogen during years of limited precipitation. Vigil did observe one year where yield of sunflower did respond to nitrogen, but only when the yield potential was greater than 2,000 kg/ha. He found that rainfed sunflowers have the ability to utilize soil residual nitrogen

from depths beyond one meter that most crops cannot access.

Irrigated production in the Central Plains has the ability to produce greater yields as compared to rainfed production. Schneekloth (2005) found that irrigated sunflowers can produce 50 percent greater yields with full or limited irrigation when timed appropriately. In years with below average precipitation and less than adequate beginning soil moisture, irrigation increases yield by 100 to 200 percent of rainfed yields. Additions of water early in the growth cycle tend to decrease oil content as compared to rainfed production. However, withholding irrigation until the later reproductive growth stages can increase oil content as compared to rainfed production.

A gap exists in research for irrigated production of sunflowers and nitrogen management. All of the fertility work has also been with fertility applied at planting. With many irrigation systems, the ability to apply nitrogen during the growing season is a possibility and has the potential to increase nitrogen use efficiency and reduce applications.

Methods and Procedures

An irrigated site in Burlington, Colorado was established with a crop rotation of winter wheat, corn, sunflower, and soybean. This site included three irrigation management strategies for each crop, varying from full irrigation management to a limited allocation. Currently, the average annual allocation for all crops will be at nine inches with more irrigation allocated for irrigated corn production (12 inches) and less for wheat, sunflower, and soybean (nine, five, and nine inches respectively). Limited irrigation management will follow

strategies developed by Colorado State University and the University of Nebraska for each of the four crops. In 2009, the site was moved to Akron, Colorado. Irrigation management strategies were full irrigation management and an annual allocation of five inches.

Within each of the pie shapes treatments, nutrient management strategies and rates will be randomized in a randomized complete block design. Nitrogen rates of 0, 75, 150 and 225 lbs per acre were applied at planting as 32-0-0. Two alternative strategies that will simulate Fertigation will be utilized by splitting applications of nitrogen during the growing season at two different rates. These rates were 0 or 75 lbs N pre-plant with 75 lbs N applied at R3. Chlorophyll readings were taken at the R1 growth stage for full irrigation sunflowers. Soil samples were taken prior to planting and post harvest to determine the nitrogen uptake by sunflowers at each of the nitrogen rates. Soil sampling depths include 0-6 inches, 6-24 inches, and 24-36 inches. In 2009, soil samples an addition sample of 36 to 48 inches was included for deeper soil nitrogen. This will also allow for the understanding of the potential reduction of

nitrogen within several depths of the soil.

Grain yields were taken by harvesting two rows for a total row length of 12 feet. These samples were thrashed and analyzed for moisture, seed size, and oil content.

Results

Weather conditions for Burlington were near average for precipitation in 2006. Precipitation in 2007 was below average. Good growing conditions resulted in better than average yields in 2006 and lower yields in 2007. Maximum grain yields were greater than 3,000 lbs per acre for both allocation and full irrigation. Grain yields increased with increasing nitrogen to 150 lbs per acre Nitrogen (Table 1a and 1b). Grain yields were maximized with 150 lbs of nitrogen applied pre-plant for both allocated and full irrigation sunflowers. Grain

Table 1a. Grain yields for nitrogen rates for allocation irrigation sunflowers.

Grain Yield (lbs/acre)				
N Rate	Year			Average
lbs/acre	2006	2007	2009	
0	2784	2335	2722	2614
75	2804	2779	2607	2730
150	3085	2736	2393	2738
225	3037	2726	2347	2703
75+75	3180	2848	2823	2950
0+75	3099	2694	2739	2844

Table 1b. Grain yields for nitrogen rates for full irrigation sunflowers.

Grain Yield (lbs/acre)				
N Rate	Year			Average
lbs/acre	2006	2007	2009	
0	2597	2472	2641	2570
75	2670	2532	2371	2524
150	3073	2941	2485	2833
225	2274	2785	2151	2403
75+75	3035	3045	2505	2862
0+75	2823	2514	2614	2650

Table 2. Oil content for nitrogen rates for allocation and fully irrigated sunflowers

N Rate lbs/acre	Oil Content (%)			
	2006		2009	
	Alloc	Full	Alloc	Full
0	50.4	50.5	48.5	50.2
75	50.1	50.4	48.2	50.2
150	49.4	50.0	47.2	48.9
225	48.7	48.9	45.7	48.7
75+75	48.5	50.0	47.4	50.1
0+75	49.3	49.5	46.6	48.7

Table 3. Seed size for nitrogen rates for allocation and fully irrigated sunflowers (2006)

N Rate lbs/acre	Seed Size g/100 seed	
	Alloc	Full
	0	9.4
75	8.7	9.0
150	10.4	9.1
225	10.1	8.4
75+75	9.5	10.5
0+75	9.5	8.8

applying the entire application pre-plant. However, applying 75 lbs N post in allocated irrigation resulted in similar yields as compared to 150 lbs N pre-plant in the allocated irrigation. Applying 75 lbs N post for full irrigation did not maximize grain yields but was greater than applying 75 lbs N pre-plant in 2006 and similar yields in 2007. In 2009, splitting applications of N resulted in greater yields as compared to all pre-plant applications with the similar amount of total N applied.

Oil content of sunflowers decreased with addition of nitrogen (Table 2). This is similar to previous work. Oil content decreased by 1.5 to 3 percent for 225 lbs of N applied as compared to 0 lbs N. Late season

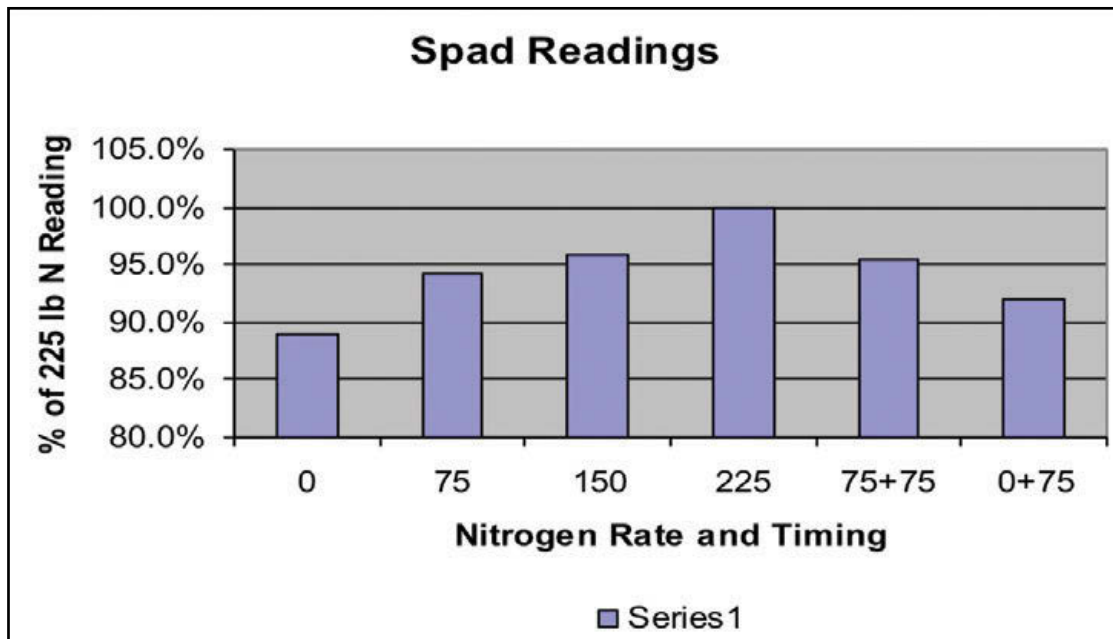


Figure 1. Chlorophyll readings of full irrigation sunflowers relative to 225 lbs of N applied.

yields increased approximately 400 and 500 lbs per acre from 0 to 150 lbs per acre for allocated and full irrigation, respectively. The first 75 lbs of N did not greatly increase yields as compared to 0 lbs N for full irrigation (70 lbs per acre), while yields for allocated irrigation increased approximately 200 lbs per acre. Applications of N above 150 lbs per acres resulted in similar or lower yields for both allocated and full irrigation. Grain yields for 0 and 75 lbs N were greater for allocated irrigation as compared to full irrigation sunflowers in 2006 and greater for full irrigation

than allocated irrigation in 2007. Precipitation in 2009 was above average, and temperatures were below average. In 2009, additions of pre-plant nitrogen decreased yield as compared to no nitrogen additions. Late season applications of nitrogen did increase yield as compared to the application of similar pre-plant nitrogen applications.

Splitting nitrogen applications or applying nitrogen during the early reproductive growth stages increased grain yields. Splitting 150 lbs of N between pre-plant and post resulted in similar yields as compared to

applications of N also generally suppressed oil content as compared to similar nitrogen rates applied pre-plant. Nitrogen applications did not affect seed size (Table 3).

Chlorophyll readings of full irrigation sunflowers at or near R1 growth stage indicated less nitrogen in the leaves for all fertilizer rates as compared to 225 lbs N applied (Figure 1). Chlorophyll readings increased with increasing nitrogen applied pre-plant. For corn, a relative reading of less than 95 percent indicates that nitrogen may be limiting for production. Only the

150 lb pre-plant application was above the 95 percent threshold. This threshold appears to have maximized grain yields without corrective additions of fertilizer. Readings less than 95 percent resulted in lower grain yields without additional N applied.

Residual Soil Nitrogen

Soil samples were taken spring and fall for allocated irrigation sunflowers. Spring soil samples for full irrigation were taken, but fall samples were not taken at this time.

Spring residual soil nitrogen averaged 62 lbs per acre for the allocation treatments (Figure 2). Fall residual showed that application of 75 lbs per acre N or less resulted in nitrogen reduction in the 3 foot sample. The reduction in N averaged 37 to 47 lbs per acre as compared to spring soil residual. Applications of 150 lbs N had similar soil residual in the fall as compared to spring.

Applications of 225 lbs N resulted in an increase of 75 lbs per acre residual N.

Residual soil nitrogen by depth is shown in Figure 2. Applications of

75 lbs per acre N or less resulted in reduced nitrogen amounts in each of the 3 sample depths to 3 feet. Applications of 150 lbs N per acre resulted in increases in residual N in

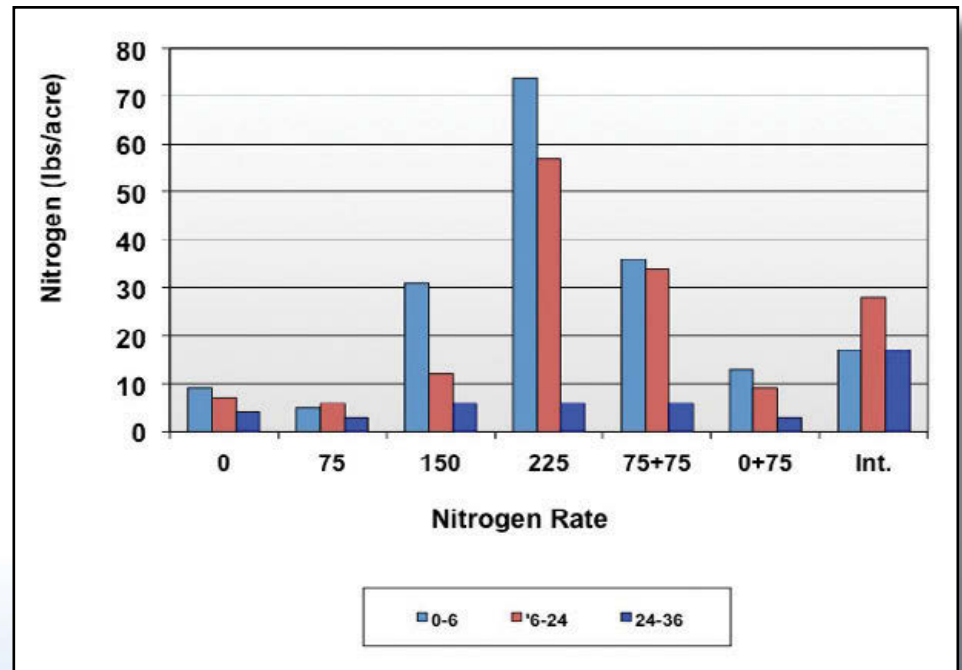


Figure 2. Residual soil nitrogen for allocation irrigation sunflowers 2006



Late vegetative water stress of Growth Stage Irrigation treatment. Photo by Joel Schneekloth

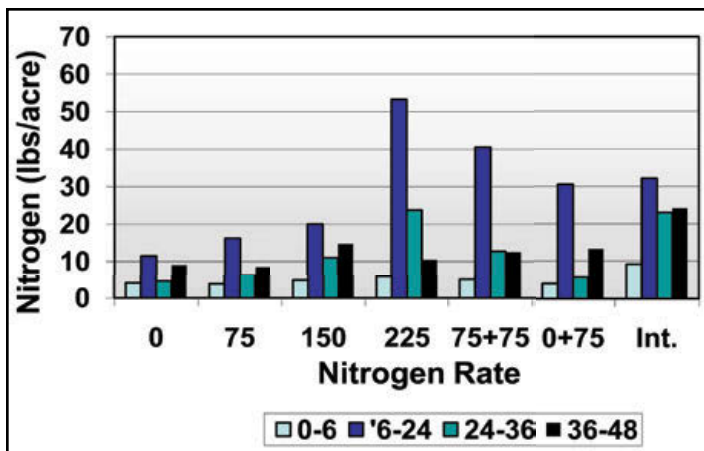


Figure 3. Residual soil nitrogen for allocation irrigation sunflowers 2009

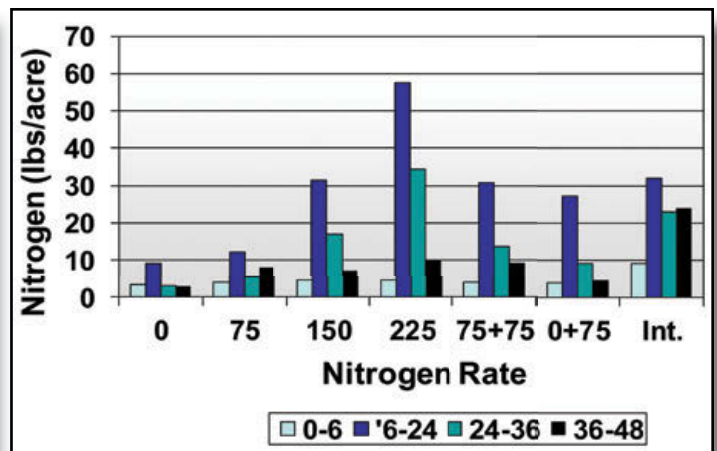


Figure 4. Residual soil nitrogen for full irrigation sunflowers 2009

the 0 to 6 inch sample but reductions in the 6 to 24 and 24 to 36 inch samples. Applications of 225 lbs N per acre increased residual N in the 0 to 24 samples. A split application of 75 lbs pre-plant and 75 lbs reproductive resulted in increase N in the 0 to 6 inch sample with similar N in the 6 to 24 inch sample. All application rates resulted in reduced N in the 24 to 36 inch sample. Applied nitrogen appeared to not leach past the 24 inch sample depth due to irrigation management.

Spring residual soil nitrogen averaged 88 lbs per acre in 2009 (Figure 3). Applications of N up to 150 lbs per acre resulted in reductions in residual N by 20 to 60 lbs N per acre for allocation irrigation. Increasing N applications resulted in less N removal. Pre-plant applications of 225 lbs per acre resulted in increases of N residual by five lbs per acre. However, an increase in the 6 to 24 inch soil depth was reported with decreases in all other depths. Application of 75 lbs N at the R1 growth stage resulted in similar or greater soil residuals in the fall compared to spring in the 6 to 24 depth with overall decreases in N residual. These results were similar in the full irrigation management as well.

Conclusions

Grain yields for sunflowers increased with nitrogen. In 2006 and 2007, grain yields were maximized with applications of 150 lbs of N pre-plant. However, the economics of nitrogen applications was marginal at today's price. With limited irrigation, late season applications of nitrogen appear to have added benefits to yield as compared to pre-season applications. Water management practices appear to impact the

economic application of N. However, in 2009 pre-plant applications of N decreased grain yields as compared to 0 N. Applications of 75 lbs at R1 growth stage did result in yields equal to or greater than 0 lbs N. When irrigation is limited in the vegetative growth stage, application of N greater than 75 lbs per acre did not increase revenues. However, when full irrigation practices are used, applications of 150 lbs per acre generated the greatest returns. ●



Photo by
Messycupcakes
Photography

PLHC Water History Projects

Mary Swanson, Marketing and Development Coordinator,
Public Lands History Center

It is nearly impossible to study water-related challenges in Colorado without encountering the vast network of canals, dams, and laws developed during the late-nineteenth and early twentieth-centuries. This physical and legal infrastructure—and those responsible for it—reshaped the Colorado landscape and allowed an arid environment to support millions of new inhabitants. Despite this, few research projects in Colorado specifically focus on understanding the social, economic, environmental, and political conditions that produced the state's water infrastructure. With so many urgent research needs in the state, understanding the ecological impacts of the past policies often supersedes understanding the past policies themselves, and as a result, important historical data is never uncovered.

Colorado State University's Public Lands History Center (PLHC) is beginning to reverse this trend. Since 2010, the PLHC has brought faculty experts and graduate students in history together to work on three different water histories in the state: an administrative history of the Fort Collins Water Utilities, an administrative and environmental history of the Farmers Reservoir and Irrigation Company (FRICO), and a digital history project detailing agricultural and urban water use on the Cache La Poudre River. The PLHC's goal is that each of these histories provides water managers with information and questions that can help water managers explain and improve their practices.



Michigan Ditch (the line in the trees that looks like a road) carries water from Michigan River over Cameron Pass to Joe Wright Reservoir where water then flows into the Poudre River. The ditch redirects the water flow to Fort Collins from its natural route towards Wyoming.

Photo courtesy of Christy Dickinson

Mark Fiege, PLHC Council member, describes the center's approach in this way: "As environmental historians, we seek to understand the reciprocal influences of nature on humanity and humanity on nature. Our work is inherently interdisciplinary. We borrow methods from many disciplines, but resist approaches that reduce explanation of environmental change to one or a few variables. Instead, we hope to connect multiple interdependent variables in explanations of the past." PLHC researchers craft reports based on archival research, current and past management decisions, ecological data, and a variety of other sources.

Synthesizing information produced over time across different disciplines is often complicated and lengthy process. Just ask Christy Dickinson, the PLHC graduate student

researcher who updated the history of the Fort Collins Water Utilities. When she was first asked to work on the project, Dickinson expected it to be fairly straightforward. She knew that the 30-year-old existing history needed more discussion of social, economic, political, and environmental forces that influenced local water policy decisions, but she didn't expect to rewrite the entire document.

As she became more familiar with the project, however, Dickinson noticed something peculiar about that the organizational structure of the 1983 history. Instead of presenting a chronological narrative, *From Bucket to Basin* divides the history of the four departments within the utility—water supply, water distribution, water quality, and water treatment—into separate



In 1971, the city of Fort Collins acquired Michigan Ditch and Joe Wright Reservoir near Cameron Pass to plan for the city's growing water needs. Constructed in 1902, the ditch and reservoir system required extensive renovations, resulting in one of the largest projects the utilities had undertaken until then. The utilities completed the expansion and renovation in 1980.

Photo courtesy of Christy Dickinson

chapters. Dickinson believes this organizational structure reflected the compartmentalization of utilities during its early years. She explains that because each department had a number of complex responsibilities, the Water Utilities could not consider the entire operation because the science and technology for each department was specific to their unique responsibility. This

compartmentalization, moreover, sometimes muddled cause-and-effect relationships. In some cases, it was unclear who or what precipitated policies changes within the utility.

To outline cause and effect more clearly, Dickinson worked with Mark Fiege and PLHC Program Manager Maren Bzdek to integrate the utility's new history in three

new, chronological chapters. Each one traces how shifting political forces, scientific assumptions, and environmental conditions informed utility policy. She writes, "Dr. Fiege helped me envision how the natural element of water connected all of the departments and how they truly shared deep and dynamic relationships to each other, much like a natural ecosystem." She hopes that in illuminating the connections between the Utilities' four sub-divisions, her research will help inform future management decisions.

In 2010, a relatively small oral history project for FRICO—one the oldest and largest mutual ditch companies in Colorado—turned into a contract to write a book-length manuscript detailing the history of the company. The company, undergoing some administrative changes, asked the PLHC to conducting a series of oral interviews of former employees and individuals associated with the FRICO. From June of 2010 and August 2011, graduate researcher Clarissa Trapp recorded and transcribed a number of oral interviews with individuals associated with FRICO. Trapp interviewed farmers, a former financial officer, former board members, and a wife of the company's beloved ditch rider (individuals responsible for keeping the water flowing).

After completion of the project, the PLHC suggested that the oral interviews could be incorporated into a larger and more comprehensive history of the company. FRICO agreed, and in spring of 2012, graduate student researcher Hayley Brazier began work on the project under the direction of Mark Fiege and Reagan Waskom. To date, Brazier has been studying the expansive reservoir and canal system that spans more four hundred miles and supplies water to several

municipalities including the cities of Thornton, Westminster, Broomfield, and Northglenn. She is incorporating Trapp's oral histories, company documents, and archival research into a corporate history spanning from the late nineteenth-century to the present. One of the most interesting things about FRICO is its survival. While many other Colorado irrigation companies have closed or have been purchased by cities to become public entities, FRICO has remained a private corporation for 111 years.

When the history is complete, FRICO will have a detailed history that will preserve the company's institutional memory and guide contemporary managers as they consider the consequences of past decisions.

The PLHC's third water history project to date, the Poudre River Digital History Project, is also the largest. A multi-year endeavor funded by the Colorado Agricultural Experiment Station, the Poudre history website will present digitized historical information about the watershed including archival resources, maps, and photographs and will make use of digital tools such as image analysis, digitized maps, Geographic Information Systems (GIS), and animations.

PLHC graduate students researchers Hannah Braun and Ashley Baranyk spent the first year collecting and organizing a significant amount of site content relating to the Poudre River watershed, water diversion and transfer projects, water management, and the agricultural to urban landscapes in the Fort Collins area, as well as investigating and evaluating various digital tools to "tell the story" through a website.

Now in its second year, the PLHC has created a prototype website, and is working with Geography



PLHC graduate student researcher, Hayley Brazier, outside the Farmers Reservoir and Irrigation Company (FRICO)'s office. Photo courtesy of Hayley Brazier

Professor and GIS expert Steve Leisz to combine aerial and satellite photography, census information, land use and land cover data to present interactive, visual representations of the Poudre watershed's over time.

“ When the project is complete, FRICO will have a detailed history that will preserve the company's institutional memory and guide contemporary managers as they consider the consequences of past decisions. ”

A primary focus of this effort, PLHC researcher Blake Stewart explains, is to show how—through ditches and canals—the Cache La Poudre River extends into the city of Fort Collins. Stewart hopes that the new website will elevate and inform public debate

when water use in the community is contested. The site is expected to go live in May of 2014.

When asked about their experiences working at the PLHC on Colorado water projects, Dickinson, Brazier, and Stewart all had positive things to say. Brazier describes the value of her research inexperience as “incalculable,” and Dickinson states she cannot overemphasize how important it was to have a research center guide her efforts. It was Stewart, however, that captured the PLHC's approach to water history when he described everything he had learned on the project. “The importance of understanding water,” he explains “and where it comes from, how it is delivered, and how people perceive and use it cannot be underestimated, and environmental history helps us answer many of these questions.”

To learn more about the PLHC and its work or inquire about research services, contact Maren Bzdek at maren.bzdek@colostate.edu or (970) 491-6130. ●

Senate Bill-019 Brings Out Discussion About Agricultural Water Conservation

Lindsey Middleton, Editor, Colorado Water Institute

MaryLou Smith, Policy and Collaboration Specialist, Colorado Water Institute

Threat of water shortage in Colorado along with increasing demand has water users and managers from many sectors reconsidering the benefits of water conservation. Ag water conservation has become a hot topic in the state due to a bill, SB 13-019, introduced in the last Colorado legislative session by Senator Gail Schwartz, District 5, with Representative Randy Fischer (District 53) sponsoring the bill in the House.

The bill brought to the forefront an issue that has been controversial for some time, as many believe that little if any water in Colorado is meaningfully available for conservation, hence the saying “one farmer’s waste becomes the next farmer’s water right.” Still, agricultural producers are being asked to look deeper into the opportunity for conservation, despite the complexity return flows brings to the issue.

“How do we find some additional tools, besides our instream flow programs, to motivate Ag water users to adjust their diversions at specific times? That was the thinking originally,” explains Schwartz of her motivation for introducing SB-019 in January of this year. “In the long term, we asked what would be some tools, such as infrastructure, that would allow Ag users to count on running less water without risking the loss of any historic consumptive use.”

Some had urged Schwartz to wait for more discussion about Ag water conservation among various constituencies before introducing the bill, but she chose to move

ahead. “This being the second year of drought we were facing, I thought it would be more important to move forward,” explains Schwartz. After introducing the bill, Schwartz approached the Colorado Water Congress (CWC). CWC is often a first step for water legislation, and their formal support of a bill can help ease a bill through the voting process. As a result of discussions with CWC, Schwartz put the bill on a slow track, asking CWC to form a sub-committee and review the issues in more depth.

According to CWC State Affairs Committee member Dick Brown, who represents Pikes Peak Regional Water Authority on the committee, “The bill got narrower in scope [as we went on], which is not uncommon.” Among other changes, the bill was reduced to Water Districts 4, 5, and 6 on the West Slope.

Brown adds that Schwartz agreed to CWC revisions and amended the bill accordingly. The CWC voted to support the amended SB-019 and to work with Senator Schwartz over the summer (when Colorado’s legislature is not in session) to discuss concerns with the excised portions of the bill.

The amended bill was passed by the state legislature in April. Changes included removing a section that would allow a water judge to approve a change of water right for conserved water in certain cases.

The bill as passed is already having a positive effect on some. Linn Brooks of Eagle River Water and Sanitation says her region’s tourism-based economy, which relies on river flows, benefits from Senator Schwartz’s bill,

even in its truncated form. In fact, Eagle River Water and Sanitation has already begun to reach out to water rights owners in their region to conserve on a broader scale.

“We acknowledge that this tool may be difficult to use in other areas where water administration is more complicated,” says Brooks, “but we believe it can work for us.”

Brooks testified for SB-019 before the House Agriculture, Livestock, and Natural Resources Committee out of a desire to protect cooperating diverters.

“The part of SB-019 that did pass alleviated the concerns of diverters that they would get penalized for cooperating,” says Brooks—concern that conservation hurts historic use averages has been a holdup for such efforts in the past.

The Eagle River Water and Sanitation District, located near the headwaters of the Colorado River Basin, draws water from the Eagle River and Gore Creek. They are the second largest municipal water provider on the Western Slope.

“Healthy streamflows support fishing, boating, and the aesthetic values that draw visitors and drive our economy,” says Brooks. Outreach to diverters in 2012 resulted in cooperation from irrigation diversions, golf courses, and others agreeing to a 15 percent reduction in diversions initially and up to 25 percent as flows dropped through the 2012 summer season. But while diverters were willing to divert less, they questioned what the long-term effect on their water



In the drought year 2012, Eagle River Water and Sanitation District gained cooperation from its diverters to leave some of their water in the stream to help protect Gore Creek and other waterways essential to tourism. Now, SB-019 assures those diverters that their water conservation will not negatively affect their water rights long term.

Photo by Jason St Peter

rights might be.

SB-019, says Brooks,

supports these cooperative efforts by protecting those who participate from being penalized in terms of historic consumptive use calculations if they ever require a change of use.

Among other aspects, SB-019 contains language that gives appropriators a “safe harbor” when they decrease their consumptive use. It calls for water judges to not consider any decrease in use resulting from a variety of programs, including certain water conservation programs, land fallowing programs, and water banking programs.

Brown, who was part of the CWC sub-committee providing recommendations for the bill, says that there was some debate about

aspects of SB-019. “Some folks were really nervous that this was going to be a significant change in water policy since it tackled the issue of use it or lose it,” he says.

One of the objections to the original bill had to do with unintended consequences for other areas of the state, such as the Rio Grande Basin. “From what I have seen,” says Schwartz, “through recent legislation we are channeling different options for different basins.” She says by applying SB-019 to most of the West Slope, the bill was able to seize upon a timely opportunity and serve as a pilot for applications elsewhere. “We have the opportunity with roundtables to really look at specific needs for different basins,” she says.

Schwartz says dialogue will continue as part of summer and fall sessions at the capitol. “We have more time,” she says, “but we will nudge people into having the conversation rather than have it evolve on its own.”

One group that is taking up the challenge of looking at Ag water conservation from the producer’s point of view is the Colorado Ag Water Alliance. “We want to see what opportunities might exist for Ag conservation instead of just saying it can’t work,” said CAWA member Robert Sakata. A CAWA committee will be meeting with Senator Schwartz this summer.

“These are difficult conversations, and I think we have to have them,” says Schwartz. ●

A Wealth of Irrigation Information in the Water Archive

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

“Irrigation on the American continent is older than historical records.”

—Elwood Mead, *Irrigation Institutions*, 1903

Historical records of irrigation in Colorado date back about 150 years. The earliest are typically leather-bound ledgers, weighty and well worn, filled with meticulous handwriting on lightly lined pages. The handwriting may be difficult to decipher now, not due to faded ink but rather eyes more accustomed to standard type fonts. Yet this writing, in these ledgers, captures the formative years of Colorado’s oldest water organizations: ditch companies.

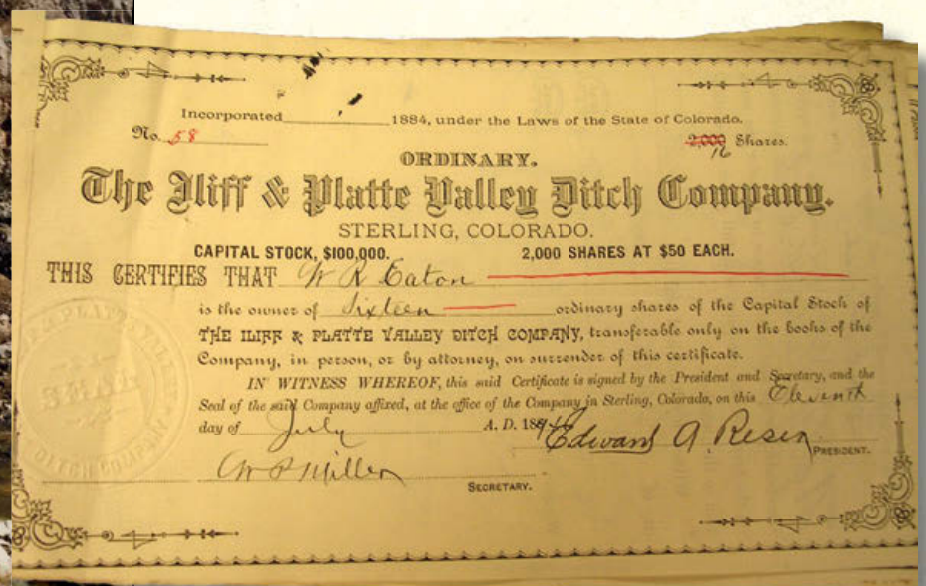
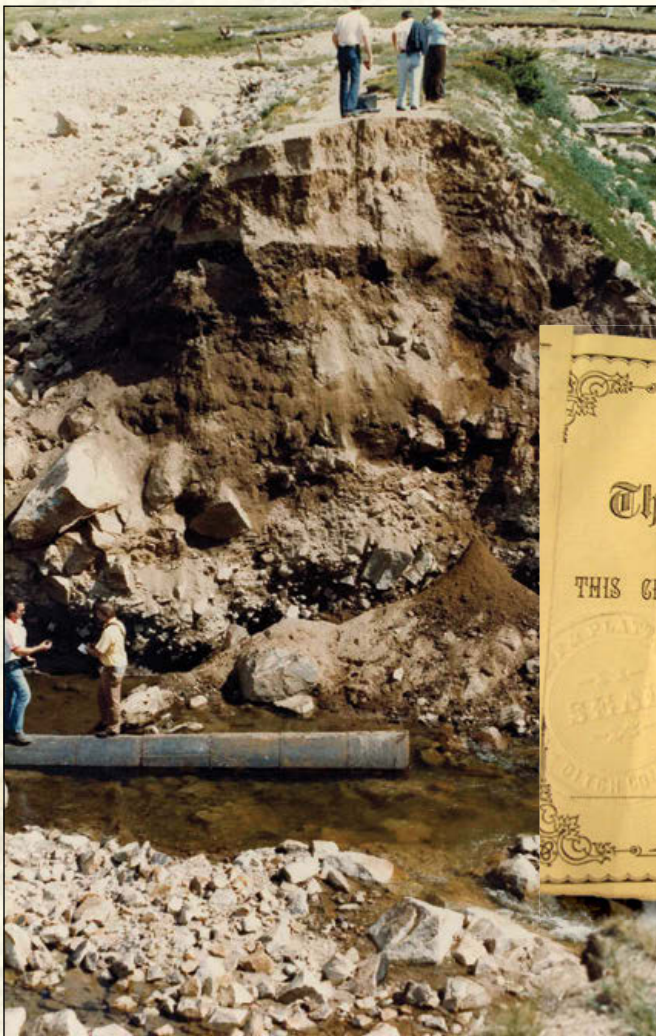
Settlers in the region began irrigating decades before ditch companies were

formed, and Native Americans were doing so before that, but it was not really until irrigation organizations formed that recordkeeping began. Colorado’s earliest ditch companies, created to collectively move water from streams to fields, date from the 1860s. Farmers, ranchers, and entrepreneurs created hundreds more from the 1870s through the 1890s as the competition for water increased. As time went on, many ditch companies succeeded, but some failed, others merged, and some were taken over for industrial or municipal use.

incorporation? What about the stock certificates, shareholder lists, water records, and legal documents created in the course of company operations, planning and reporting? Such documentation would reveal much about the development and use of water for agriculture in the state, not to mention the stories of the people who made it all happen.

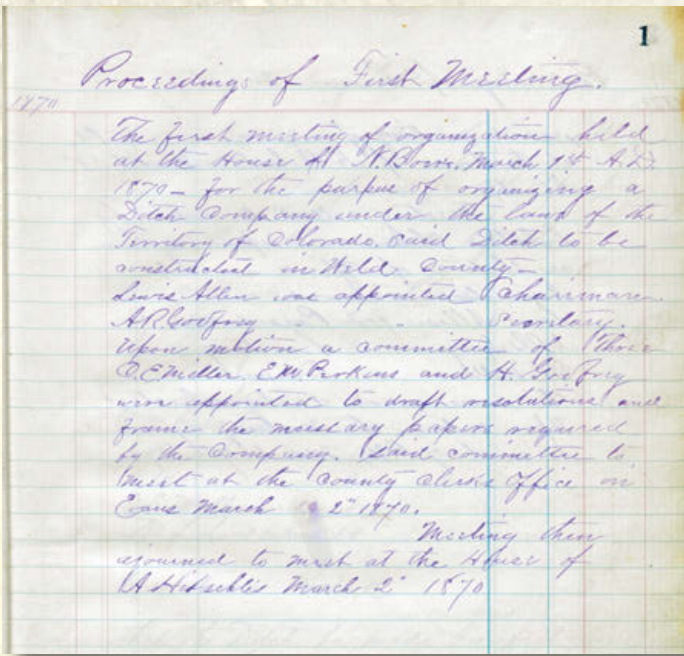
In visiting and talking with ditch companies across the state, I have discovered that the existence and status of historical irrigation records varies. Ditch companies that carry on more than one hundred years after their formation typically hold on tightly to their historical records. They know the significance of the minute books, stock ledgers, and hand-drawn maps for documenting their water rights, uses, and practices. The materials may be stored in a bank vault, in the lawyer’s office,

Where is all this history preserved? What happened to all those ledgers of meeting minutes hundreds of ditch companies surely created? All the bylaws and articles of



Left: The 26-foot-high Lawn Lake Dam failed July 15, 1982, causing years of litigation for the Reorganized Farmers Ditch Company. Above: Stock certificate for the Cliff and Platte Valley Ditch Company, July 11, 1894.

Courtesy of the CSU Water Resources Archive



Proceedings of the first meeting for the organization which became the Godfrey Ditch Company, March 1, 1870.

Courtesy of the CSU Water Resources Archive

or even in the current secretary's basement. Often the materials are not organized and sometimes are covered in cobwebs, dust or, in the worst cases, mold. When municipalities or industries inherit such documentation upon becoming the owners of a ditch, they may or may not value the ledgers and papers.

Very few ditch companies have taken advantage of archival repositories to store, preserve, organize, and make their historical records publicly available. How few? I sought the answer to this very question by conducting a study of Colorado ditch company records in 2011. I searched archival databases and library catalogs and also queried a regional archives listserv to seek publicly accessible ditch company collections in archival repositories. The study, published in 2012 in the online *Journal of Western Archives*, revealed exactly how few such collections there are. (For full article, see Rettig, Patricia J. (2012) "Tracing the Source of Irrigation: An Examination of Colorado Ditch Company Collections in Archival Repositories," *Journal of Western Archives*, Vol. 3.1.

Available at: <http://digitalcommons.usu.edu/westernarchives/vol3/iss1/1>

I discovered only twelve Colorado ditch company collections in publicly accessible archival repositories anywhere in the entire United States. One of the collections is outside of Colorado (at Wichita State University), leaving only

eleven within the state. Four of the collections are at the Colorado State University Water Resources Archive, and four are at the History Colorado Center (formerly the Colorado Historical Society). The Greeley History Museum, the Boulder Public Library, and the Denver Public Library house the others. With two new ditch company collections donated since 2011, the Water Resources Archive now holds six such collections along with four related ones.

The ditch company collections in the Water Resources Archive are:

- Godfrey Ditch Company (diverts from South Platte River)
- Iliff and Platte Valley Ditch Company (diverts from South Platte River)
- Plumb and Dailey Ditch Company (diverts from Boulder Creek)
- Reorganized Farmers Ditch Company (diverts from Big Thompson River)
- Montezuma Valley Irrigation Company (transbasin diversion

from the Dolores River into the San Juan Basin)

- Consolidated Home Supply Ditch and Reservoir Company (diverts from Big Thompson River)

Collections range in size from two boxes to 52 boxes. The Archive has scanned and put online portions of the first four of the above collections. They are accessible through the Archive's website. Selections from the latter two will also eventually be scanned and posted online.

Collections in the Water Resources Archive related to Colorado ditch companies document:

- North Poudre Irrigation Company (oral histories)
- DARCA (Ditch and Reservoir Company Alliance; organizational records)
- The Ditch Project (150 years of Boulder County ditches)
- Water Supply and Storage Company (oral histories)

At the Water Resources Archive, we believe historical records of ditch companies across the state are important to preserve and make accessible. Each financial ledger, ditch rider notebook, or letter to shareholders is a unique piece of the state's water history. They should be preserved before inks fade, papers crumble or rusty paperclips degrade pages. We are happy to provide our services to organize, inventory, store, and make these materials available for historical research and educational purposes.

For more information about ditch company collections or others in the Water Resources Archive, as well as how to donate materials, please see the website (<http://lib.colostate.edu/water/>) or contact me (970-491-1939; Patricia.Rettig@ColoState.edu) at any time. ●

Water Research Awards

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

Bailey, Larissa, Cooperative Fish & Wildlife Research, DOI-NPS-National Park Service, Investigating the Impact of Introduced, Endangered Cutthroat Trout on Boreal Toad Breeding Success & Recruitment, Year 2, \$9,000

Baker, Daniel W, Civil & Environmental Engineering, City of Fort Collins, Assist City with Stormwater Program, \$7,000

Bau, Domenico A, Civil & Environmental Engineering, Colorado Water Conservation Board, Modeling the Influence of Conjunctive Water Use on Flow Regimes in the South Platte River Basin Using the South Platte Decision Support System, \$12,776

Bauder, Troy A, Soil & Crop Sciences, Colorado Department of Agriculture, Training and Education for Agricultural Chemicals and Groundwater Protection, \$205,000

Bessen, Richard A, Microbiology, Immunology & Pathology, HHS-NIH-NIAID-Allergy & Infect Diseases, Mechanisms of Prion Transport, \$14,563

Bestgen, Kevin R, Fish, Wildlife & Conservation Biology, DOI-Bureau of Reclamation, Population Abundance & Dynamics of Introduced Northern Pike, Yampa River, Colorado, \$10,000

Bledsoe, Brian, Civil & Environmental Engineering, Colorado Trout Unlimited, Flushing Flow Quantification - Fraser River, CO, \$39,341

Brummer, Joe E, Soil & Crop Sciences, Colorado Water Conservation Board, Assessing the Agronomic Feasibility of Single-Season Irrigation Deficits on Hay as Part of a Western Slope Water Bank, \$50,000

Cabot, Perry Edmund, CSU Extension, Arkansas Groundwater Users Association, A Multi-Media Program for Reporting Crop and Turf Water Use Estimates from the Colorado Agriculture Meteorological Network, \$26,942

Carlson, Kenneth H, Civil & Environmental Engineering, Noble Energy, Inc., Regional Real-time Monitoring of Oil and Gas Operation, \$150,000

Chavez, Jose L, Civil & Environmental Engineering, Regensis Management Group, Evaluation of Corn ET Estimates from Multiple Remote Sensing Scales, \$37,661

Cooley, Daniel Stuart, Statistics, NSF - National Science Foundation, Advancing Extreme Value Analysis of High Impact Climate and Weather Events, \$857,275

Cooper, David Jonathan, Forest & Rangeland Stewardship, USDA-USFS-Forest Research, Riparian Willow Inventory and Monitoring Partnership, \$10,000

Cooper, David Jonathan, Forest & Rangeland Stewardship, DOI-NPS-National Park Service, Monitoring Water Levels and Vegetation Cover in the Grand Ditch Restoration Study Area in Rocky Mountain National Park, Colorado, \$11,780

Cooper, David Jonathan, Forest & Rangeland Stewardship, DOI-NPS-National Park Service, Remove Final Levee Segment to Complete Restoration of Wetland-Riparian Habitat along Lower Glorieta Creek, Pecos National Historical Park, \$98,996

Doesken, Nolan J, Atmospheric Science, Environment Canada, Enhancements to CoCoRaHS Information Systems, \$55,000

Garcia, Luis, Colorado Water Institute, Various "Non-Profit" Sponsors, Developing a Decision Support System for the South Platte Basin, \$10,000

Gates, Timothy K, Civil & Environmental Engineering, DOI-Bureau of Reclamation, Toward Optimal Water Management in Colorado's Lower Arkansas River Valley: Monitoring and Modeling to Enhance Agriculture and Environment, \$50,000

Grunau, Lee, Colorado Natural Heritage Program, DOI-USFWS-Fish & Wildlife Service, Tamarisk Control on Pueblo Chemical Depot, \$9,918

Jacobi, William R, Bioagricultural Sciences & Pest Management, Denver Water Department, Health of Cottonwood Trees along Colorado's High Line Canal in 2013, \$14,771

Johnson, Brett Michael, Fish, Wildlife & Conservation Biology, Wyoming Game & Fish Department, Quantifying Piscivory in Buffalo Bill Reservoir: Are the Wild Oncorhynchus Fisheries Sustainable?, \$45,964

Julien, Pierre Y, Civil & Environmental Engineering, DOI-Bureau of Reclamation, Critical Review of Sediment Plug Formation Hypotheses, \$52,875

Kaczynski, Kristen, Forest & Rangeland Stewardship, DOI-NPS-National Park Service, Restoration of Riparian Willows in Rocky Mountain National Park, Colorado, \$74,255

Lemly, Joanna, Colorado Natural Heritage Program, Colorado Division of Parks and Wildlife, Wetland Habitat Evaluation Database, \$19,018

Loftis, Jim C, Civil & Environmental Engineering, DOI-NPS-National Park Service, Developing and Enhancing National Water Quality Databases for Clean Water Act Integrated Reporting, \$275,215

Ojima, Dennis, Natural Resource Ecology Laboratory, DOI-USGS-Geological Survey, DOI North Central Climate Science Center, \$507,914

Pritchett, James G, Agricultural & Resource Economics, Colorado Water Conservation Board, Developing Metrics for Colorado Agriculture's Production and Efficiency with Water Resources, \$43,131

Rathburn, Sara L, Geosciences, DOI-USGS-Geological Survey, Reconstructing Flow and Climate History of the Yellowstone River, Eastern MT, Using Cottonwood Dendrochronology, \$43,448

Rathburn, Sara L, Geosciences, DOI-NPS-National Park Service, Flow and Sediment Transport Monitoring, Upper Colorado River, RMNP, \$5,578

Roesner, Larry A, Civil & Environmental Engineering, Urban Drainage & Flood Control District, Develop the Colorado Center for Stormwater Management, \$42,500

Rondeau, Renee, Colorado Natural Heritage Program, The Nature Conservancy, Enhancing Resilience of Riparian and Wetland Habitats for the Gunnison Sage-grouse in Gunnison Basin, \$16,443

Thornton, Christopher I, Civil & Environmental Engineering, CONTECH Construction Products, Inc., Overtopping Performance Testing, \$118,646

Thornton, Christopher I, Civil & Environmental Engineering, CONTECH Construction Products, Inc., Culvert Baffle Testing, \$108,429

Thornton, Christopher I, Civil & Environmental Engineering, DOD-ARMY-Corps of Engineers, Full Scale Wave Overtopping Testing, \$108,750

Calendar



Photo by
Bill Cotton

August

- 17 **Eagle River Watershed Council 2013 Riverfest; Eagle, CO**
Riverfest 2013 is a celebration of the new access points on the Colorado through rafting, food, music, and dancing.
www.erwc.org
- 21-23 **Colorado Water Congress Annual Summer Conference; Steamboat Springs, CO**
Summer Conference and Membership Meeting
www.cowatercongress.org

September

- 5 **Transformational Solutions for Water in the West; Albuquerque, NM**
New Mexico Water Resources Research Institute is collaborating with the Sandia National Laboratories (SNL) and the Atlantic Council of the United States to host the conference.
wri.nmsu.edu/
- 8-11 **2013 RMSAWWA/RMWEA Joint Annual Conference; Keystone, CO**
Joint Annual Conference of the Rocky Mountain Section of the American Water Works Association (RMSAWWA) and the Rocky Mountain Water Environment Association (RMWEA)
www.rmsawwa.net/RMSJointAnnualConference.htm
- 15-18 **28th Annual WaterReuse Symposium; Denver, CO**
The world's premier conference devoted to sustaining supplies through water reuse and desalination
www.watereuse.org/symposium28

October

- 7 **Valuing Colorado's Irrigated Agriculture: A Workshop for Water Policy Makers; Colorado Springs, CO**
Prominent economists will share their expertise on policies, methods and approaches to the valuation of irrigation water as it is managed in the endeavor of agriculture.
www.coagwater.org
- 8-10 **Sustaining Colorado Watersheds Conference; Avon, CO**
Water: What is the New Normal?
www.coloradowater.org/Conferences
- 25 **Colorado WaterWise 5th Annual Water Conservation Summit**
A workshop featuring the best water conservation practices in Colorado. www.coloradowaterwise.org/

November

- 6-7 **2013 Upper Colorado River Basin Water Conference; Grand Junction, CO**
Sharing Experiences Across Borders. The Water Center provides an opportunity for water experts focused on the Upper Colorado River Basin to share information about current projects and ideas for future projects.
www.coloradomesa.edu/watercenter/UpperColoradoRiverBasinWaterForum.html
- 13-15 **NWRA Annual Conference; San Antonio, TX**
National Water Resources Annual Conference
<http://www.nwra.org/events/2013/11/annual-conference-6/>

January

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

March

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

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*Irrigation in the San Luis
Valley, Colorado.
Photo by Michael Real*

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