Final Report of

The Lower South Platte Irrigation Research and Demonstration Project

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Neil Hansen[1], James Pritchett[2], Bruce Lytle[7], Tom Holtzer[3], Joe Brummer[1], Luis Garcia[4], Joel Schneekloth[5], Bruce Bosley[5], Alan Helm[5]

A Cooperative Project

of

Parker Water and Sanitation District
Department of Soil and Crop Sciences, Colorado State University
Department of Bioagricultural Sciences and Pest Management, Colorado State University
Department of Agricultural and Resource Economics, Colorado State University
Department of Civil and Environmental Engineering, Colorado State University
Colorado State University Extension
Fort Collins, Colorado

[1] Associate Professor, Dept. of Soil and Crop Sciences, Colorado State University, Fort Collins, CO 80523-1170
[2] Associate Professor, Dept. of Agricultural and Resource Economics, Colorado State University, Fort Collins, CO 80523-1170
[3] Professor, Dept. of Bioagricultural Sciences and Pest Management, Colorado State University, Fort Collins, CO 80523-1170
[4] Professor and Head, Dept. of Civil and Environmental Engineering, Colorado State University, Fort Collins, CO 80523-1170
[5] Colorado State University Extension, Fort Collins, CO 80523-1170
[6] Professor, Dept. of Soil and Crop Sciences, Colorado State University, Fort Collins, CO 80523-1170
[7] President, Lytle Water Solutions, LLC, Highlands Ranch, Colorado

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List of Acronyms

ac	acre
bu	Bushels (1 bu corn grain = 56 lbs, 1 bu wheat grain=60 lbs)
CSU	Colorado State University
CWCB	Colorado Water Conservation Board
ET	evapotranspiration
PWSD	Parker Water and Sanitation District
T	Tons (2000 lbs)
WUE	Water use efficiency

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Executive Summary

This report presents the results of work completed under a grant from the Colorado Water Conservation Board (CWCB) to Parker Water and Sanitation District (PWSD). The CWCB grant is part of the Alternative Agricultural Transfer Methods Grant Program (Contract No. C-150426).

Competition for limited water supplies is increasing in Colorado due to increasing urban populations. Water right transfers from agricultural to municipal use are anticipated as populations grow because agriculture holds a majority of water rights in basins that are over appropriated. Significant fallowing of formerly irrigated land is certain to follow these transfers. Amidst a backdrop of increasing competition for limited water supplies, new approaches and technology for conserving agricultural water is desirable. Shifts from irrigated to fallowed land or dryland cropland will significantly impact the economic viability of agricultural producers and have far reaching indirect effects on businesses and communities that support irrigated agriculture. Agricultural and municipal stakeholders are very concerned about the impacts of increased water transfers.

A cooperative project between PWSD and Colorado State University (CSU) was initiated in 2007 to evaluate cropping systems options that address both production and water conservation goals. This project benefitted from funding from the CWCB, PWSD, the CSU Agriculture Experiment Station and CSU Extension. The principle objective of this project is to develop a model to sustain irrigated agriculture while meeting the increasing urban water needs in Colorado. This project evaluates alternatives to agricultural land dry-up in a cropping system study and is conducted in four phases: 1. Concept Discovery and Feasibility Study, 2. Viable Cropping Practices with Reduced Consumptive Water Use, 3. Regional Adoption and Economic Impacts, and 4. Administration and Basin Level Hydrology.

The objective of the first study phase was to identify and evaluate a feasible set of cropping systems that have potential to meet municipal and industrial water demands while sustaining agricultural production. The approach used was to evaluate existing research and published information, to seek input and suggestions from a focus group, and to conduct personal interviews with irrigators in the South Platte River Basin. Cropping systems with potential to reduce consumptive use by at least 20% compared to continuous corn with full irrigation were sought. The discovery phase identified rotational cropping, limited irrigation, and partial season irrigation cropping systems as potential water conserving practices.

Rotational cropping refers to sequences of full-irrigation crops with fallow or dryland crops in subsequent years. Potential dryland crops for rotational cropping include winter wheat, annual forage crops such as triticale or hay millet, corn, sunflower, and proso millet.

Limited irrigation cropping is the application of less water than required to meet the full water demand of the crop, with an emphasis on applying the limited water during critical crop growth stages to optimize the beneficial effects of the water. All crops in a limited irrigation system receive irrigation but at lower levels than fully irrigated crops. Potential limited

irrigation crops identified are corn, winter wheat, annual forages, sugarbeet, sunflower, soybean, and canola.

Partial season irrigation is a combination of full irrigation during part of the growing season with no irrigation during other parts of the same growing season. Partial season irrigation has relevance to perennial hay crops and success has been documented for alfalfa. A set of proposed cropping systems was identified for further evaluation in Phase 2.

Phase 2 of the study is a controlled small plot and an on-farm field-scale evaluation of water-conserving cropping systems. The objectives of the controlled research were to document irrigation water application, consumptive water use, crop productivity, and profitability of representative water-conserving cropping systems. A controlled research site was established in Iliff, Colorado with a linear-move sprinkler irrigation system customized for research and with an on-site weather station. The site facilitates research on approximately 250 small plots where a water balance approach is used to determine evapotranspiration (ET) and drainage, crop yield, and water use efficiency (WUE). The objective of the on-farm demonstrations is to evaluate the practicality and feasibility of the cropping systems when practiced on full-sized fields with farmers managing the system. Detailed results of the 2008, 2009, and 2010 cropping seasons are reported in the main portion of the document. In summary: the average consumptive use for continuous corn was 24.6 ac-in/yr. Rotational cropping systems that alternate irrigated crops with fallow or dryland crops were effective at reducing ET, with average ET reductions of 30-40% (7-10 ac-in/yr) compared to continuous corn. Rotating irrigated crops with dryland crops was a much more water-efficient approach than rotating with a non-cropped fallow because of high evaporation and moderate drainage during fallow. Winter wheat or annual forage crops such as triticale are good choices for the dryland phase of these rotations because they use residual water and nutrients from irrigated crops and have lower production risk than dryland summer grain crops like corn. Irrigated corn produced after a fallow period or after a dryland crop had higher yields and water use efficiency than continuous corn, illustrating the benefits of crop rotation to maximize water use efficiency.

Limited irrigation cropping systems reduced ET by an average of 30% (7 ac-in/yr) compared to continuous corn. Both rotational cropping and limited irrigation of sugarbeet and an annual forage crop saved 40% (9 ac-in/yr) of the reference crop ET. Sugarbeet is drought tolerant and shows good adaptability to limited irrigation. Soybean had moderate yield but is a lower water use crop than corn even under full irrigation. Its growth and performance suggested it may be a good alternative crop for water-conserving cropping systems in the South Platte River basin, but effort is needed to identify soybean varieties that are adapted to local soil and environmental conditions. Iron-deficiency was especially evident as a local production challenge.

An on-farm evaluation of limited irrigation corn established that limited irrigation techniques can be successfully implemented into production scale, farmer-managed systems and can maintain viable levels of production. While rotational cropping and limited irrigation systems both reduce ET relative to fully-irrigated continuous corn, the rotational cropping systems have an economic advantage over limited irrigation systems because they maximize yields of profitable cash crops in the irrigated phase of the rotation and use lower input crops in the dryland phase.

Partial season irrigation cropping systems were evaluated using alfalfa and alfalfa/grass mixes. Full-irrigation of alfalfa, as is common in much of the South Platte Basin, had the highest annual ET among all cropping systems evaluated in the study, exceeding 30 ac-in per year (2.5 ac-ft/yr). When irrigation of alfalfa was terminated after the first hay harvest, annual ET was reduced by more than 40% to 18 ac-in/yr (1.5 ac-ft, i.e. 12 inches of saved consumptive use), while yield was only reduced by 30%, reflecting increased water use efficiency for partial season irrigation of alfalfa. A second year of observations did not show stand loss from the partial season irrigation approach. An on-farm study of partial season irrigation alfalfa was conducted on a well-established stand of alfalfa in 2008. In that study, alfalfa yields were no different when irrigation was terminated after the first harvest compared to full-irrigation alfalfa. It was concluded that the mature alfalfa stand in the on-farm study accessed water from a shallow water table. No similar observation was made under the controlled study, suggesting that the potential effects of partial season irrigation on water use by alfalfa varies according to specific site conditions. The controlling factors are depth to water table and rooting depth as a function of stand age. Limiting stand age may be one approach to reduce potential contribution from sub-irrigation. Yields of alfalfa/grass mixtures were less than those for pure alfalfa but the effects of partial season irrigation were similar. There was a less noticeable improvement in water use efficiency for the alfalfa/grass mixtures.

An objective of the third project phase was to develop a regional economic impact model to quantify the direct and indirect economic effects of adopting alternative irrigation systems. The South Platte River Basin expects to fallow as many as 266,000 (twenty-two percent) of its irrigated acres in the next twenty-five years. Each irrigated acre is estimated to generate economic activity equivalent to $690 in the basin. Economic effects of drying up irrigated land will be substantial, especially in sparsely populated rural areas with few other alternatives. The project also sought to understand the potential of South Platte farms to adopt limited irrigation, rotational cropping, partial season irrigation and the barriers to adoption. A farmer survey was a key instrument to determine the potential for water leasing rather than ‘buy and dry’ fallowing, as well as the adoption of limited irrigation strategies. The producer survey gauged the amount of water that might be made available in water leasing arrangements and the necessary compensation needed for farmers to participate in a lease arrangement. More than 60% of survey respondents are willing to lease water, with an aggregate of between 50,000 and 60,000 acre-feet of potential water supplies just among those who responded. Survey respondants indicated that preferred compensation ranged from $300 - $500 per acre of irrigated cropland. Most farmers would prefer not to lease their entire water portfolio, thus these respondents are likely to remain in agriculture and generate positive economic activity.

The fourth phase of the project addressed administrative and hydrologic considerations necessary for the successful implementation of rotational fallowing and limited irrigation cropping practices as water savings approaches in Colorado. Specifically, the project evaluated the potential for an approach to demonstrate ET based on analysis of satellite imagery using a model called Remote Sensing of Evapotranspiration (ReSET). Four irrigated fields with available irrigation and soil moisture records in the South Platte Basin were used for this research. Irrigation on these fields was not deliberately managed in a limited irrigation scheme, but the fields were chosen because the irrigation supply was identified as limiting. The actual ET for each of these fields was calculated and documented using the ReSET model. The actual seasonal ET estimated by the ReSET model compared very well to reported irrigation records with an accuracy of up to 98% and not less than 92% for fields with normal growing conditions. ReSET was able to detect abnormal growing conditions on some fields, such as late crop development or areas that did not have a good crop stand, and the model results quantified the reduction in ET due to such conditions. These results show the potential for using the ReSET model to monitor and quantify the ET from agricultural fields as well as to detect areas where low ET occurs inside fields due to local conditions such as pest infestations or agronomic conditions or limited irrigation.

This project has a large outreach education component. Results from the demonstration sites are the basis of field days, workshops, seminars, and web-based information. In 2007 through 2010, educational outreach programs reached nearly 3,500 people consisting of farmers, agricultural professionals, agency staff, water and watershed organizations, community leaders, and the general public. A spreadsheet decision tool has been developed to help farmers determine the tradeoffs of various limited irrigation and water saving strategies. The spreadsheet allows farm managers to input their own business information and contrast alternative water saving cropping strategies. There is a large and growing interest and demand for information about the potential of limited irrigation cropping systems in Colorado and a need to continue this project into the future.

This project documented several farm-level approaches that reduce consumptive water use while avoiding fallowing of irrigated lands. The variety of crop choices, rotations, and irrigation methods to achieve water savings can be tailored to individual farm needs. The project further documented interest among agricultural water rights-holders to implement such practices as part of water lease agreements. Project participants, in dialog with the advisory board, CWCB, and stakeholders, have identified key issues that need to be addressed for implementation of these alterative water-conserving cropping practices in water transfer agreements. The primary issues identified were 1) to develop a practical means of calculating and verifying consumptive water use and water savings in alternative systems that will satisfy Water Court requirements, and 2) satisfying the requirement to maintain historic return flow patterns with alternative cropping practices. These two issues are the subject of a grant titled “Lower South Platte Irrigation Research and Demonstration Project” funded by CWCB. It is anticipated that the combined outcomes of this project and the new grant will bring alternatives approaches for water transfers to a reality in Colorado.

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Statement of Problem

Increasing urban growth has created a demand for water that could be partially satisfied through reallocation of water from irrigated agriculture. A statewide water supply survey predicts that 266,000 irrigated farm acres will be converted to dryland cropping or pasture within the next 25 years, mostly due to transfer of water from agricultural users to meet the water needs associated with population growth (Colorado Water Conservation Board, 2004). A dry-up of irrigated farmland would significantly impact the economic viability of agricultural communities and have far reaching indirect effects on businesses that support irrigated agriculture. One component of this project is to evaluate the potential economic impact of drying up irrigated farmland. The project futher seeks to identify water-conserving cropping systems that can help meet municipal water demands while avoiding dry-up of irrigated farm land.

This project is led is a cooperation between PWSD and CSU and was initiated in 2007. The project was developed in four phases: 1. Concept Discovery and Feasibility Study, 2. Viable Cropping Practices with Reduced Consumptive Water Use, 3. Regional Adoption and Economic Impacts, and 4. Administration and Basin Level Hydrology.

Project Objective

The principle objective of this project is to develop a model to sustain irrigated agriculture while meeting the increasing urban water needs in Colorado.

PHASE 1: CONCEPT DISCOVERY AND FEASIBILITY STUDY

Phase 1: Background and Objective

The objective of this project phase is to identify and evaluate a feasible set of cropping systems that have potential to meet municipal and industrial water demands while sustaining agricultural production. For a cropping system to be part of the feasible set, it was determined that it should meet the following criteria:

- Reduce consumptive use by at least 20% from an historical baseline. The baseline selected for the purpose of this study is a full irrigation, continuous grain corn system with conventional farming and irrigation approaches.
- Consumptive use savings from irrigation, and maintenance of return flows, can be scientifically documented in Water Court proceedings.
- The cropping system is profitable for farmers under expected prices and yields.
- The cropping system can be adapted with existing technology, equipment, capital and labor in the South Platte River Basin.

Phase 1: Approach

The approach used to obtain a set of feasible, water-conserving cropping systems was to 1) evaluate existing research and published information, 2) seek input and suggestions from a focus group, and 3) conduct personal interviews with irrigators in the South Platte River Basin. The evaluation of existing research and published materials focused specifically on the central Great Plains region because of its relevance to environmental conditions in Colorado. Information was gathered from extension publications, research journals, and on-going research. The focus group was done as a part of the established project advisory committee (see Appendix 1) during a meeting held May 21, 2007. The focus group included a brief presentation by the project staff followed by open discussion and input by the committee. The personal interviews with irrigators were conducted in March and April of 2007. The interviews were conducted with farmers leasing land from PWSD between the towns of Iliff and Proctor (names held confidential). At each interview, an overview of the goals of the project was provided and the following questions were used to help guide producer input:

- In what ways do you feel that agricultural water rights are changing or may change in Colorado?
- How can the CSU study best address your concerns about the future of Colorado water?
- What potential water-saving cropping options would you like to be considered in the study?
- Will you please share your comments and concerns about the limited irrigation cropping systems described by CSU?
- What outcomes do you hope this study will produce?
- Would you be willing to participate in an on-farm study of limited irrigation or rotational fallowing?

The ideas obtained from research, focus group, and farmer interviews were combined and evaluated according to the listed criteria to produce a feasible set of water-saving cropping alternatives.

Phase 1: Results

Evaluation of existing research and published information. There is a large body of research related to the efficient use of irrigation and results have been utilized to develop various computer models that schedule irrigations, guide cropping system planning, or even predict crop yield as a function of moisture stress. Results of these experiments and models are highly variable due to the large number of factors that ultimately affect crop yield. While many studies report applied irrigation and irrigation efficiency, fewer studies report a complete water balance with specific information on consumptive water use by the crop. Further, there is little research that has integrated the various elements of a cropping system on water use. The research and published information reported here were chosen because of the potential application to water-conserving cropping systems under the broader goals of the project.

A few reported research projects have evaluated limited irrigation cropping systems in the Great Plains (Hergert et al., 1996; Schneekloth et al., 1991). Limited irrigation is defined as the application of less water than required to meet the full ET demand of the crop, with an emphasis on applying the limited water during critical crop growth stages. A Nebraska study illustrated that under limited irrigation, corn produced an average of 9% higher yield when grown in a wheat-corn-sorghum rotation as compared to continuous corn (Schneekloth et al., 1991). The effect of rotation on corn yield was due to changes in soil water storage at planting time, and not improved water use efficiency. In the same study, the limited irrigation corn yields (average irrigation of 6.0 ac-in) increased by 75% when compared to dryland corn. Yield increase depended upon precipitation, and ranged from 38% in a wet year to 120% in a dry year. Results of limited irrigation for wheat showed a similar trend, with no yield improvement from irrigation in two out of four years and as much as a 4-fold increase the other years. Yield increased by an average of 18% for full irrigation corn and 0% for full irrigation wheat when compared to the limited irrigation systems, illustrating that the return per unit of irrigation water was less for applied water amounts above those for the limited irrigation system. Some additional studies confirm that the yield increase per unit of irrigation declines with increasing irrigation amounts (Hergert et al., 1993).

Crop residues at the soil surface influence the water balance by increasing water capture and retention. Numerous studies have documented improved crop yields, water use efficiencies, and water storage efficiencies with reduced or no-till systems relative to conventional tillage. The greatest gains have been observed in dryland cropping systems. Reduced tillage is also an important element in limited irrigation systems. Residue quantities at the soil surface are a function of accumulation, disturbance, and decomposition. Higher biomass production equates to greater accumulation of crop residues. Conversion of fully-irrigated cropping systems to limited irrigation will reduce productivity and potential accumulation of crop residues at the soil surface. Inversely, crop residue accumulation will be significantly greater under limited irrigation as a result of higher yield when compared to dryland systems. Reducing residue-disturbing operations in the cropping system (chopping, tillage, fertilizer injection, etc) conserves the integrity of the residue at the soil surface. Finally, environmental conditions and residue composition determine the decomposition rates of the crop residues. A Texas limited irrigation study contrasted production and water conservation variables among tillage practices in a wheat-sorghum-fallow rotation (Unger, 1994). In this study, there were no tillage effects on yield of wheat or sorghum. The inclusion of a fallow period allowed for adequate moisture storage for wheat, regardless of tillage. This illustrates that the benefits of reduced tillage over conventional tillage is most evident in cropping systems that impose water stress, or by nature are intensive systems. Norwood et al. (1990) conducted a long-term study at Garden City and Tribune, KS, to evaluate the effects of reduced tillage and varying cropping systems on yield of dryland winter wheat and grain sorghum. Conventional, reduced, minimum, and no-tillage systems were compared in wheat-fallow and wheat-sorghum-fallow rotation. These treatments were compared with conventional tillage in sorghum-fallow, continuous sorghum, and continuous wheat. An increase of available soil water yield occurred because of a reduction in tillage. Reduced tillage resulted in increased wheat-fallow and wheat-sorghum-fallow yields at all locations. At the Garden City site, sorghum yields under the wheat-sorghum-fallow system demonstrated a 67% increase over continuous sorghum yields. Reduced tillage of wheat-sorghum-fallow at Tribune produced 73% higher yields than continuous sorghum and conventional tillage of wheat-sorghum-fallow produced yields equivalent to continuous sorghum yields, 60% of the time.

Irrigation timing relative to critical crop growth stages is an important management tool that can be used to maximize the efficiency of limited irrigation water use. The basic premise is to avoid water stress during key physiological growth stages that influence yield, while saving water by permitting some water stress during less critical growth stages. Critical growth stages and the effects of water stress vary with crop species. For example, grain sorghum in Kansas (Hooker, 1985) showed that it was important to have adequate water supply at the growth differentiation stage. A single irrigation at this stage resulted in grain yields that were reduced less than 10% of yields from a full irrigation comparison. The irrigation efficiency was significantly higher for the limited irrigation, growth stage-timed irrigation compared to conventional approaches. The efficiency of limited irrigation applied at critical growth stages varied widely from year to year depending on precipitation. As discussed previously, achieving greatest irrigation water use efficiency on a farm scale requires some flexibility on how, when, and where to apply water based on precipitation and soil moisture conditions. A study done by Schneekloth et al. (2004), compared water management strategies to reduce the amount of water applied during the vegetative and late grain fill growth periods of corn using furrow irrigation at a site in North Platte, NE. Gated-pipe was used to supply five irrigation water strategies for this experiment, including rainfed, limited irrigation (6.0 ac-in and 10.0 ac-in), late initiation of irrigation, and full irrigation. The late-initiation of irrigation system delayed any irrigation until the reproductive stages of crop growth. Results indicate average grain yields (1998-2000) for corn receiving late initiation water treatment were 2% less than yields produced by full irrigation (Full = 215 bu ac^{-1}, Late = 212 bu ac^{-1}). Average grain yields were 3% less for corn receiving 10 ac-in of water, compared with full irrigation (10 ac-in = 209 bu ac^{-1}). The average grain yields of corn receiving 6.0 ac-in of water were 90% of yields with full irrigation (6.0 ac-in = 197 bu ac^{-1}). With regards to rainfed corn treatments, average yields reflected a 50% decrease compared to corn receiving full irrigation (Rainfed = 110 bu ac^{-1}). These results illustrate higher water use efficiency for limited irrigation applied during critical growth stages of corn compared to full irrigation.

Stewart et al. (1981) conducted a study which used a system that fully irrigated the upper one-half of a field, with limited irrigation on the next one-fourth of the field and a dryland system on the remaining one-quarter of the field that utilized tail-water runoff from the fully irrigated section of the field plot. Six irrigation treatments were applied during the course of this study, including: dryland, dryland-furrow dammed, every furrow fully irrigated (total irrigation=24 ac-in), every furrow partially irrigated (total irrigation=10 ac-in), every second furrow partially irrigated (total irrigation 7 ac-in), and every third furrow partially irrigated (total irrigation 5 ac-in). Results indicate that all water applied in irrigation furrows was retained in the field for the partially irrigated systems, while the fully irrigated system had as much as 40% of the applied water lost in tailwater. The every furrow partially irrigated system produced 90% of the grain yield as compared with full irrigation while the every second and every third furrow treatments yielded 80% and 63% of fully irrigate plots, respectively. The dryland treatments yielded only 35% of the fully irrigated system. This study shows the potential of limited irrigation to save water while maintaining reasonable crop yields well above the potential when completely drying up irrigated land. It further illustrates a high potential for optimizing the efficient use of limited amounts of irrigation water in corn.

Research was conducted by Norwood and Dumler (2002) at Garden City, KS comparing grain yield and water use of short (NK Brand 4640 Bt) and long season (NK Brand 7333 Bt) corn hybrids, in the wheat-corn-fallow system, to determine if limited irrigation is a viable alternative to dryland in an area of declining ground water. Irrigation regimes included dryland, a 6 ac-in water application, and a 12 ac-in water application. Average grain yields from 1998-2000 for dryland and 6 ac-in irrigation of Hybrid 1 were 108 bu ac^{-1} (72% of yield at 12 ac-in irrigation) and 139 bu ac^{-1} (97% of yield at 12 ac-in irrigation), respectively. For Hybrid 2, average yields for the same period were 97 bu ac^{-1} (59% of 12 ac-in) and 153 bu ac^{-1} (93% of 12 ac-in), respectively. In terms of water use efficiency (WUE), the dryland and 6 ac-in irrigation for both hybrids exceeded the WUEs of the 12 ac-in irrigation. There was no significant difference in the WUEs between corn hybrids at the dryland and 6 ac-in irrigation levels.

Klocke et al. (1996) found that growing season use of stored water strongly influences the soil's capacity to store off-season precipitation and minimizes leaching in crop rotations of corn, corn-soybean, and winter wheat. Limited irrigation (6 ac-in) created approximately the same soil water storage as rainfed crops during the non-growing season. The limited irrigation regime reduced the potential of off-season leaching and produced 82-89% of fully irrigated yields (18% reduction for continuous cropping and 11% for wheat-corn-soybeans). Conversely, fully-irrigated crops had the highest leaching potential because of increased available soil water at the end of the growing season. The authors also state, "an irrigator raising continuous corn with an adequate water supply could reduce his net return to land, labor, and management by \$52 ac^{-1} by changing from full irrigation to limited irrigation management." In the South Platte River Basin, the results of this study suggest the potential concern of altered return flows resulting from limited irrigation strategies.

The potential for limited irrigation of perennial crops, such as alfalfa, was evaluated. Water saving potential from alfalfa is high because it is a high water-use crop produced on large areas of irrigated land. Alfalfa yield exhibits a linear relationship to ET. Literature from a broad area of western states showed an average yield to ET relationship of 0.18 T ac^{-1} in^{-1}. Early season harvests have greater water use efficiency than late harvest, suggesting that combining full irrigation in spring with no irrigation during less efficient summer growth periods may be a more effective water-saving approach than season-long deficit irrigation. Management practices that can influence WUE under deficit irrigation include stand age, growth stage at harvest, and alfalfa variety. A potential complication with controlled deficit irrigation of alfalfa is an uncertain contribution to ET from a water table. As alfalfa roots develop over time, a significant percentage of total ET can come from water tables shallower than approximately 8 ft and the percentage of ET from the water table increases as availability of water from precipitation or irrigation declines. An outcome of this effort includes a detailed analysis of alfalfa water use relationships published in a scientific journal (Lindenmayer et al., 2010).

Several existing research projects in Colorado were evaluated as part of the concept discovery process. One research project being conducted by Northern Colorado Water Conservancy District and CSU evaluates the potential of partial season irrigation of alfalfa. The field study evaluated four irrigation strategies: Full Irrigation (FI), Stop Irrigation After 2nd Cutting (S2), Spring and Fall Irrigation (SF), and Stop Irrigation After 1st Cutting (S1). Changes in yield, ET, WUE, stand density, and forage quality were measured. Results of the study showed that yield decreased with ET in a fashion similar to previous research. Over a two year period, average yields were reduced by 1.6, 1.9, and 3.4 T ac^{-1} compared to the FI treatment for the S2, SF, and S1 treatments, respectively. Average ET was reduced by 11, 10, and 19 in compared to the FI treatment for the S2, SF, and S1 treatments, respectively. WUE increased as irrigation decreased with an average WUE of 0.34, 0.44, 0.42, and 0.47 T ac^{-1} in^{-1} for the FI, S2, SF, and S1 treatments, respectively. Also, alfalfa crown density, measured to assess stand health, was higher in the S2 and S1 treatments compared to the FI and SF treatments. Forage quality increased as ET decreased, which may help economically offset the reduced yield. Partial season irrigation of alfalfa is a promising approach to conserve agricultural water to meet changing water demand while still keeping an irrigated agricultural system in production. Partial season irrigation may be promising for perennial grass hay species that have shallow root development or for alfalfa where the water table is deep enough to limit access to water by roots.

A field study evaluating limited irrigation corn, sunflower, and soybean was conducted near Burlington, CO from 2006-2008. Both soybean and sunflower proved to be adaptable to limited irrigation systems. A similar study in Akron, CO showed that sunflowers are most responsive to limited irrigation applied at the bud initiation and early flower growth stages (Schneekloth, personal communication). Another study evaluated limited irrigation soybean, with a total irrigation of 6 ac-in. Limited irrigation soybean yielded 88% of the full irrigation treatment in North Platte, NE. The study did not quantify ET.

An on-going research study at the CSU Agricultural Research, Development, and Education Center near Fort Collins is evaluating limited irrigation practices for crop rotations that include alfalfa, corn, wheat, and sunflower. The project has shown reduced yields but improved water use efficiency through growth stage timed limited irrigation for corn. Sunflower and wheat were also shown to have good potential in water-saving cropping practices. An associated demonstration of furrow-irrigated, limited irrigation corn conducted on a private farm near LaSalle, Colorado has shown that limited irrigation corn can be done in a production setting.

Focus Group Meeting and Interviews with Irrigators. A focus group meeting was held May 21, 2007 in Atwood, Colorado and consisted of members of the project advisory committee (Appendix 1). Interviews of irrigators were conducted during May and June, 2007. The following key issues were highlighted from participants:

- Water-saving cropping practices evaluated should consider return flows. Systems that have negative water supply effects to downstream users should not be promoted by the study.
- Practices that address soil salinity may be an efficient means of improving crop water use efficiency. Some local crop consultants are recommending the use of gypsum as an amendment for salt-affected soils.
- Studies should include traditional crops as much or more than alternative crops. Sugarbeet should be included.
- In ditch systems, timing of irrigation is controlled by availability of water in the ditch and cannot be completely controlled, limiting the ability to apply a growth stage-based irrigation system.
- Quantification of water use is complicated in areas with high water table and for crops with deep rooting systems. This is an especially relevant concern for alfalfa in the South Platte River Basin.

- Crop insurance is a significant hurdle for limited irrigation cropping practices.
- There is a need for detailed monitoring in the studies of crop water stress, water use, precipitation, and irrigation return flows.

Phase 1: Summary

Based on the results of the literature review, local studies, and input from the interviews and the focus group, a list of candidate crops were identified with potential for limited irrigation, dryland, or partial season irrigation (Table 1). Several rotations were proposed using these crops in rotational cropping, limited irrigation, or partial season irrigation systems (Table 2). The cropping systems were selected with the expectation that they will reduce consumptive use by at least 20% compared to continuous-corn with full irrigation. The options include rotations with fallow and dryland crops. The feasibility study also attempted to estimate potential profitability for farmers, but there was not enough information on input cost and yields of alternative irrigation practices to verify these. Most of the crops can be produced by adaption of existing technology, equipment, capital and labor in the South Platte River Basin. There may not currently be a local market for some of the alternative crops such as soybean and canola.

Table 1. Crops identified with potential for adoption in limited irrigation, dryland, or partial season irrigation approaches to water conservation.

Limited Irrigation	Dryland	Partial Season Irrigation
Corn Sunflower Sugarbeet Wheat Soybean Canola Annual Forage Crops (sorghum, foxtail millet, triticale)	Wheat Annual Forage Crops (sorghum, foxtail millet, triticale) Corn Proso Millet Sunflower	Alfalfa Alfalfa/Grass Mixtures Cool Season Perennial Forage Grasses Warm Season Perennial Forage Grasses

Table 2. Crop rotations selected for rotational cropping, limited irrigation, and partial season irrigation field study.

Rotation Fallow Systems
Corn – Fallow Corn – Fallow – Dryland Winter Wheat Sugar beet – Dryland Hay Millet Corn – Soybean – Dryland Winter Wheat – Winter Canola Corn – Sunflower – Winter Wheat – Dryland Triticale
Limited Irrigation Systems
Sugar beet – Hay Millet Corn – Soybean – Winter Wheat – Winter Canola Corn – Sunflower – Winter Wheat – Triticale
Partial Season Irrigation Systems
Various species of perennial grass hay Alfalfa Alfalfa grass mixtures

Phase 2: Developing Viable Cropping Practices With Reduced Consumptive Water Use

Phase 2: Background and Objectives

While Phase 1 established a feasible set of alternatives, basic field research was needed to scientifically document water savings and profitability. Phase 2 of the study used field research in a controlled setting and in on-farm settings to evaluate water-conserving cropping systems. The objectives of the controlled research were to document irrigation water application, consumptive water use, crop productivity, and profitability. The controlled research is designed to allow scientifically defendable, replicated research plots with individualized control of irrigation amounts. The objective of the on-farm demonstrations was to evaluate the practicality and feasibility of the cropping systems when practiced on full-sized fields with farmer management.

Phase 2: Approach

Controlled Research. The controlled research study was located on a 35-acre field approximately 1 mile to the East of Iliff, CO (Figure 1). The predominant soil at this site is a Loveland Clay Loam with lesser amounts of Nunn Clay Loam. The soils are formed in flood plains and stream terraces from the nearby South Platte River and consist of calcareous loamy alluvium over mottled sand and gravel. The depth of topsoil above the sand and gravel layers is very heterogeneous, creating variable above-ground plant growth. A typical profile consists of 24 inches of clay loam, over 10 inches of sandy clay loam, over gravelly coarse sand. The depth of clay loam textured materials varies widely and ranges from only 24 inches thick to as much as 50 inches thick. The soils are somewhat poorly drained. A field drainage ditch runs approximately 10 feet below the soil surface parallel to the north boundary of the field and improves the natural drainage of the site. The native vegetation type is salt meadow with mixed perennial grasses. Historically, the site has been managed under furrow irrigation of annual small grain and forage crops. This site is typical of much of the irrigated farmland in close proximity to the South Platte River.

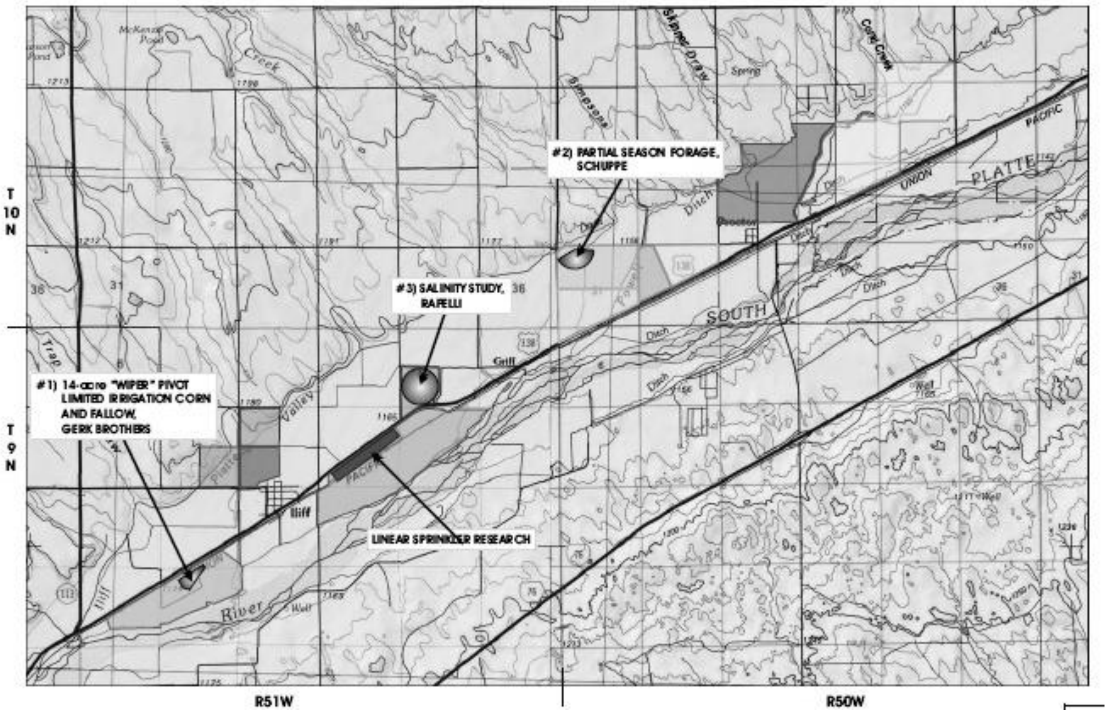

Figure 1. Locations of controlled, linear-move sprinkler and on-farm research sites. The town of Iliff is shown for reference. Image provided by Lytle Water Solutions.

Figure 2. Soils map of the controlled research site. The predominant soil is a Loveland Clay Loam (58) with lesser amounts of the Nunn Clay Loam (83)

A custom-manufactured, linear-move sprinkler system was erected on the site in June, 2007 (manufacturer T-L Irrigation, Hastings, NE; local supplier Pivots Plus, Iliff, CO). The sprinkler has a length of approximately 700 feet divided among four tower spans. Water is supplied to the sprinkler from a parallel irrigation ditch through an integrated pump and filter system. The ditch is filled with groundwater pumped from an on-site well using a submersible pump set in the well. The sprinkler is divided into 11 individually-controlled, 60-foot wide sections that make up the width of individual research plots. Water to each section is controlled by a hydraulic valve actuated with a manual switch in a control panel on the system tractor. Water is delivered through 12 individual drop nozzles in each 60-foot section with 5-foot nozzle spacing. The travel distance of the sprinkler is approximately 2,200 feet. The field length is divided into three main ranges, each separated by an access lane planted to grass. Each main range is further subdivided into 4 plot segments approximately 125 feet in length. The linear move sprinkler allows the study to include side-by-side treatments of water application levels under similar soil, climatic and geographic conditions. Further, the sprinkler allows intensive comparison of many different irrigation and crop regimes, precise control and documentation of water savings, and efficient use of land and labor resources in the research area.

A research design was created that allowed evaluation of the full set of feasible cropping systems identified in Phase 1 of the study (see detailed plot map, Appendix 2). The design created approximately 250 individual plots and was organized to group large blocks of individual crops to facilitate farm operations. Blocks of crops rotate annually throughout the study site during the life of the study. Every crop phase within each rotation is present every year. For example, the corn, wheat, and fallow phases of a wheat-corn-fallow rotation are each present in each study year. In addition, there are 4 replications of each cropping system, which facilitates the statistical comparisons among cropping systems. Thus, the number of plots devoted to each cropping system is equal to the product of the number of phases in the rotation and 4 replications. For example, the wheat- corn-fallow rotation had 3 phases x 4 replications for a total of 12 plots. The plots were arranged in a randomized, strip plot design.

An on-site weather station was installed to monitor and record weather information and for use in calculating ET by accepted energy balance methods. The weather station is part of the

CoAgMet network (www.coagmet.com; Iliff station). Weather station sensors measure air temperature, humidity, wind speed and direction, solar radiation, precipitation, and soil temperature. Data is logged hourly and reported daily. An alfalfa-based reference ET is calculated and reported using the Penman-Kimberly model. Soil moisture is determined using a neutron probe moisture meter (Campbell Pacific Nuclear, 503DR Hydroprobe). Access tubes made of galvanized steel conduit were installed in the center of each plot to a depth of 6 ft (to 10 ft for alfalfa plots). A calibration was performed to relate soil volumetric water content to the ratio of the raw neutron probe reading and a daily standard count (Figure 3). Soil moisture was assessed weekly from planting till harvest of summer crops and during active growth periods of winter annual crops.

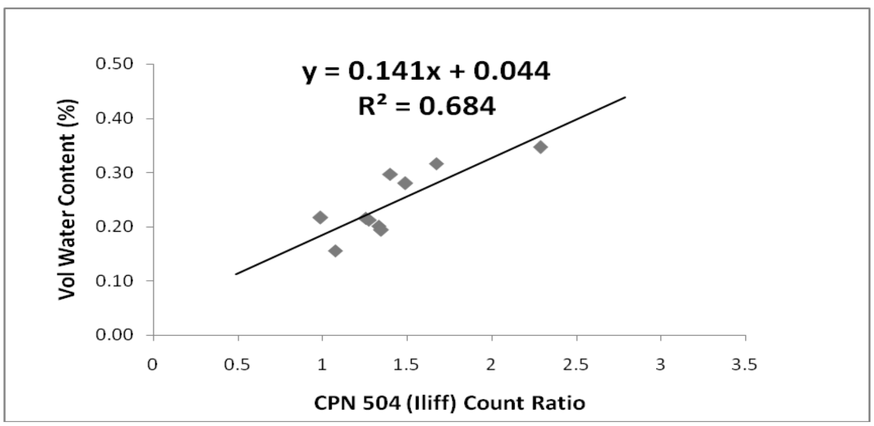

Figure 3. Calibration relationship of the ratio between the reading and a standard reading from the neutron probe soil moisture meter (CPN 503) and the volumeteric soil water content.

ET was determined using a water balance method. This method balances all of the water inputs and losses according to the following formula:

$$ET = \Delta\Theta + I + P - R - D$$

Where:

$\Delta\Theta$ is the change in soil moisture

I is the amount of irrigation applied.

P is the amount of precipitation.

R is runoff

D is the deep percolation

The $\Delta\Theta$ value was calculated from weekly soil moisture measurements with a neutron probe in 1 foot increments down to 6 ft for annual crops and 10 ft for alfalfa. Precipitation was obtained from a weather station, which also measured temperature, solar radiation, humidity, and wind. The experiment did not measure runoff or deep percolation. The combination of these values was estimated using weekly soil moisture measurements and daily rainfall and irrigation amounts. Specifically, the soil water holding capacity was determined individually at the location of each neutron probe access tube in the study. Weekly measured water content was then used to determine the soil water deficit at the time of the measurement. A daily water budget was then used to update the soil water deficit. An estimate of daily ET was made using the reference ET value and a crop specific crop coefficient. Water loss by drainage or runoff was calculated on all days when the daily water input from rain and irrigation exceeded the estimated soil water deficit. In this report, water losses are referred to as drainage because little runoff was observed. Total grain and biomass yields were determined and water use efficiency was calculated as the ratio of grain or biomass yield to ET.

Crops were managed according to conventional practices and in cooperation between CSU and local farmers. The 2007 cropping season was the first year of the study, but was not an ideal year for data collection because the sprinkler was not useable until late in the growing season. The first winter annual crops (wheat, triticale, and canola) were planted in the fall of 2007 and were evaluated in 2008. The perennial hay crops were planted in the fall of 2007 but had very poor establishment. They were reseeded in the summer of 2008 and established well. Grain samples from every plot were collected for determination of grain moisture content and test weight. Forage crop yield was determined by collecting the forage from 20 feet of individual windrows and weighing in a suspension balance. A subsample was then collected for determination of moisture content and forage quality.

On-Farm Research. On farm demonstration of cropping systems were conducted to test water-saving concepts under the conditions of production-scale systems. In each case, farmers conducted all crop management practices and CSU staff monitored the demonstrations, made soil and water measurements, and assessed yields.

1. Limited Irrigation and Conservation Tillage Corn Grain Production

Farm cooperator(s):	Alan and Randy Gerk
Study years:	2007, 2008
Site description:	14 ac sweep of pivot following alfalfa
	Adjacent fully irrigated corn reference
Practices demonstrated:	Limited irrigation corn with growth stage timed irrigation
	Strip tillage
Concepts evaluated:	Reduced planting populations
	Reduced N fertilizer inputs
	ET and water use efficiency

2. Partial Season Irrigation of Established Alfalfa and Grass Meadow Hay

Farm cooperator(s):	Mike Schuppe (alfalfa) and Gordon Schuppe (Hay Meadow)
Study years:	2007
Site description:	6 ac interior span of center pivot alfalfa
	6 ac interior span of center pivot grass meadow hay
	Adjacent fully irrigated spans of both crops
Practices demonstrated:	Partial season irrigation
Concepts evaluated:	Focusing irrigation to cool seasons
	Maintaining stand under dry conditions
	ET and water use efficiency

3. Evaluation of Soil Salinity and Salinity Remediation Methods

Farm cooperator(s):	Nick Raffaeli
Study years:	2007, 2008, 2009
Site description:	Center pivot irrigated corn East of Iliff
Practices demonstrated:	Land application of gypsum for remediation of salt affected soils
Concepts evaluated:	Effects of salinity and gypsum on ET and crop yield

Phase 2: Results

Controlled Research. The objectives of the controlled research were to document irrigation water application, consumptive water use, crop productivity, and profitability. The controlled research was designed to allow scientifically-defendable, replicated research plots with individualized control of irrigation amounts.

Precipitation. Annual precipitation during 2008 totaled 14.5 in (Figure 4). June was drier than normal, but the month of July was fairly wet, with 4.2 in of rain. The largest single day rainfall was 2.1 in on July 26. Other large single day rainfall totals include 1.3 in on August 16 and 0.74 in on May 24. All other rain events were smaller than 0.5 in per day. The annual total is a typical rainfall for this region, which averages between 13 and 19 in of rain per year. A wetter year was experienced in 2009, with a total annual precipitation of 16.3 in. In 2010 annual precipitation totaled 14.6 in. The precipitation pattern was similar to 2009 in the early summer, but then was drier in the month of September.

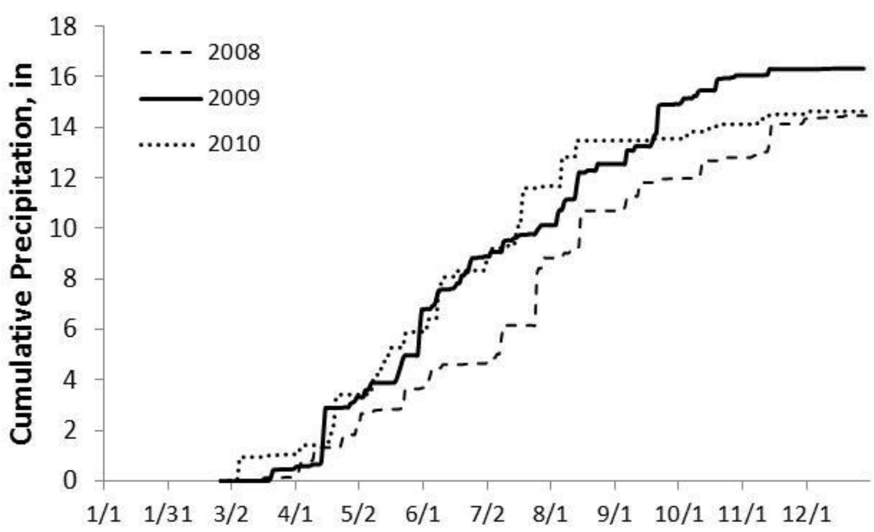

Figure 4. Cumulative precipitation for the 2008, 2009, and 2010 study years at the controlled research site near Iliff, CO.

Rotational Cropping and Limited Irrigation Systems. The water balance approach was used to determine average ET for the cropping system of each crop within each study year from 2008-2010. Results of individual study years are given in Appendix 3. The average crop and rotation ET values over the three study years are given in Table 3. For this study, the full irrigation, continuous-corn treatment was used as the reference system and the ET for all other systems were compared to that reference. The full irrigation, continuous corn treatment had an average of 17.3 ac-in/yr of applied irrigation and an average ET of 24.6 ac-in/yr, with 2.7 in of estimated drainage. The average corn yield was 152 bu/ac and water use efficiency was 6.2 bu/ac/in (Table 4, system #1).

The corn-fallow system was evaluated as a rotational cropping approach to water conservation (Table 4, system #2). In this rotation, the fallow was managed to maintain a clean, weed-free soil surface with minimum tillage and crop residue covering >30% of the soil surface. The corn in this system was managed and irrigated the same as the full irrigation, continuous-corn and the ET was similar, averaging 23.2 ac-in/yr. The corn yield in the corn-fallow system was higher than for continuous corn, with an average of 197 bu/ac. A yield drag for continuous, reduced-till corn has been widely observed and is often associated with increased pressure of pests and diseases in continuous monoculture-based systems. The higher yield in the rotational cropping system resulted in improved water use efficiency of 8.5 bu/ac/in (Table 4, system #2). The fallow year in the system has an average ET of 11.0 ac-in/yr with very little loss of water to drainage. Thus, fallow-reduced ET relative to a continuous corn system, but clean fallowing was not an efficient means of storing water in the soil profile for the subsequent crop due to high evaporation rates. Rotation average ET for the corn-fallow system was 17.1 ac-in/yr, representing a savings of 7.5 ac-in/yr relative to continuous-corn, or a 30% savings in ET. The drawback to a corn-fallow production system is that half of the land is fallow each year.

The corn-fallow-dryland winter wheat rotation is a rotational cropping system that uses even less water than the corn-fallow system because no irrigation is applied two out of three years (Table 4, system #3). Corn in this rotation yielded the same (197 bu/ac) as the corn in the corn-fallow rotation and higher than full irrigation continuous-corn, even though it was managed and irrigated the same. This further shows the benefits of crop rotation to maximize water use efficiency. The water balance for the fallow in this system behaved similarly to the corn-fallow system. The dryland winter wheat had an average ET of 12.8 ac-in/yr and a grain yield of 57 bu/ac. ET of dryland wheat was only 3.6 inches greater than the clean fallow, but the wheat generated 57 bu/ac of grain. This is an illustration of the disadvantage of water transfers that are based on fallowing of land, because fallow is a poor means of conserving water and generates no crop. Rotation average ET for the corn-fallow-winter wheat rotation is 15.6 ac-in/yr for a savings of 9.0 inches (~40% savings) relative to full irrigation, continuous corn.

A rotation of sugarbeet and hay millet was evaluated in both rotational cropping and limited irrigation approaches (Table 4, system #s 4 and 5). The full irrigation sugarbeet had an average of 14.7 ac-in/yr of applied irrigation, ET averaged 23.8 ac-in/yr, and yield was 35.6 T/ac. Full irrigation sugarbeet had an ET similar to the ET of full irrigation corn, but there was essentially no drainage from the sugarbeet crop. The average ET of dryland hay millet was 7.8 ac-in/yr. This rotational cropping system saved an average of 8.8 ac-in/yr of ET relative to full irrigation, continuous corn (~40% savings). In the limited irrigation system, both sugarbeet and hay millet crops were irrigated at levels below the full demand of the crop. Irrigation for limited irrigation sugarbeet averaged 7.9 ac-in/yr, ET averaged 17.8 ac-in/yr, and yield averaged 32 T/ac. The limited irrigation sugarbeet had higher water use efficiency (1.8 T/ac/in) than the full irrigated sugarbeet (1.5 T/ac/in). Limited irrigation hay millet had an average irrigation of 4.4 ac-in/yr, an ET of 12.7 ac-in/yr, and a yield of 1.6 T/ac. It is unclear why the limited irrigation and dryland hay millet had similar yields despite very different ET values. The limited irrigation sugarbeet-hay millet rotation had an average annual ET of 15.3 ac-in and an ET savings of 9.3 ac-in/yr (~40% savings) (Table 4, system #5). With the sugarbeet systems, there was not a clear water savings advantage to either the rotational cropping or limited irrigation approach but there was a modest yield advantage for full irrigation sugarbeet in the rotational cropping system. Sugarbeet proved to be very adaptable to limited irrigation.

A corn-soybean-winter wheat-canola rotation was evaluated in both rotational cropping and limited irrigation approaches (Table 3, system #s 6 and 7). In the rotational cropping system full irrigation was applied to corn (18 ac-in/yr), soybean (8 ac-in/yr), and canola (6 ac-in/yr), while the winter wheat was produced as a dryland crop. The full irrigation corn in this rotation behaved similar to the corn in other rotations, with an average ET of 24.9 ac-in/yr and average yield of 187 bu/ac. This again confirms the water use advantage of corn in rotation as opposed to continuous corn. Full irrigation soybean ET averaged 17.2 ac-in/yr and yield averaged 37 bu/ac. Soybean is a lower water using crop than corn even under full irrigation (Table 4, system #6). The soybean yield from this study is moderate but good enough to demonstrate that soybean has potential to be a profitable crop. Its growth and performance suggested it may be a good alternative crop for both rotational and limited irrigation systems in the South Platte River basin. Soybean is susceptible to iron-deficiency when grown in alkaline soils like those in the South Platte, which causes leaf chlorosis (yellowing) and can suppress yields. Chlorosis was observed in the soybeans, especially in 2010. It was interesting to observe that the iron-deficiency chlorosis was less severe under limited irrigation. While soybean was identified as a good potential crop in a water conserving rotation, canola was not a productive alternative crop. The canola crop looked nice in the field and produced ample pods, but a majority of the pods had no seed. Thus ET for this crop was relatively high at 18 inches, but the yield was only 13 bu/ac. Additional work will be done to identify why canola yields were so poor. Sensitivity to salinity is suspected. The dryland winter wheat had an average ET of 12.1 ac-in/yr and yield of 54 bu/ac. The full rotational cropping system had an average ET of 17.9 ac-in/yr, about 7.0 ac-in/yr ET savings compared to full irrigation continuous corn (30% savings). The same rotation managed under limited irrigation (all crops irrigated) had an average annual ET of 16.6 ac-in for a savings of 8 ac-in relative to full irrigation continuous corn (33% savings). Corn and soybean performed well under limited irrigation, maintaining or exceeding the water use efficiency for full irrigation. Water use efficiency of limited irrigation wheat was similar to that of dryland wheat. Although the amount of saved ET was similar between the rotational cropping and the limited irrigation approaches, under a typical grain market scenario, the loss in corn yield with limited irrigation would not be offset by the gain in wheat yield. Therefore, a crop rotation with full irrigation corn and dryland wheat would be preferred over a limited irrigation approach.

A corn-soybean-winter wheat-winter triticale rotation was evaluated in both rotational cropping and limited irrigation approaches (Table 3, system #s 7 and 8). In this rotational cropping system, full irrigation was applied to corn (18 in) and soybean (9 in), while both winter wheat and triticale were produced as dryland crops. The full irrigation corn had an ET similar to the corn in the other rotational cropping systems (24.8 in), but yield was somewhat reduced (180 bu/ac). ET from full irrigation soybean was 19.0 inches and yield was 30 bu/ac. The dryland winter wheat yield following sobyean was lower than dryland wheat in other rotations (43 bu/ac). The dryland triticale was produced as an annual forage crop. The hay yield of 2.9 T/ac is a very good dryland yield. Triticale and other annual forages may be well suited to rotational cropping systems. They are able to produce by scavenging residual water and fertility from the preceding irrigated crop, and have less risk of failure than grain crops. The rotational cropping system had an average annual ET of 17.1 in and an ET savings of 7.4 in (~30% savings). Similarly, the limited irrigation approach for the same rotation had an average annual ET of 16.8 in and an ET savings of 7.8 in (31% savings).

Understanding the effects of changing irrigation and cropping patterns on return flows is an important issue in the South Platte River basin. Some inferences can be made about the effects of rotational cropping and limited irrigation systems on return flows from the drainage estimates made in the controlled study. The continuous corn reference system had an average annual drainage of 2.7 ac-in/yr. All of the alternative cropping systems had less drainage than the full-irrigation, continuous-corn reference and in some cases drainage was nearly eliminated. When drainage was expressed as a percent of growing season precipitation + irrigation, there was 10% drainage for fully irrigated continuous corn but only 1% in limited irrigation corn (Table 3). Similarly, there was 8% drainage for fully irrigated soybean but only 4% for limited irrigation soybean. In general, average annual drainage will be greater for a rotational cropping system than for limited irrigation systems because of the higher likelihood of drainage during phases with crops under full irrigation. However, we acknowledge that drainage, i.e. return flow, has to be maintained at historic rates, volumes, and timing or these alternative agricultural methods will not be acceptable as transferrable water rights in Water Court. Therefore, more work is planned related to maintaining return flows in the work that is being funded by the CWCB for the upcoming research to be conducted from 2011 to 2013.

Table 3. Cropping system water balance, including irrigation, precipitation, soil water use (positive value) or storage (negative value), drainage, and evapotranspiration (ET), yield, and water use efficiency. All values are averages from three crop years, 2008-2010.

#1 A. Continuous Corn (Full)

Crop	Irrigation (in)	Precip (in)	Soil Moisture	Drainage (in)	ET (in)	Yield	Yield Units	WUE (Yld/ET)
A. Corn	17.3	10.5	-0.4	-2.7	24.6	152.1	bu/ac	6.19
Rotation Average	17.3	10.5	-0.4	-2.7	24.6			
	$ET_{continuous\ corn}$ - $ET_{rotation\ average}$				0.0			

#2 A. Corn (Full) B. Fallow

Crop	Irrigation (in)	Precip (in)	Soil Moisture	Drainage (in)	ET (in)	Yield	Yield Units	WUE (Yld/ET)
A. Corn	17.3	10.5	-0.4	-4.1	23.2	197.2	bu/ac	8.5
B. Fallow	0.0	10.5	-0.1	-0.3	10.0			
Rotation Average	8.6	10.5	-0.3	-2.2	16.6			
	$ET_{continuous\ corn}$ - $ET_{rotation\ average}$				8.0			

#3 A. Corn (Full) B. Fallow C. Wheat (Dry)

Crop	Irrigation (in)	Precip (in)	Soil Moisture	Drainage (in)	ET (in)	Yield	Yield Units	WUE (Yld/ET)
A. Corn	17.9	10.5	-0.4	-3.4	24.7	197.3	bu/ac	8.0
B. Fallow	0.0	9.6	0.1	-0.5	9.2			
C. Wheat	0.0	10.6	2.6	-0.4	12.8	57.4	bu/ac	4.5
Rotation Average	6.0	10.2	0.8	-1.4	15.6			
	$ET_{continuous\ corn}$ - $ET_{rotation\ average}$				9.0			

#4 A Sugar Beet (Full) B. Hay-millet (Dry)

Crop	Irrigation (in)	Precip (in)	Soil Moisture	Drainage (in)	ET (in)	Yield	Yield Units	WUE (Yld/ET)
A. Sugar Bee	14.7	9.1	0.1	-0.2	23.8	35.6	T/ac	1.53
B. Hay-mille	0.0	8.3	0.5	0.0	7.8	1.6	T/ac	0.11
Rotation Average	7.4	8.7	0.3	-0.1	15.8			
	$ET_{continuous\ corn}$ - $ET_{rotation\ average}$				8.8			

#5 A. Sugar Beets (Limited) B. Hay-millet (Limited)

Crop	Irrigation (in)	Precip (in)	Soil Moisture	Drainage (in)	ET (in)	Yield	Yield Units	WUE (Yld/ET)
A. Sugar Bee	7.9	9.1	0.9	-0.1	17.8	32.1	T/ac	1.82
B. Hay-mille	4.4	8.3	0.0	0.0	12.7	1.6	T/ac	0.13
Rotation Average	6.1	8.7	0.5	-0.1	15.3			
	$ET_{continuous\ corn}$ - $ET_{rotation\ average}$				9.3			

Table 3 (Continued). Cropping system water balance, including irrigation, precipitation, soil water use (positive value) or storage (negative value), drainage, and evapotranspiration (ET), yield, and water use efficiency. All values are averages from three crop years, 2008-2010.

#6 A. Corn (Full) B. Soybean (Full) C. Wheat (Dry) D. Canola (Full)

Crop	Irrigation (in)	Precip (in)	Soil Moisture	Drainage (in)	ET (in)	Yield	Yield Units	WUE (Yld/ET)
A. Corn	17.7	10.5	-0.8	-2.5	24.9	186.5	bu/ac	7.49
B. Soybean	8.1	9.9	0.5	-1.2	17.2	36.7	bu/ac	2.13
C. Wheat	0.0	10.6	2.0	-0.5	12.1	53.8	bu/ac	4.43
D. Canola	5.8	10.6	2.0	-0.9	17.5	13.4	bu/ac	0.76
Rotation Average	7.9	10.4	0.9	-1.3	17.9			
		$ET_{continuous\ corn} - ET_{rotation\ average}$			6.6			

#7 A. Corn (Limtd) B. Soybean (Limtd) C. Wheat (Limtd) D. Canola (Limtd)

Crop	Irrigation (in)	Precip (in)	Soil Moisture	Drainage (in)	ET (in)	Yield	Yield Units	WUE (Yld/ET)
A. Corn	10.6	10.5	0.3	-0.2	21.2	167.2	bu/ac	7.90
B. Soybean	5.9	9.9	-0.2	-0.7	14.9	29.8	bu/ac	2.01
C. Wheat	3.0	10.6	1.9	-0.3	15.2	61.4	bu/ac	4.04
D. Canola	2.8	10.6	2.2	-0.4	15.2	7.7	bu/ac	0.51
Rotation Average	5.6	10.4	1.0	-0.4	16.6			
		$ET_{continuous\ corn} - ET_{rotation\ average}$			8.0			

#8 A Corn (Full) B. Soybean (Full) C. Wheat (Dry) D. Triticale (Dry)

Crop	Irrigation (in)	Precip (in)	Soil Moisture	Drainage (in)	ET (in)	Yield	Yield Units	WUE (Yld/ET)
A. Corn	17.7	10.5	-1.2	-2.1	24.8	179.8	bu/ac	7.25
B. Soybean	9.0	9.9	1.9	-1.8	19.0	30.4	bu/ac	1.6
C. Wheat	0.0	10.6	2.3	-0.1	12.7	43.6	bu/ac	3.43
D. Triticale	0.0	11.1	1.0	-0.1	12.0	2.9	T/ac	0.24
Rotation Average	6.7	10.5	1.0	-1.0	17.1			
		$ET_{continuous\ corn} - ET_{rotation\ average}$			7.4			

#9 A. Corn (Limtd) B. Soybean (Limtd) C. Wheat (Limtd) D. Triticale (Limtd)

Crop	Irrigation (in)	Precip (in)	Soil Moisture	Drainage (in)	ET (in)	Yield	Yield Units	WUE (Yld/ET)
A. Corn	10.6	10.5	-0.2	-0.3	20.5	162.2	bu/ac	7.91
B. Soybean	6.5	9.9	0.6	-0.7	16.3	26.6	lbs/ac	1.6
C. Wheat	3.0	10.6	1.8	0.0	15.4	46.0	bu/ac	2.98
D. Triticale	3.1	11.1	0.7	0.0	14.8	3.2	T/ac	0.22
Rotation Average	5.8	10.5	0.7	-0.3	16.8			
		$ET_{continuous\ corn} - ET_{rotation\ average}$			7.8			

Table 4. Drainage expressed as a percent of the growing season precipitation + irrigation.

Irrigation/Crop	Drainage (% of Precip + Irrig)
Full/corn	10.6
Limited/corn	1.2
Full/soybean	8.1
Limited/soybean	4.3
Wheat/dryland	2.8
Fallow	4.2

Partial Season Irrigation. Partial season irrigation was evaluated for established stands of alfalfa and alfalfa/grass mixes. A water balance approach was used to determine crop ET for the alfalfa and alfalfa/grass mixes (Table 5).

Full-irrigation of alfalfa was 22.0 ac-in/yr and average ET was 30.8 ac-in/yr. This ET is greater than the ET from any of the annual crops or crop rotations evaluated under rotational cropping or limited irrigation. For this reason, the full irrigation alfalfa is used as the reference crop to demonstrate the potential water savings from partial season irrigation. The fully-irrigated alfalfa yield was 3.1 T/ac. This yield is low relative to average alfalfa yields in this region, due to low water holding capacity of the soil at this site. Irrigation in the partial season-irrigation treatment of alfalfa was 5.0 ac-in/yr, all of which was applied prior to the first alfalfa cutting (early to mid June). Partial season irrigated alfalfa had an average ET of 17.6 ac-in/yr, approximately 40% of the ET from the fully-irrigated alfalfa. The limited irrigation alfalfa yield was 2.2 T/ac, a 30% yield reduction. The greater reduction in ET than the reduction in yield illustrates an increase in water use efficiency for the partial season irrigation approach.

Table 5. Growing season summary of the water balance, including irrigation, precipitation, soil water use (positive value) or storage (negative value), drainage, and evapotranspiration (ET), yield, and water use efficiency of alfalfa and alfalfa/grass mixes under full and partial season irrigation.

	2010 Partial Season Irrigation of Alfalfa and Alfalfa Grass Mixes							
Crop	Irrigation (in)	Precip (in)	Soil Moisture	Drainage (in)	ET (in)	Yield	Yield Units	WUE (Yld/ET)
Full Irrig Alfalfa	22.0	12.1	-1.0	-2.4	30.8	3.1	T/ac	0.10
Full Irrig Alfalfa/Grass	22.0	12.1	0.0	-2.1	32.1	2.3	T/ac	0.07
Limited Irrig Alfalfa	5.0	12.1	0.6	-0.1	17.6	2.2	T/ac	0.13
Limited Irrig Alfalfa/Grass	5.0	12.1	0.5	-0.2	17.4	1.4	T/ac	0.08

Partial season irrigation raises concerns of stand loss due to desiccation during the period when irrigation is terminated. This risk is greatest in coarse-textured soils with limited water holding capacity. The 2010 yields observed in this study reflect the impacts of the 2009 irrigation treatments. During the first cutting of alfalfa, both the full and limited irrigation treatments were irrigated equally, so any yield differences would reflect the impacts of the previous year's irrigation treatment. The first cutting yields were 1.2 T/ac and 1.1 T/ac for the full and limited irrigation treatments, respectively (Figure 5). These similar yields do not suggest stand decline due to limited irrigation. Irrigation was terminated for the limited irrigation treatments after the first cutting, resulting in a modest yield decline in the second cutting and a very significant yield decline in the third cutting. By the third cutting, the limited irrigation alfalfa was dormant and did not appear to be accessing water from the water table. Other research has shown the ability of deep rooted crops like alfalfa to access water from a water table. If partial season irrigation is used to conserve water in a water transfer agreement, an assessment of water table depth and ET is recommended. Remote sensing of ET is one method that could be used to evaluate ET after irrigation is terminated. Yields from the alfalfa/grass mix were consistently less than yields from the pure alfalfa, while the reaction to the limited irrigation treatment was similar. There does not appear to be any advantage to a grass mix compared to pure alfalfa from water or water savings perspectives.

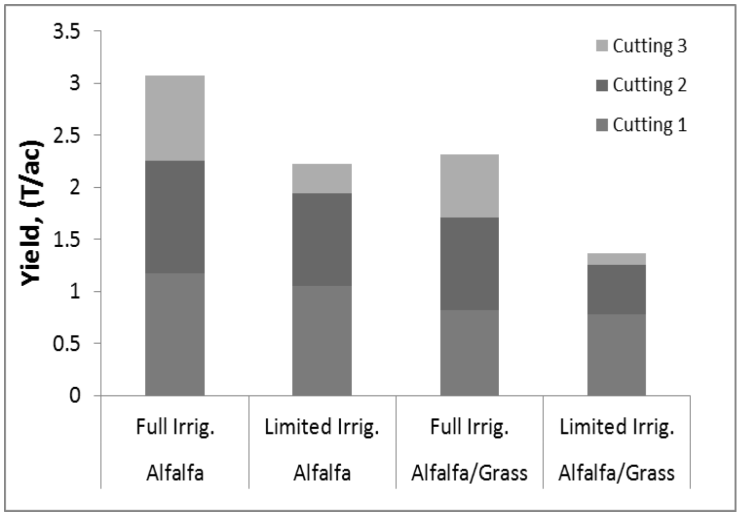

Figure 5. Yield of alfalfa and alfalfa grass mixes in response to full or limited irrigation. The limited irrigation treatment was a partial season irrigation with irrigation being terminated after the first cutting.

On-Farm Research. The objective of the on-farm demonstrations was to evaluate the practicality and feasibility of the cropping systems when practiced on full-sized fields with farmers managing the system. Results of three on-farm projects are reported.

Limited Irrigation and Conservation Tillage Corn Grain Production. A 14-acre field irrigated with a center-pivot sprinkler was utilized for an on-farm comparison of full and limited irrigation corn managed with conservation tillage practices. Limited irrigation was achieved by manually turning off sprinkler drop nozzles for entire spans of the sprinkler during non-critical growth periods. The limited irrigation crop yields were compared to the conventional full irrigation yields on both sides of the controlled span. Using a water balance approach, crop ET was determined to be 26 ac-in for full irrigation and 19 ac-in for limited irrigation. Although the corn crop showed signs of water stress during vegetative growth, it recovered well when irrigation resumed. The limited irrigation crop was shorter in stature than the full irrigation treatment. A high-intensity wind storm just prior to harvest caused some plants and ears to fall to the ground, but the damage was noticeably worse in the taller, full irrigation corn. As a result, corn yield was 147 bu/ac for full irrigation and 167 bu/ac for limited irrigation. Without the wind damage, it is expected that the full irrigation corn would have had a higher yield than the limited irrigation corn. Nonetheless, the demonstration showed that irrigation water management at a field production level can effectively reduce ET while maintaining profitable yields.

Partial Season Irrigation of Established Alfalfa and Grass Meadow Hay. In 2007, an on-farm study of partial season irrigation was conducted in a field that was divided between alfalfa and grass meadow hay. This was accomplished by manually turning off irrigation drop nozzles for one tower span on a center-pivot sprinkler following the first alfalfa harvest while the remainder of the field was irrigated normally by the producers. The crops inside the span (partial season irrigation) were compared to the crops on either side of the span (full irrigation). Full irrigation for both alfalfa and grass hay totaled 25 ac-in, while limited irrigation totaled 13 ac-in. A water balance approach was used to estimate ET, with soil moisture determined weekly with a neutron probe. Full irrigation alfalfa yielded 4.5 T/ac and the limited irrigation alfalfa yielded 4.2 T/ac (Figure 6). As estimated by the water balance method, ET was 24 ac-in and 14 ac-in for full and limited irrigation alfalfa, respectively. The small reduction in yield from the limited irrigation treatment suggests that the limited irrigation alfalfa was using more water than accounted for in the water balance. It is suspected that the rooting system of the established alfalfa was deep enough to access water from the water table. The water balance approach used in this study had no means of quantifying sub-irrigation. It is typical in this region for alfalfa to require approximately 5 inches of ET per ton of dry matter harvested, confirming that 14 inches of ET is an underestimation for the limited irrigation yield of 4.2 T/ac. Based on the assumption of 5 ac-in of ET per ton of dry matter, the partial season irrigation treatment would be expected to use 21 ac-in of water. The water balance approach accounted for 14 ac-in, leaving 7 ac-in of potential sub-irrigation. Under these assumptions, nearly 30% of the total ET was obtained via sub-irrigation. Irrigation management alone may not be an effective approach for reducing ET for deep rooted crops in areas with a high water table. For grass meadow hay, full irrigation had a yield of 1.9 T/ac and ET of 27 ac-in and the limited irrigation has a yield of 0.9 T/ac and an ET of 16 ac-in. Perennial grasses have much more shallow root systems and as a result were more responsive to limited irrigation.

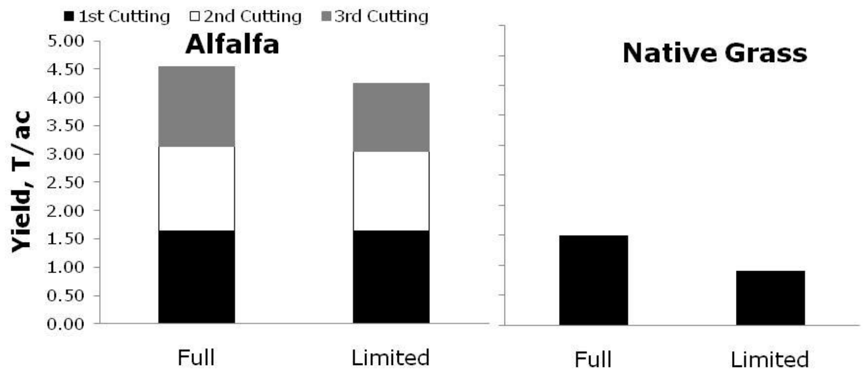

Figure 6. Yield of alfalfa and native grass hay crops under full and limited irrigation in an on-farm evaluation during 2007.

Evaluation of Soil Salinity and Salinity Remediation Methods. Some soils in the South Platte River Basin are affected by saline and sodic soil conditions. Salinity and sodicity can negatively affect water use efficiency. An on-farm study evaluated the use of gypsum as a soil amendment on a field with moderate levels of salinity and sodicity. Gypsum was applied at different rates in full length field strips as follows: 1200 lbs/ac - surface applied; 1200 lbs/ac – incorporated into the soil with tillage; 2400 lbs/ac – incorporated; no gypsum control. All crop treatments were managed and irrigated identically and yields were monitored. A complete water budget was not determined in this study. There were no observed differences in crop yield among any of the treatments in 2007, 2008, or 2009. Remediation of saline or sodic soils is not considered a high priority for water conservation at this time in the South Platte Basin.

Phase 2: Summary

Crops evaluated for their potential use in a rotational cropping or limited irrigation systems include corn, winter wheat, sugarbeet, sunflower, soybean, triticale, canola and hay millet. Partial season irrigation is being evaluated for alfalfa and alfalfa/grass mixes. Corn and alfalfa are the dominant crops produced under irrigation in Colorado, representing about 80% of the irrigated acres.

A controlled field study used a water balance approach to evaluate ET and drainage, yield, and water use efficiency and savings in ET were determined relative to full irrigation, continuous-corn. Rotational cropping systems were effective at reducing ET, with average ET reductions of 7-10 ac-in/yr (30-40%) compared to continuous corn. Rotating irrigated crops with dryland crops was a more water efficient approach than rotating with non-cropped fallow land because of high water losses to evaporation and drainage during fallow. Corn produced after a fallow period or dryland crop had a higher yield and water use efficiency than continuous corn, illustrating the benefits of crop rotation to maximize water use efficiency.

Both rotational cropping and limited irrigation of sugarbeet in rotation with an annual forage crop saved 10 ac-in/yr compared to the reference crop ET (40%). Sugarbeet is drought tolerant and shows good adaptability to limited irrigation. Soybean had moderate yield but is a lower water use crop than corn even under full irrigation. Under limited irrigation, soybean had higher water use efficiency and was less susceptible to iron deficiency chlorosis. Its growth and performance suggested it may be a good alternative crop for water-conserving cropping systems in the South Platte River Basin. Canola did not yield well in the study, having a high degree of empty seed pods. Salinity is suspected as a potential cause.

Full and limited irrigation sunflower had similar levels of ET but had lower yields in limited irrigation. The aggressive rooting and water scavenging ability of sunflower allowed it to access more water from the soil under limited irrigation. Crops with deep root systems will be less effective for reducing ET through irrigation management. Yields of crops the year following sunflower were depressed. In proximity to riparian areas such as the site in this study, bird predation can be another significant obstacle for profitable sunflower production. Triticale was evaluated as a dryland and limited irrigation crop in rotation. It had good production levels with very low input.

Both rotational cropping and limited irrigation systems effectively reduced ET relative to full irrigation, continuous-corn. Rotational cropping systems have an economic advantage over limited irrigation systems because they can maximize yields of profitable cash crops and then use lower input crops in the dryland phase of the rotation. Small grains and annual forages may be well suited to rotational cropping systems. They can produce by scavenging residual water and fertility from the preceding irrigated crop, and have low risk of failure.

Partial season irrigation of alfalfa or other perennial crops is a promising approach to water savings. Alfalfa is a commonly grown, high water use crop in the South Platte River Basin. Results showed that terminating the irrigation after the first harvest significantly reduced evapotranspiration but had a lesser effect on total yield. After one year of the partial season irrigation, the alfalfa stand remained productive. An on-farm study on an older alfalfa stand demonstrated sub-surface irrigation capability from partial season irrigated alfalfa, but no sub-surface irrigation was observed on a 3-year old stand in the controlled study. The variable results illustrate that documenting water use by deep rooted perennials like alfalfa must consider the potential for sub-irrigation.

While water savings would be greatest by complete dry-up of irrigated land, the crop production in dryland is too low to maintain sustainable agricultural production. As Colorado citizens make decisions about the future of water use and how water transfers will be used to address growing urban populations, limited irrigation and rotational cropping systems should be considered as a means of meeting urban water needs while maintaining viable irrigated agricultural systems. This study demonstrated that multi-year crop rotations under reduced tillage practices were very effective at maintaining profitable production levels while reducing consumptive water use. These rotational systems consist of full irrigation for high input crops such as corn and non-irrigated low input crops, such as winter wheat or annual forages. These rotational cropping systems was especially attractive from the perspectives of farm adaptability and risk management.

Phase 3. Regional Adoption and Economic Impacts

Phase 3. Background and Objectives

Adoption of innovative, water-saving cropping systems has the potential to extend throughout the South Platte Basin in order to satisfy the water needs of growing municipalities. The objectives of this study phase were to evaluate the potential of South Platte farms to adopt limited irrigation, rotational cropping, or other water-saving cropping systems and to evaluate the barriers to adoption. A farmer survey was a key instrument to obtaining this information. Additionally, a strong potential for spillover effects into the regional economy exists because adopting alternative irrigation systems will have effects on farm cash flow and productivity. Altered cash flows create ripple effects that include, but are not limited to, agribusinesses that sell inputs directly to adopting farms, businesses that receive revenues from adopting farms' and agribusiness employees that spend their wages locally and a changing sales/property tax base. Another objective of this project phase is to develop a regional economic impact model to quantify these effects.

Phase 3: Results and Conclusions

Quantifying Economic Activity: The economic activity generated by irrigated agriculture in the South Platte Basin (Table 6) has been quantified and these results are reported in a variety of venues. In sum, the basin expects to fallow as many as 266,000 (twenty-two percent) of its irrigated acres in the next twenty-five years. An irrigated acre generates significant economic activity in the basin, so potential losses are substantial in sparsely populated rural areas with few other alternatives. Impacts include the direct loss of crop sales, the lost revenues to agribusinesses that supply irrigated farms, and the wages spent by affected employees.

Table 6. Economic activity generated by irrigated agriculture[a]

Basin	Population Increase by 2020 (%)	Additional Annual Water Demand (ac-ft)	Forecasted Fallowing of Irrigated Acres	Economic Activity $/ac
Arkansas	55%	98,000	23,000 to 72,000	$428
Rio Grande	35%	43,000	60,000 to 100,000	$1,235
South Platte	65%	409,700	133,000 to 266,000	$690

[a]Population, water demand and lost irrigated acres drawn from the Colorado Water Conservation Board, Statewide Water Supply Initiative (2004). Thorvaldson and Pritchett (2006) provide economic activity estimates.

The economic activity represents a snapshot of the activity generated by irrigated agriculture in these basins. It is not a forecast for lost economic activity as it does not capture adaptation, multiple year impacts or the potential threshold impacts if economic activity is sufficiently limited to drive firms out of business.

Producer Survey: One alternative to 'buy and dry' strategies is gaining interest. The alternative allows farmers to lease a portion of their water portfolio to cities. Leased water is generated as farmers fallow their land on a rotational basis or reduce the consumptive use of their cropping operations by limiting irrigation or fallow rotation. Importantly, the limited irrigation cropland remains in production so that rural economies suffer reduced impacts vis-a-vis buy and dry activity. But will farmers adopt limited irrigation strategies or rotational cropping if water lease markets materialize? The producer survey objective was to gauge potential adoption of limited irrigation strategies, the amount of water that might be made available in water leasing arrangements, the necessary compensation needed for farmers to participate and their perceptions of lease arrangements. The results of the survey suggest that more than 60% of the respondents are willing to lease, garnering between 50,000 and 60,000 acre feet of potential water supplies and preferred compensation ranges from \$300 - \$500 per acre of irrigated cropland. Most farmers would prefer not to lease their entire water portfolio, thus these respondents are likely to remain in agriculture and generate positive economic activity. The next step in this research wasto uncover the barriers to adopting limited irrigation practices noting where they might be overcome with cost shares and technical assistance.

Spreadsheet Decision Tool: Many farmers in Colorado face limited irrigation water supplies. Limitations are imposed by a variety of circumstances including declining groundwater levels, significantly higher energy costs, evolving water case law and decreasing return flows in river systems. Regardless of the circumstance, farmers face the same question: what is the "best" allocation of limited water resources?

This research objective sought to develop a spreadsheet decision tool to help farmers determine the tradeoffs of various limited irrigation and water saving strategies. The spreadsheet allows farm managers to input their own business information and contrast potential limited irrigation strategies.

Crops examined in the spreadsheet tool include corn, alfalfa, wheat, dry beans and sunflowers. A copy of the spreadsheet and a technical document describing its use can be found at: http://limitedirrigation.agsci.colostate.edu/ under the resources tab. The underlying crop water production functions have been developed as part of the research performed in the field at the Iliff site, and as part of a literature review. The spreadsheet decision tool provides a basis for the risk analysis that follows. This tool also informs the work of other Alternative to Agriculture Transfer projects.

Risk Decision Analysis: The risk profile of a fully-irrigated farm is likely to change when water supplies are limited. The research objective was to provide preliminary insights into how the risk profile may change. The "benchmark" for the analysis is a fully-irrigated, center pivot, continuous-corn operation and a continuous alfalfa operation. The limited irrigation opportunities include limited irrigation corn (12 inches applied water), limited irrigation alfalfa (12 inches applied water), corn-dryland wheat rotation, corn (15 inches applied) - wheat (6 inches applied)-sunflower (6 inches applied) rotation. In general, limited irrigation scenarios tended to increase the variability of net cash returns, but substantially increased the likelihood of failing to meet a critical cash flow. In this case, the critical level of cash flow is treated as $130,000 that includes a land payment, machinery payment and family living expenses. Depreciation is not treated as an expense when calculating the critical cash flow. This research is to be augmented with the crop rotations that have been developed in the first two phases of this study.

Phase 4. Administration and Basin Level Hydrology

Phase 4. Background and Objectives

This phase of the project addressed administration and hydrologic consideration necessary for the successful implementation of rotational fallowing and limited irrigation cropping practices as water savings approaches in Colorado. Rotational fallow and limited irrigation cropping systems, addressed in other phases of this study, are innovative potential solutions to the changing water needs in Colorado. Adoption of these practices will require that state agencies have confidence that consumptive water use savings are real and that they can be quantified. Practical means of documenting these savings need to be developed. Satellite image methods are a potential means of documenting irrigation approaches, water use, and water savings. Use of satellite images to determine water use has been successfully documented and used by Bastiaanssen et al. (1998a and b and 2000). They developed SEBAL that uses Landsat 5/7 imagery and can be used with other image formats as well and METRIC that stems from SEBAL (Allen et al., 2005) but adds an internal calibration and a better method for calculating seasonal ET. A model called Remote Sensing of Evapotranspiration (ReSET), has been developed at Colorado State University (Elhaddad and Garcia, 2008). It expands the capabilities of SEBAL and METRIC and has been applied using Landsat 5/7 imagery. The objective of this project phase wasto demonstrate the potential for satellite imagery to verify and quantify water savings from water saving cropping practices other than land dry-up.

Phase 4. Approach

The scope of the work proposed was to estimate daily and seasonal evapotranspiration (ET) for selected fields in the South Platte Basin using the ReSET model and the seasonal ET tool, both developed by the Integrated Decision Support Group (IDS) at Colorado State University. Seven Landsat 5 images (Figure 7) were processed to create the single ET grids (Figure 8). The images are for path/row 32/32 and were obtained from the USGS earth resources observation systems (EROS) center. The image dates are 5/11/2006, 5/27/2006, 6/28/06, 7/14/2006, 7/30/2006, 8/31/2006 and 9/16/2006. The IDS seasonal tool that creates seasonal ET estimates from individual ET grids created by the ReSET model were used to estimate the seasonal ET for the selected study fields for the season starting on 5/15/2006 and ending on 9/6/2006 (Figure 9).

Fields selected for study:

Four fields were selected for monitoring (Franson 5, Franson 8, Boo north and Boo south). The areas and crops grown onthose fields, with final results, are shown in Table 7.

Table 7. Area and ET estimated by ReSET for the selected fields.

Field	Area (acres)	Crop	ReSET ET from 5/15 to 9/6 (mm)	Irrigation & Rain from 5/15 to 9/6 (mm)
Franson 5	130	Corn	606	637
Franson 8	130	Corn	605	615.8
Boo North	128	Corn	529	708
Boo South	125	Soy beans	566	520

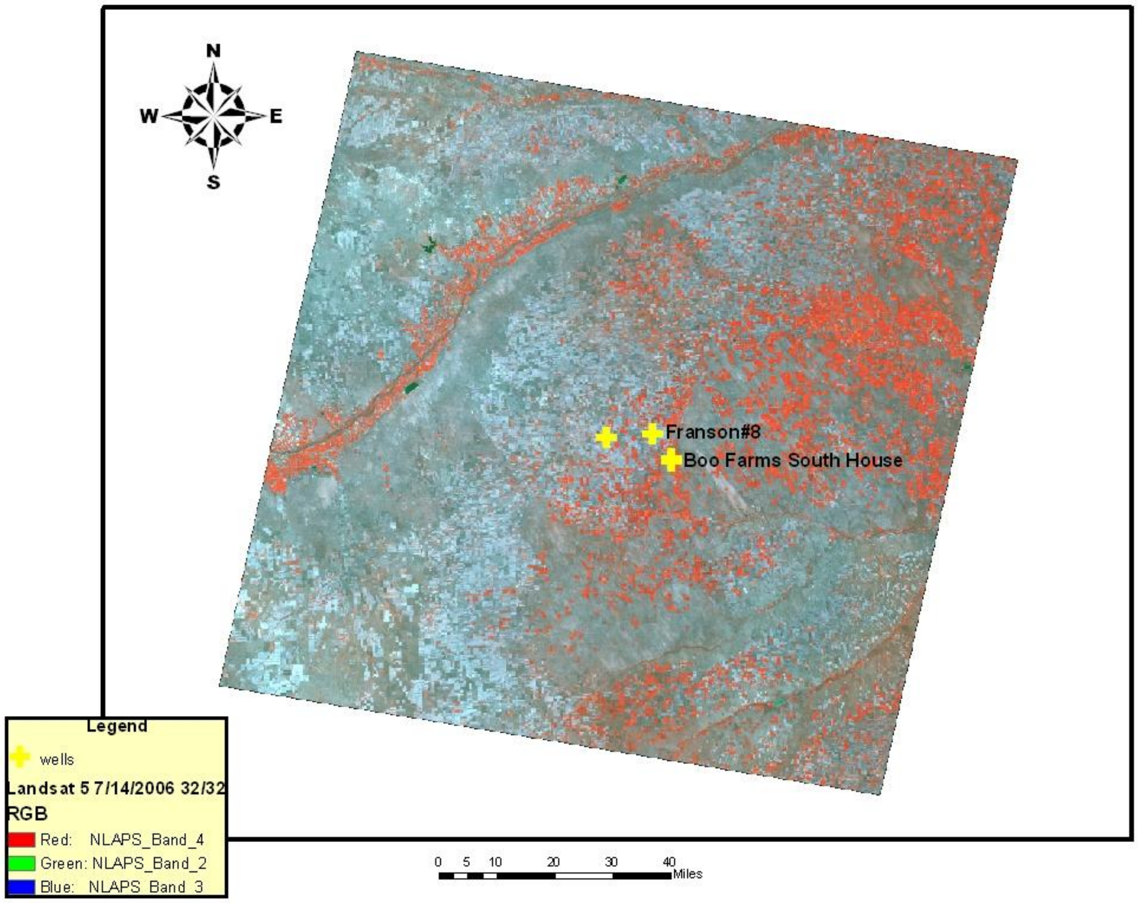

Figure 7. Landsat 5 imagery Path 32 Row 32 on 7/14/2006 for the Boo and Franson farms

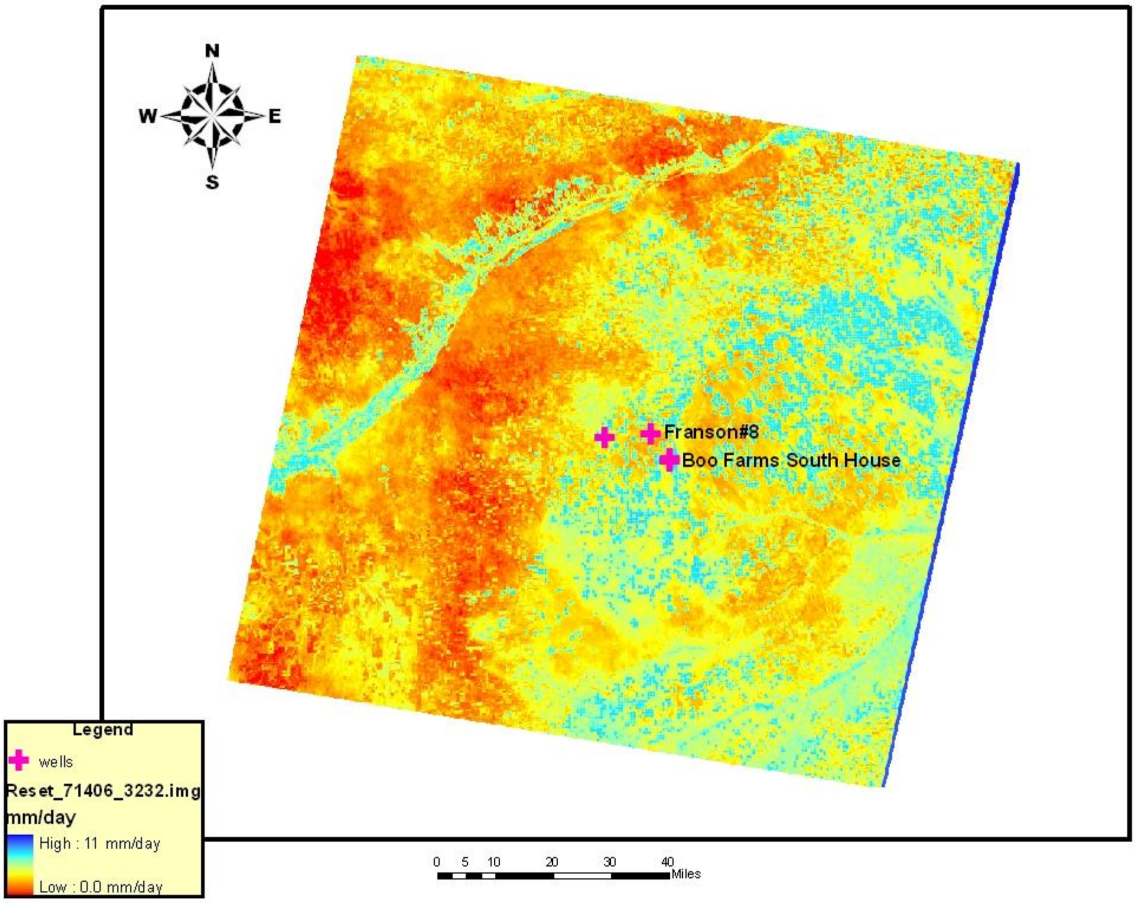

Figure 8. Daily ET (mm/day) for Path 32 Row 32 on 7/14/2006 for the Boo and Franson farms.

Phase 4. Results

The seven single ET grids that were developed by the ReSET model were used to capture the temporal and spatial details within the study area. The semi-weekly satellite monitoring of the study fields sheds light on the agricultural activities occurring in the fields, starting from the irrigation events as shown in Figure 9 for the Boo farms, to activities during the growing season. For example, Figure 10 shows that the Boo North, which was growing corn that was not homogenous until mid-July, which greatly impacted the values of ET on that date (7/14/2006). Similar observations can be seen on 7/30/2006 (Figure 11), where the ET grid is displayed using two scales to show the ET variability on that date. The difference in daily ET on that day was estimated to be over 10%. Using the ReSET model for monitoring of field ET enabled us to detect under-irrigated areas on some of the fields other than the study fields (Figure 12). Using the IDS seasonal ET tool and the single ET grids developed by the ReSET model the seasonal ET was calculated. The seasonal ET for each field was calculated as the mean value of all pixels within the field after buffering the fields with 60 meter inwards to eliminate the thermal contamination on the field edges. Seasonal ET for the growing season of fields is shown in Figure 13. Figure 14 shows the seasonal ET estimated by ReSET for each of the study fields, the actual and buffered field boundary is also shown for the Franson#8 field. The crop development on any field on the images can be traced using the ReSET model approach. Figure 15 and Figure 16 display seven stages of agriculture activities on the Franson #8 field from the first irrigation event on 5/19/06 to senescence on 9/16/06. Seasonal ET for the study fields estimated using the ReSET model matched closely with the irrigation and rain data for those fields except for the Boo North field, which was cultivated with corn (Figure 10) and had a 25% difference between the ReSET estimated seasonal ET and the irrigation and rain data from that field. This field had two issues that were detected using the remote sensing. First, the field had a late crop development as seen in Figure 10. This could have been due to a number of different local conditions which are field dependent (not cultivated on time, no irrigation water on time, lack of fertilizer, soil problems). This means the ET from this field until 7/14/06 was lower when compared to the field just south of it (Boo farms south of the house) that had soy beans. This late development decreased the final seasonal ET monitored by ReSET. The second issue with this field is that parts of the field never had a good crop throughout the season, which is obvious when looking at the west and east edges of the field where low ET areas can be seen. The crop development in these areas was poor, as can be seen on the false color Landsat image (Figure 17). Even if the poor crop development in those areas is caused by reasons other than the lack of irrigation water, the irrigation water in those areas is still not fully used by the crop and that is why it cannot be detected by the ReSET model. These two issues most likely contributed to the 25% difference between the ReSET actual ET estimates and the irrigation and rain field data. The difference between the ReSET actual ET estimate and the irrigation, rain data for the other three fields ranged between 1.7% and 8%, which supports the accuracy and practicality of using the ReSET model in irrigation management for agriculture fields. (really long paragraph)

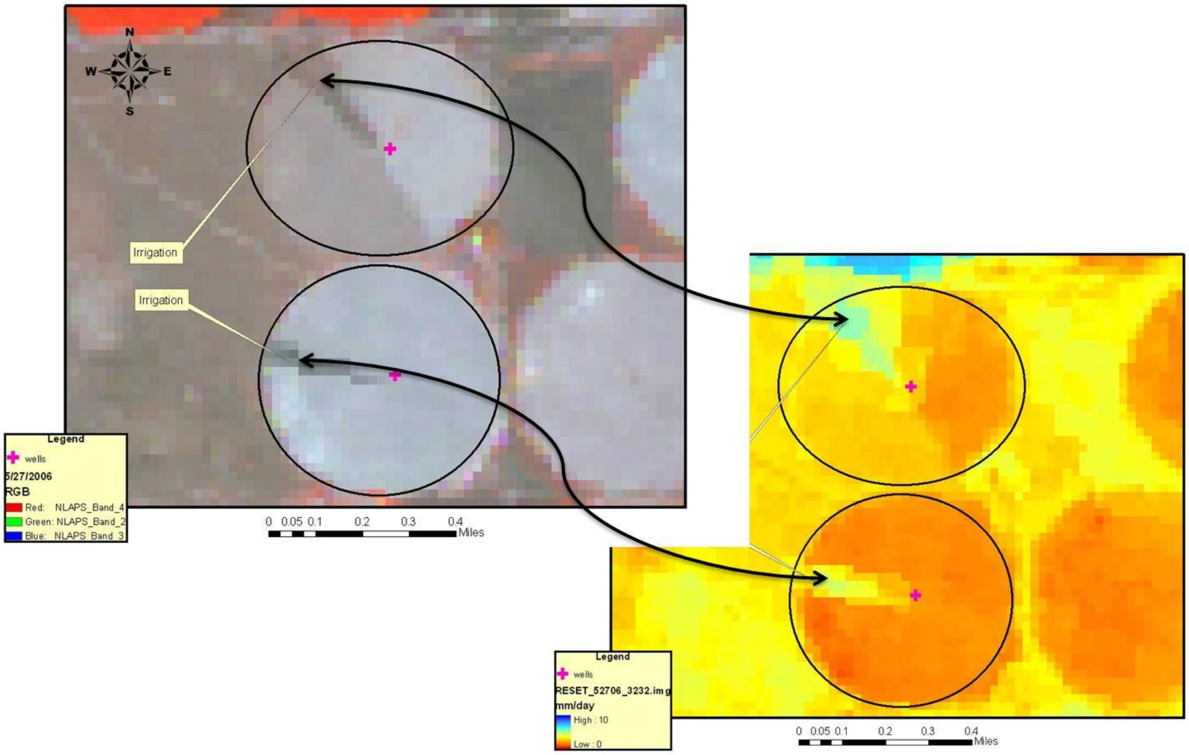

Figure 9. Boo farms fields with irrigation event showing on ET grid of 5/27/2006

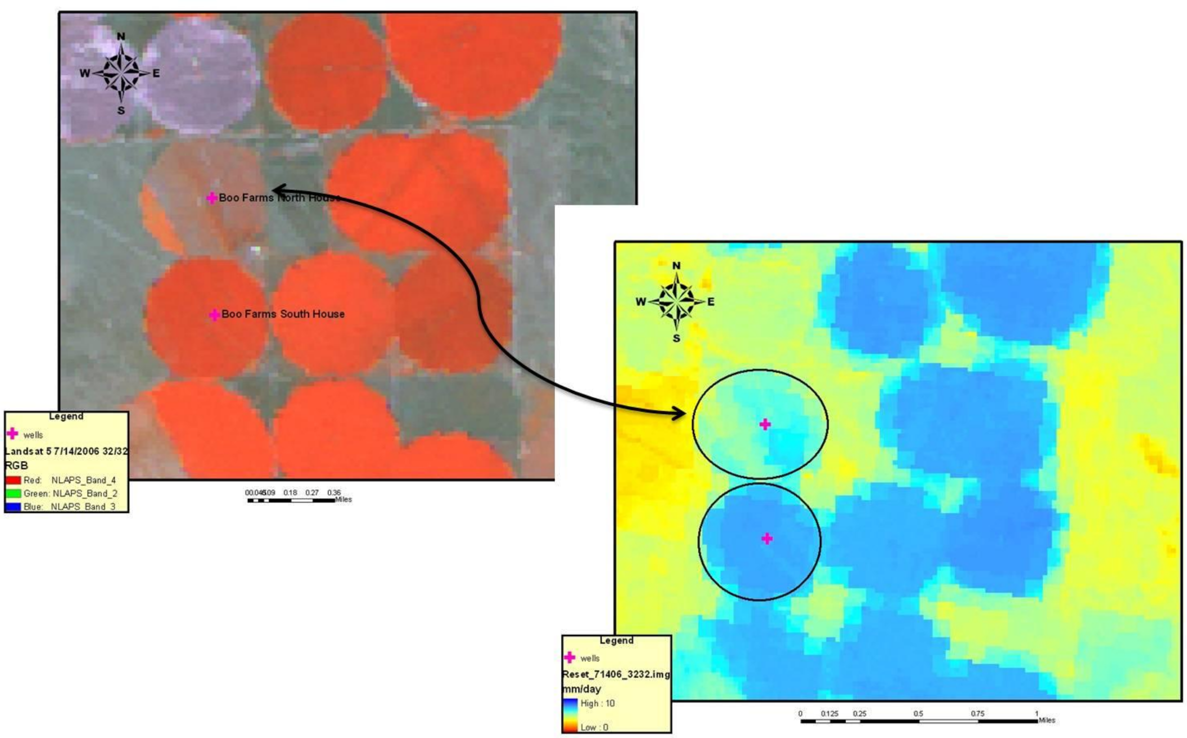

Figure 10. Boo farms fields on 7/14/2006 partially cultivated fields

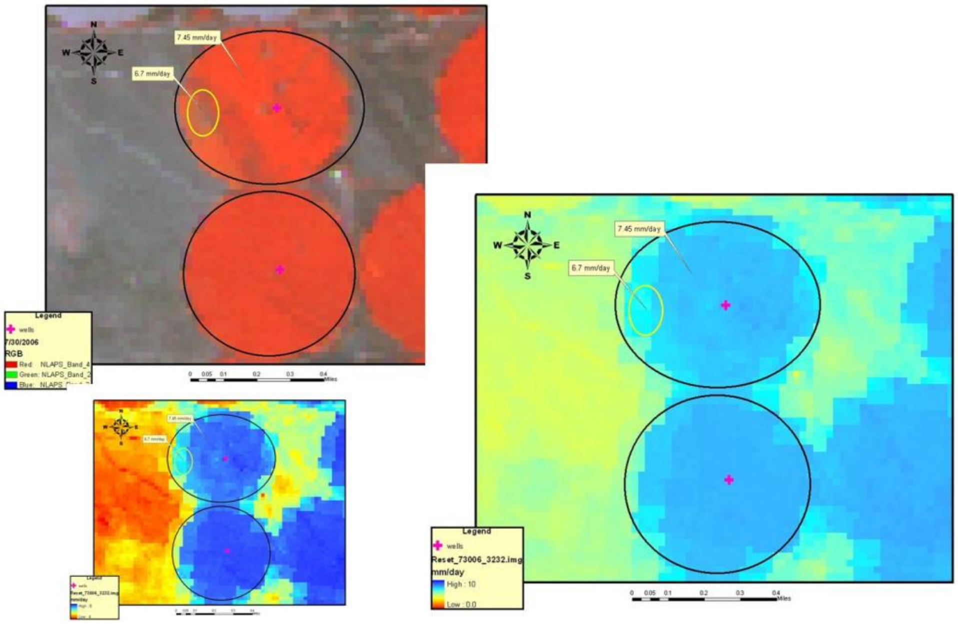

Figure 11. ET variability within the Boo farms fields on 7/30/2006 and on the ET grid.

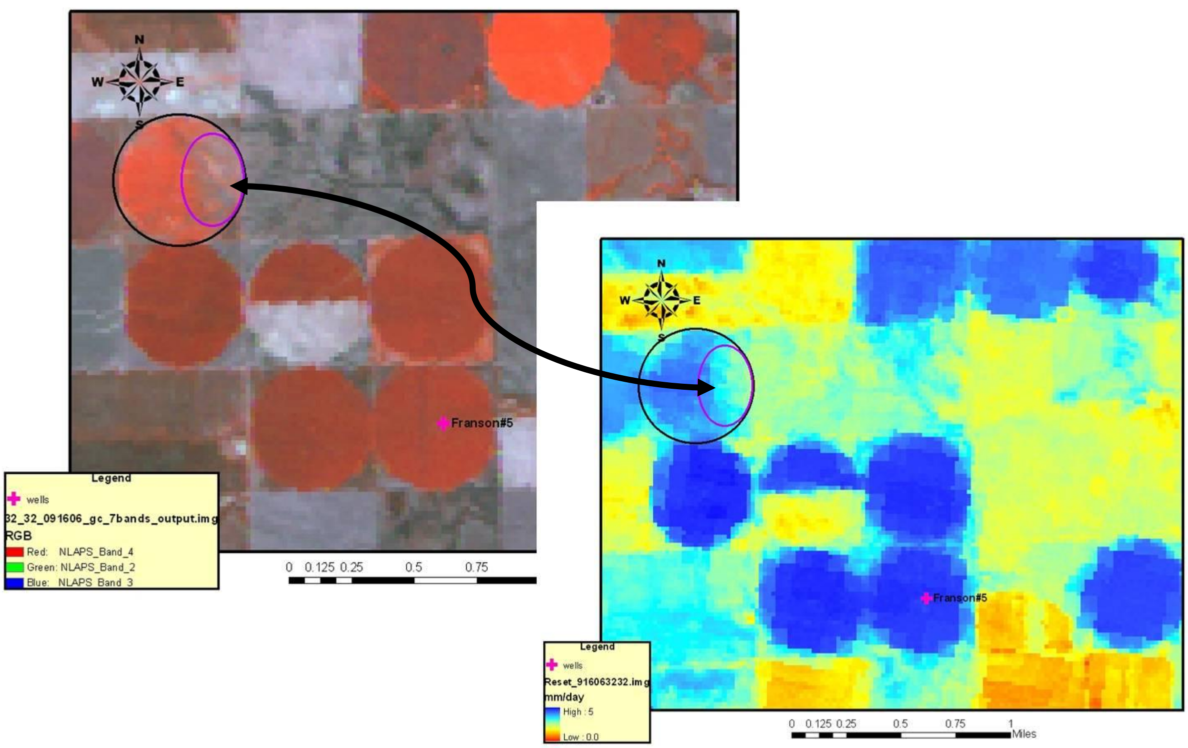

Figure 12. Fields with under irrigated areas

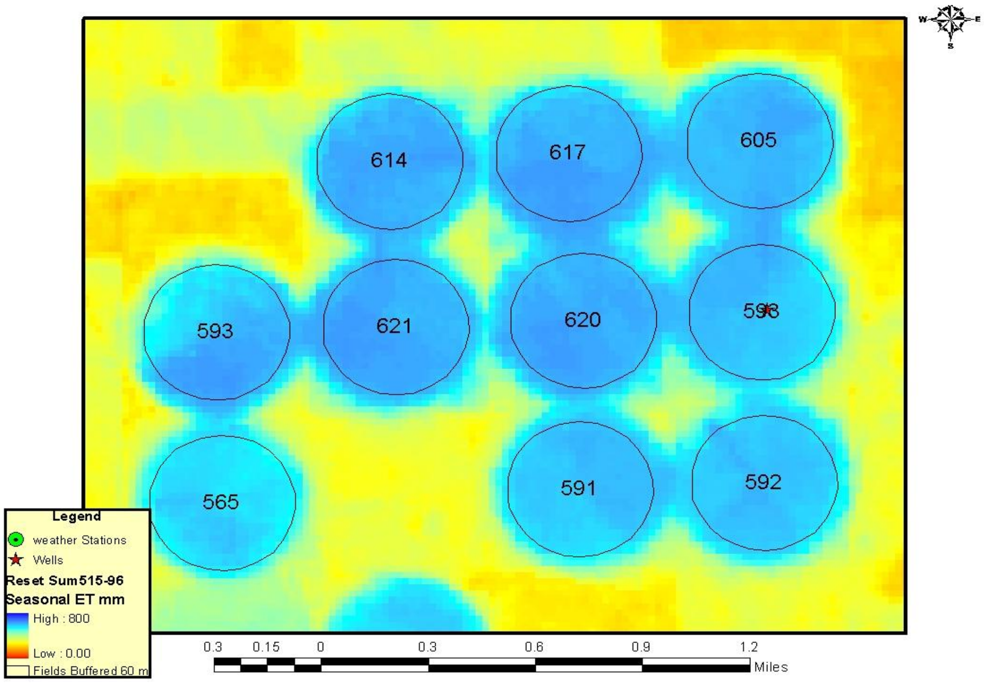

Figure 13. Seasonal ET from 5/15/06 to 9/6/06 with 60m buffered boundaries (Franson 8).

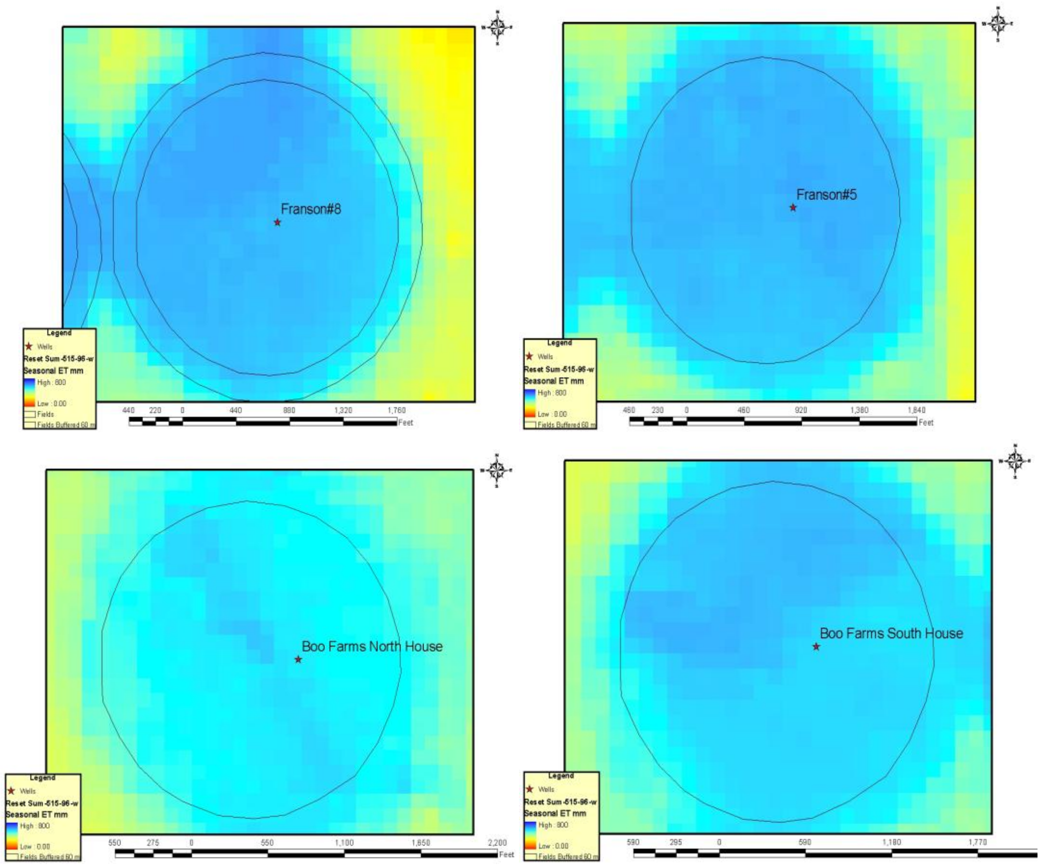

Figure 14. Seasonal ET (mm) for Franson#5, Franson#8 and Boo farms fields.

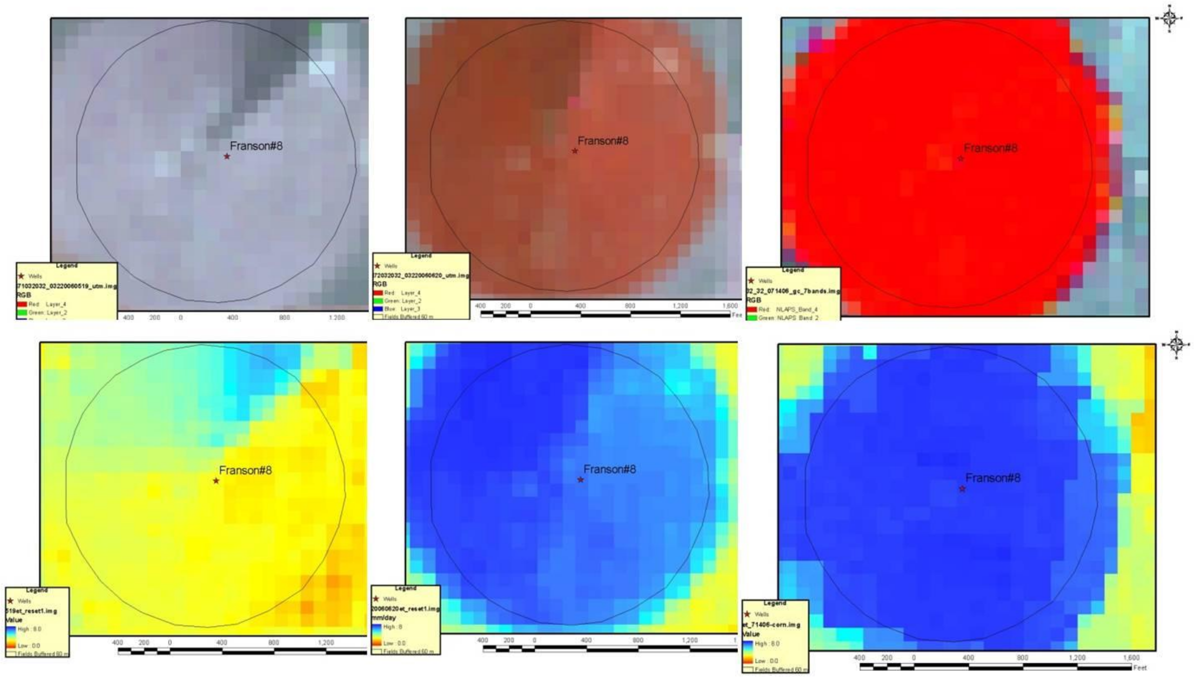

Figure 15. Crop ET at different times for Franson #8 field (first half of the season).

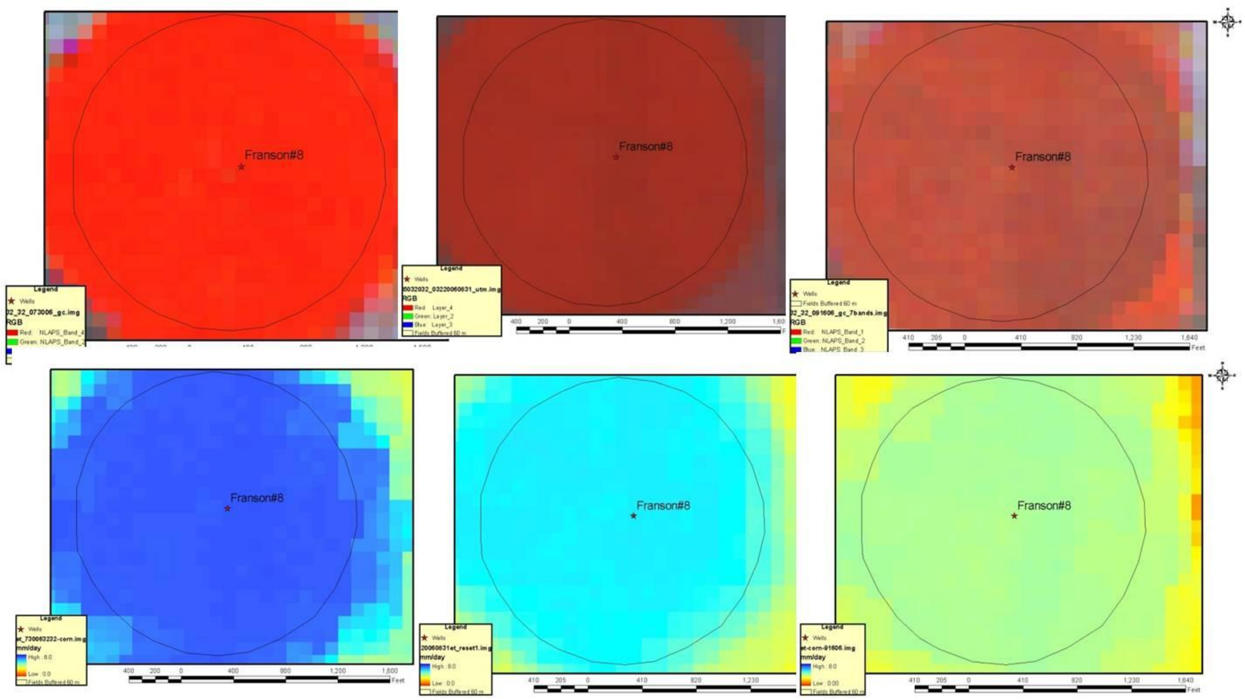

Figure 16. Crop ET at different times for Franson #8 field (second half of the season).

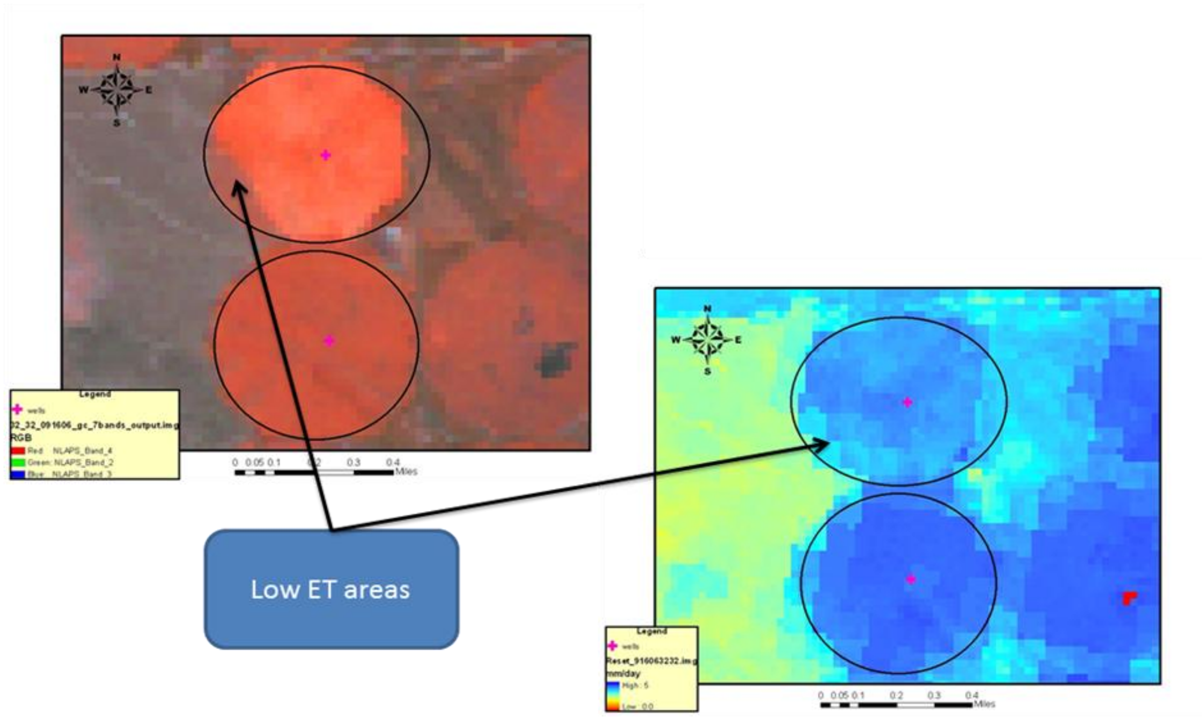

Figure 17. Boo Farms fields for Landsat 5 image and ET on 9/16/06 showing low ET areas.

Phase 4. Summary

The results of the remote sensing of ET work conducted as part of this project clearly show that there is a high potential for the use of remote sensing of ET to quantify the actual ET from each field. In the event that a field is not fully irrigated the actual ET estimated from remote sensing reflect the reduction in ET. The ability to estimate the reduced ET is a great advantage as it relates to documenting the impact of limited irrigation on crop ET. If limited irrigation systems are to become a source of saved consumptive water use for transfer of water from agriculture to municipal use, a practical means of calculating and verifying consumptive water use and water savings will be needed to satisfy Water Court requirements. These results show the potential for utilizing remote sensing to verify consumptive water use, but work is needed to further develop and validate ET measurements, crop coefficients, and stress coefficients under cropping practices with reduced consumptive use. Alternative water conservation approaches that avoid complete land dry-up are more likely to be adopted if methods such as remote sensing of ET can be validated and accepted by Water Court. A new study has been funded to CWCB to further explore the use of remote sensing of ET for limited and partial season irrigation. The study will utilize the Iliff field site with larger plots of limited irrigation corn. ET will be precisely measured in the field with multiple state of the art methods to validate the remotely sensed ET. The project will further develop crop stress coefficients that can be used with standardized combination equations (such as ASCE Standardized and Penman-Monteith equations).

Conclusions

1. Phase 1: Concept Discovery And Feasibility Study

   The discovery phase of the project identified the following water saving cropping approaches:

   1) rotational cropping – rotations of full irrigation crops and fallow or dryland crops

      Candidate dryland crops: winter wheat, annual forage crops, corn, sunflower, and proso millet.

   2) limited irrigation – all crops in the rotation are irrigated, but irrigation is less than full ET demand. Irrigation is targeted to sensitive growth stages specific to each crop.

      Candidate crops: corn, winter wheat, annual forages, sugarbeet, sunflower, soybean, and canola.

   3) partial season irrigation - perennial crops fully irrigated during for part of the growing season combined with periods of no irrigation.

      Candidate crops: alfalfa, cool season grass hay crops.

2. Phase 2: Developing Viable Cropping Practices With Reduced Consumptive Water Use

   a. Rotational cropping with fallow: research identified an ET savings of 7 ac-in/yr when irrigated corn was rotated with a year of clean fallow as compared to full irrigation continuous-corn. ET savings were lower than expected due to high evaporative loss during fallow.

   b. Rotational cropping with dryland crops: Rotating irrigated crops with dryland crops was a more water efficient approach than rotating with fallow. Corn produced after a dryland crop had a higher yield and water use efficiency than continuous corn and similar ET, while dryland crops like winter wheat produced well without irrigation.

   c. Corn, soybean, and sugarbeet were good crops for limited irrigation. Crop rotations under limited irrigation resulted in ET savings of 7-10 ac-in/yr, a level similar to the ET savings for the rotational cropping systems evaluated, but there was no fallowed land. An on-farm study of limited irrigation corn showed that irrigation water management at a field production level can effectively reduce ET while maintaining potentially profitable yields.

   d. There is less drainage and potential return flow for limited irrigation compared to full irrigation.

   e. Partial season irrigation of alfalfa reduced annual evapotranspiration to 18 ac-in/yr compared to 30 ac-in/yr for full irrigation. An on-farm study of partial season irrigation alfalfa indicated that alfalfa accessed water from a shallow water table.

3. Phase 3. Regional Adoption and Economic Impacts
   a. The South Platte River basin expects to fallow as many as 266,000 (twenty-two percent) of its irrigated acres in the next twenty-five years. Each irrigated acre is estimated to generate economic activity equivalent to $690 in the basin.
   b. More than 60% of survey respondents are willing to lease water, with an aggregate of between 50,000 and 60,000 acre-feet of potential water supplies just among those who responded.
   c. Preferred compensation ranges from $300 - $500 per acre of irrigated cropland. Most farmers would prefer not to lease their entire water portfolio, thus these respondents are likely to remain in agriculture and generate positive economic activity.
4. Phase 4. Administration and Basin Level Hydrology
   a. Practical means of documenting water savings in limited irrigation need to be developed.
   b. The results of the remote sensing show a high potential for quantifying ET at a field scale using remote sensing.
   c. A future study will explore remote sensing and other means for documenting water savings of alternative, water-conserving cropping practices.

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Appendix 1: Project Advisory Committee

Last	First	Address	City	Zip	Email
Altenhofen	Jon	220 Water Ave	Berthoud	80513	jaltenhofen@ncwcd.org
Frank	Joe	100 Broadway Plaza, Suite 12	Sterling	80751	jmfrank@lspwcd.org
Lingreen	Bob	335 E Chestnut Street	Sterling	80751	Circle@Sterlingcomputers.com
Manuello	Gene	138 Club Rd	Sterling	80751	geno1@kci.net
Patterson	Joe	201 S 3rd St	Sterling	80751	JPatterson@PINNBANK.COM
Nettles	Dave	810 9th St. 2nd Floor	Greeley	80631	David.Nettles@State.CO.US
Odor	Jack	833 Wilson Ave	Fort Morgan	80701	schuetzen1@yahoo.com
Reck	Mark	PO Box 407, 302 N. 3rd St.	Sterling	80751	marcreck@reckagri.com
Schuppe	Gordon	26785 CR 63	Iliff	80736	gschuppe@kci.net
Stieb	Leo	24153 County Rd. 55	Iliff	80736	Lstieb@yahoo.com
Stromberger	Brad	30608 County Rd. 385	Iliff	80736	stromber@Kci.net
Yahn	Jim	PO Box 103	Sterling	80751	nsidyahn@kci.net

Appendix 2: Detailed Plot Map of Controlled Research Site

Cropping System	1		2		3	4		1		2	
	101	**102**	**103**	**104**	**105**	**106**	**107**	**108**	**109**	**110**	**111**
2007	C F	C L	C L	C F	C	C	F	Can F	Can L	T L	T
2008	S F	S L	~~Sun L~~	~~Sun F~~	C	F	C	C F	C L	C L	C F
2009	W	W L	W L	W	C	C	F	S F	S L	S L	S F
2010	Can F	Can L	T L	T	C	F	C	W	W L	W L	W
	201	**202**	**203**	**204**	**205**	**206**	**207**	**208**	**209**	**210**	**211**
2007	C F	C L	C F	C L	C	C	F	Can F	Can L	T	T L
2008	S F	S L	~~Sun F~~	~~Sun L~~	C	F	C	C F	C L	C F	C L
2009	W	W L	W	W L	C	C	F	S F	S L	S F	S L
2010	Can F	Can L	T	T L	C	F	C	W	W L	W	W L
	301	**302**	**303**	**304**	**305**	**306**	**307**	**308**	**309**	**310**	**311**
2007	C L	C F	C F	C L	C	C	F	Can L	Can F	T	T L
2008	S L	S F	~~Sun F~~	~~Sun L~~	C	F	C	C L	C F	C F	C L
2009	W L	W	W	W L	C	C	F	S L	S F	S F	S L
2010	Can L	Can F	T	T L	C	F	C	W L	W	W	W L
	401	**402**	**403**	**404**	**405**	**406**	**407**	**408**	**409**	**410**	**411**
2007	C L	C F	C L	C F	C	C	F	Can L	Can F	T L	T
2008	S L	S F	~~Sun L~~	~~Sun F~~	C	F	C	C L	C F	C L	C F
2009	W L	W	W L	W	C	C	F	S L	S F	S L	S F
2010	Can L	Can F	T L	T	C	F	C	W L	W	W L	W

Cropping System	1		2		5			1		2	
	501	**502**	**503**	**504**	**505**	**506**	**507**	**508**	**509**	**510**	**511**
2007	W	W L	W L	W	F	C	-	S F	S L	~~Sun L~~	~~Sun F~~
2008	Can F	Can L	T L	T	W	F	C	W	W L	W L	W
2009	C F	C L	C L	C F	C	W	F	Can F	Can L	T L	T
2010	S F	S L	S L	S F	F	C	W	C F	C L	C L	C F
	601	**602**	**603**	**604**	**605**	**606**	**607**	**608**	**609**	**610**	**611**
2007	W	W L	W	W L	F	C	W	S F	S L	~~Sun F~~	~~Sun L~~
2008	Can F	Can L	T	T L	W	F	C	W	W L	W	W L
2009	C F	C L	C F	C L	C	W	F	Can F	Can L	T	T L
2010	S F	S L	S F	S L	F	C	W	C F	C L	C F	C L
	701	**702**	**703**	**704**	**705**	**706**	**707**	**708**	**709**	**710**	**711**
2007	W L	W	W	W L	F	C	W	S L	S F	~~Sun F~~	~~Sun L~~
2008	Can L	Can F	T	T L	W	F	C	W L	W	W	W L
2009	C L	C F	C F	C L	C	W	F	Can L	Can F	T	T L
2010	S L	S F	S F	S L	F	C	W	C L	C F	C F	C L
	801	**802**	**803**	**804**	**805**	**806**	**807**	**808**	**809**	**810**	**811**
2007	W L	W	W L	W	F	C	W	S L	S F	~~Sun L~~	~~Sun F~~
2008	Can L	Can F	T L	T	W	F	C	W L	W	W L	W
2009	C L	C F	C L	C F	C	W	F	Can L	Can F	T L	T
2010	S L	S F	S L	S F	F	C	W	C L	C F	C L	C F

Cropping Systems:
1 = CSWCa 2 = CSWT 3 = CC 4 = CF 5 = CFW
S = Soybean C = Corn W = Wheat ~~Sun = Sunflower~~ F = Fallow T = Triticale
CC = Continuous Corn Can = Canola

Cropping System	6				7	
	901	**902**	**903**	**904**	**905**	**906**
2008	Sug F	Sug L	AG	AG L	A F AG	A L AG
2009	S Can	S Can L	Sug F	Sug L	A F AG	A L AG
2010	Sug F	Sug L	S Can	S Can L	A F AG	A L AG
2011	S Can	S Can L	Sug F	Sug L	A F AG	A L AG
	1001	**1002**	**1003**	**1004**	**1005**	**1006**
2008	Sug L	Sug F	AG L	AG	A L AG	A F AG
2009	S Can L	S Can	Sug L	Sug F	A L AG	A F AG
2010	Sug L	Sug F	S Can L	S Can	A L AG	A F AG
2011	S Can L	S Can	Sug L	Sug F	A L AG	A F AG
	1101	**1102**	**1103**	**1104**	**1105**	**1106**
2008	Sug L	Sug F	AG L	AG	A L AG	A F AG
2009	S Can L	S Can	Sug L	Sug F	A L AG	A F AG
2010	Sug L	F	S Can L	S Can	A L AG	A F AG
2011	S Can L	S Can	Sug L	Sug F	A L AG	A F AG
	1201	**1202**	**1203**	**1204**	**1205**	**1206**
2008	Sug F	Sug L	AG	AG L	A F AG	A L AG
2009	S Can	S Can L	Sug F	Sug L	A F AG	A L AG
2010	Sug F	Sug L	S Can	S Can L	A F AG	A L AG
2011	S Can	S Can L	Sug F	Sug L	A F AG	A L AG

1301 (7)	1302 (8)	1303 (9)	1304 (10)	1305 (11)
West Wheat	Pub Wheat	Medw Br. 2	Tall Fes F	Hybrid Br.
Pub Wheat	Cres Wheat	Int Wht 1	Newhy	Russ Wild
Int Wht 1	Orchard	Medw Br. 1	Russ Wild	Newhy
Medw Br. 2	Slendr Wh	Tall Fes F	Int Wht 2	Medw Br. 2
Orchard	Newhy	Hybrid Br.	Pub Wheat	Orchard
Int Wht 2	Tall Fes Q	Tall Wheat	Orchard	Tall Fes F
Cres Wheat	Russ Wild	Cres Wheat	West Wheat	Medw Br. 1
Slendr Wh	Int Wht 2	Tall Fes Q	Tall Fes Q	West Wheat
Tall Fes F	West Wheat	West Wheat	Cres Wheat	Slendr Wh
Russ Wild	Tall Fes F	Pub Wheat	Int Wht 1	Int Wht 2
Hybrid Br.	Hybrid Br.	Russ Wheat	Slendr Wh	Tall Wheat
Medw Br. 1	Tall Wheat	Orchard	Medw Br. 1	Cres Wheat
Newhy	Int Wht 1	Slendr Wh	Hybrid Br.	Tall Fes Q
Tall Wheat	Medw Br. 2	Newhy	Tall Wheat	Pub Wheat
Tall Fes Q	Medw Br. 1	Int Wht 2	Medw Br. 2	Int Wht 1

1306 (7)	1307 (8)	1308 (9)	1309 (10)	1310 (11)
Russ Wild	Newhy	Int Wht 2	Hybrid Br	
Tall Fes F	Tall Fes Q	Hybrid Br.	Tall Wheat	
Int Wht 1	Int Wht 2	Medw Br. 2	Int Wht 2	
Newhy	West Wheat	Pub Wheat	Orchard	
Medw Br. 1	Orchard	Tall Fes Q	Tall Fes F	
Tall Wheat	Tall Fes F	Orchard	West Wheat	
West Wheat	Slendr Wh	Cres Wheat	Crest Wheat	
Cres Wheat	Pub Wheat	Medw Br. 1	Tall Fes Q	
Orchard	Hybrid Br.	Int Wht 1	Medw Br. 2	
Tall Fes Q	Cres Wheat	Tall Wheat	Pub Wheat	
Slendr Wh	Russ Wild	West Wheat	Int Wht 1	
Pub Wheat	Medw Br. 1	Russ Wild	Russ Wild	
Hybrid Br.	Medw Br. 2	Slendr Wh	Newhy	
Int Wht 2	Int Wht 1	Newhy	Slendr Wh	
Medw Br. 2	Tall Wheat	Tall Fes F	Medw Br. 1	

Grass Plots (15 spp.)

Cropping

S

Full season long Irrigation
Spring & Fall Irrigated
Spring only irrigation

Systems:
6 = Sug Beets Annual/Canola or Grass
Sug = Surgar Beets   AG = Annual Grass
Can = Spring Canola
7 = Alfalfa and AlfalfaGrassMix

Appendix 3: Growing season summary of crop and cropping system water balance, including irrigation, precipitation, soil water use (positive value) or storage (negative value), drainage, and evapotranspiration (ET), yield, and water use efficiency for the 2008, 2009, and 2010 seasons. The average annual ET saved is calculated relative to the full irrigation, continuous corn system.

2008

#1 A. Continuous Corn (Full)

Crop	Irrigation (in)	Precip (in)	Soil Moisture	Drainage (in)	ET (in)	Yield	Yield Units	WUE (Yld/in)
A. Corn	19.0	10.7	0.4	-2.6	27.4	146	bu/ac	5.32
Rotation Average	19.0	10.7	0.4	-2.6	27.4			
	Average Annual ET Saved				0.0			

#2 A. Corn (Full) B. Fallow

Crop	Irrigation (in)	Precip (in)	Soil Moisture	Drainage (in)	ET (in)	Yield	Yield Units	WUE (Yld/in)
A. Corn	19.0	10.7	-1.3	-0.9	27.5	171	bu/ac	6.2
B. Fallow	0.0	10.7	-0.5	-0.6	9.7			
Rotation Average	9.5	10.7	-0.9	-0.8	18.6			
	Average Annual ET Saved				8.9			

#3 A. Corn (Full) B. Fallow C. Wheat (Dry)

Crop	Irrigation (in)	Precip (in)	Soil Moisture	Drainage (in)	ET (in)	Yield	Yield Units	WUE (Yld/in)
A. Corn	20.4	10.7	0.7	-2.8	28.9	169	bu/ac	5.8
B. Fallow	0.0	8.3	0.1	-0.9	7.5			
C. Wheat	0.0	7.1	2.2	-0.2	9.1	54	bu/ac	5.9
Rotation Average	6.8	8.7	1.0	-1.3	15.2			
	Average Annual ET Saved				12.3			

#4 A Sugar Beet (Full) B. Hay Millet (Dry)

Crop	Irrigation (in)	Precip (in)	Soil Moisture	Drainage (in)	ET (in)	Yield	Yield Units	WUE (Yld/in)
A. Sugar Bee	13.9	8.3	0.3	0.0	22.5	35	T/ac	1.53
B. Millet	0.0	8.3	-0.4	0.0	7.8	1.6	T/ac	0.11
Rotation Average	6.9	8.3	-0.1	0.0	15.2			
	Average Annual ET Saved				12.3			

#5 A. Sugar Beets (Limited) B. Hay Millet (Limited)

Crop	Irrigation (in)	Precip (in)	Soil Moisture	Drainage (in)	ET (in)	Yield	Yield Units	WUE (Yld/in)
A. Sugar Bee	7.1	8.3	2.2	-0.2	17.5	33	T/ac	1.82
B. Millet	4.4	8.3	0.0	0.0	12.7	1.6	T/ac	0.13
Rotation Average	5.8	8.3	1.1	-0.1	15.1			
	Average Annual ET Saved				12.3			

2008 (Continued)

Crop	Irrigation (in)	Precip (in)	Soil Moisture	Drainage (in)	ET (in)	Yield	Yield Units	WUE (Yld/in)
#6 A. Corn (Full) B. Soybean (Full) C. Wheat (Dry) D. Canola (Full)								
A. Corn	19.0	10.7	-0.8	-1.9	26.9	173	bu/ac	6.43
B. Soybean	10.2	9.0	1.5	-1.2	19.5	38	bu/ac	1.95
C. Wheat	0.0	7.1	4.6	-0.3	11.4	48	bu/ac	4.20
D. Canola	8.2	7.1	3.5	0.0	18.8	13	bu/ac	0.71
Rotation Average	9.3	8.5	2.2	-0.9	19.2			
	Average Annual ET Saved				8.3			

Crop	Irrigation (in)	Precip (in)	Soil Moisture	Drainage (in)	ET (in)	Yield	Yield Units	WUE (Yld/in)
#7 A. Corn (Limtd) B. Soybean (Limtd) C. Wheat (Limtd) D. Canola (Limtd)								
A. Corn	10.0	10.7	1.2	0.0	21.9	152	bu/ac	6.92
B. Soybean	6.7	9.0	1.6	-0.1	17.3	38	bu/ac	2.20
C. Wheat	6.5	7.1	2.9	-0.7	15.8	57	bu/ac	3.59
D. Canola	4.4	7.1	3.7	-0.1	15.1	8	bu/ac	0.51
Rotation Average	6.9	8.5	2.4	-0.2	17.5			
	Average Annual ET Saved				9.9			

Crop	Irrigation (in)	Precip (in)	Soil Moisture	Drainage (in)	ET (in)	Yield	Yield Units	WUE (Yld/in)
#8 A Corn (Full) B. Sunflower (Full) C. Wheat (Dry) D. Triticale (Dry)								
A. Corn	19.0	10.7	-1.4	-0.8	27.5	167	bu/ac	6.06
B. Sunflower	13.0	9.0	1.5	-3.2	20.2	1887	bu/ac	93.3
C. Wheat	0.0	7.1	3.2	-0.1	10.1	38	bu/ac	3.76
D. Triticale	0.0	7.1	2.1	-0.2	9.0	2.9	T/ac	0.33
Rotation Average	8.0	8.5	1.3	-1.1	16.7			
	Average Annual ET Saved				10.7			

Crop	Irrigation (in)	Precip (in)	Soil Moisture	Drainage (in)	ET (in)	Yield	Yield Units	WUE (Yld/in)
#9 A. Corn (Limtd) B. Sflower (Limtd) C. Wheat (Limtd) D. Triticale (Limtd)								
A. Corn	10.0	10.7	0.2	0.0	20.9	155	bu/ac	7.42
B. Sunflower	8.5	9.0	2.4	-0.1	19.8	1137	lbs/ac	57.4
C. Wheat	6.5	7.1	3.4	-0.1	16.8	42	bu/ac	2.48
D. Triticale	6.7	7.1	1.2	0.0	15.0	3.2	T/ac	0.22
Rotation Average	7.9	8.5	1.8	0.0	18.1			
	Average Annual ET Saved				9.3			

2009

#1 **A. Continuous Corn (Full)**

Crop	Irrigation (in)	Precip (in)	Soil Moisture	Drainage (in)	ET (in)	Yield	Yield Units	WUE (Yld/in)
A. Corn	15.4	12.4	-1.3	-4.2	22.2	110	bu/ac	4.95
Rotation Average	15.4	12.4	-1.3	-4.2	22.2			

Average Annual ET Saved	0.0

#2 **A. Corn (Full) B. Fallow**

Crop	Irrigation (in)	Precip (in)	Soil Moisture	Drainage (in)	ET (in)	Yield	Yield Units	WUE (Yld/in)
A. Corn	15.4	12.4	-1.4	-4.6	21.8	178	bu/ac	8.2
B. Fallow	0.0	12.4	0.4	-0.3	12.5			
Rotation Average	7.7	12.4	-0.5	-2.4	17.1			

Average Annual ET Saved	5.1

#3 **A. Corn (Full) B. Fallow C. Wheat (Dry)**

Crop	Irrigation (in)	Precip (in)	Soil Moisture	Drainage (in)	ET (in)	Yield	Yield Units	WUE (Yld/in)
A. Corn	15.7	12.4	-2.1	-4.4	21.6	172	bu/ac	8.0
B. Fallow	0.0	12.4	-0.3	-0.6	11.5			
C. Wheat	0.0	12.5	2.1	0.0	14.6	59	bu/ac	4.0
Rotation Average	5.2	12.4	-0.1	-1.7	15.9			

Average Annual ET Saved	6.4

#4 **A Sugar Beet (Full) B. Canola (Dry)**

Crop	Irrigation (in)	Precip (in)	Soil Moisture	Drainage (in)	ET (in)	Yield	Yield Units	WUE (Yld/in)
A. Sugar Bee	10.2	10.9	-0.5	-0.1	20.5	36	T/ac	1.53
B. Canola	0.0	12.5	2.0	0.0	14.5		T/ac	
Rotation Average	5.1	11.7	0.7	0.0	17.5			

Average Annual ET Saved	4.7

#5 **A. Sugar Beets (Limited) B. Canola (Limited)**

Crop	Irrigation (in)	Precip (in)	Soil Moisture	Drainage (in)	ET (in)	Yield	Yield Units	WUE (Yld/in)
A. Sugar Bee	5.7	10.9	-0.3	0.0	16.3	32	T/ac	1.82
B. Canola	2.7	12.5	2.4	0.0	17.6		T/ac	
Rotation Average	4.2	11.7	1.1	0.0	17.0			

Average Annual ET Saved	5.3

2009 (Continued)

#6	A. Corn (Full) B. Soybean (Full) C. Wheat (Dry) D. Canola (Full)							
Crop	Irrigation (in)	Precip (in)	Soil Moisture	Drainage (in)	ET (in)	Yield	Yield Units	WUE (Yld/in)
A. Corn	15.7	12.4	-2.6	-3.9	21.6	162	bu/ac	7.52
B. Soybean	4.7	12.4	0.1	-0.5	16.7	41	bu/ac	2.44
C. Wheat	0.0	12.5	-1.0	0.0	11.5	70	bu/ac	6.04
D. Canola	3.7	12.5	1.9	0.0	18.1		bu/ac	
Rotation Average	6.0	12.5	-0.4	-1.1	17.0			
		Average Annual ET Saved			5.3			

#7	A. Corn (Limtd) B. Soybean (Limtd) C. Wheat (Limtd) D. Canola (Limtd)							
Crop	Irrigation (in)	Precip (in)	Soil Moisture	Drainage (in)	ET (in)	Yield	Yield Units	WUE (Yld/in)
A. Corn	7.0	12.4	-2.1	0.0	17.3	175	bu/ac	10.10
B. Soybean	2.5	12.4	-2.2	0.0	12.7	27	bu/ac	2.09
C. Wheat	1.6	12.5	0.5	0.0	14.6	70	bu/ac	4.78
D. Canola	1.5	12.5	2.1	0.0	16.1		bu/ac	
Rotation Average	3.2	12.5	-0.4	0.0	15.2			
		Average Annual ET Saved			7.1			

#8	A Corn (Full) B. Soybean (Full) C. Wheat (Dry) D. Triticale (Dry)							
Crop	Irrigation (in)	Precip (in)	Soil Moisture	Drainage (in)	ET (in)	Yield	Yield Units	WUE (Yld/in)
A. Corn	15.7	12.4	-3.0	-3.1	22.1	138	bu/ac	6.25
B. Soybean	4.7	12.4	4.4	-0.4	21.1	30	bu/ac	1.4
C. Wheat	0.0	12.5	0.7	0.0	13.2	46	bu/ac	3.48
D. Triticale	0.0	13.9	0.4	0.0	14.3		T/ac	
Rotation Average	5.1	12.8	0.6	-0.9	17.6			
		Average Annual ET Saved			4.6			

#9	A. Corn (Limtd) B. Soybean (Limtd) C. Wheat (Limtd) D. Triticale (Limtd)							
Crop	Irrigation (in)	Precip (in)	Soil Moisture	Drainage (in)	ET (in)	Yield	Yield Units	WUE (Yld/in)
A. Corn	7.0	12.4	-2.3	0.0	17.1	145	bu/ac	8.45
B. Soybean	2.5	12.4	-0.9	0.0	14.0	28	lbs/ac	2.0
C. Wheat	1.6	12.5	0.1	0.0	14.2	42	bu/ac	2.98
D. Triticale	2.0	13.9	0.6	-0.1	16.5		T/ac	
Rotation Average	3.3	12.8	-0.6	0.0	15.4			
		Average Annual ET Saved			6.8			

2010

#1 A. Continuous Corn (Full)

Crop	Irrigation (in)	Precip (in)	Soil Moisture	Drainage (in)	ET (in)	Yield	Yield Units	WUE (Yld/in)
A. Corn	17.5	8.3	-0.4	-1.3	24.0	200	bu/ac	8.32
Rotation Average	17.5	8.3	-0.4	-1.3	24.0			
	Average Annual ET Saved				0.0			

#2 A. Corn (Full) B. Fallow

Crop	Irrigation (in)	Precip (in)	Soil Moisture	Drainage (in)	ET (in)	Yield	Yield Units	WUE (Yld/in)
A. Corn	17.5	8.3	1.4	-6.9	20.2	242	bu/ac	12.0
B. Fallow	0.0	8.3	-0.4	0.0	7.9			
Rotation Average	8.8	8.3	0.5	-3.5	14.1			
	Average Annual ET Saved				10.0			

#3 A. Corn (Full) B. Fallow C. Wheat (Dry)

Crop	Irrigation (in)	Precip (in)	Soil Moisture	Drainage (in)	ET (in)	Yield	Yield Units	WUE (Yld/in)
A. Corn	17.8	8.3	0.4	-2.9	23.5	251	bu/ac	10.7
B. Fallow	0.0	8.3	0.5	0.0	8.7			
C. Wheat	0.0	12.3	3.4	-1.0	14.7	60	bu/ac	4.1
Rotation Average	5.9	9.6	1.4	-1.3	15.7			
	Average Annual ET Saved				8.4			

#4 A Sugar Beet (Full) B. Canola (Dry)

Crop	Irrigation (in)	Precip (in)	Soil Moisture	Drainage (in)	ET (in)	Yield	Yield Units	WUE (Yld/in)
A. Sugar Beet	20.1	8.2	0.4	-0.4	28.2	36	T/ac	1.53
B. Canola	0.6	12.3	0.0	0.0	12.9		bu/ac	
Rotation Average	10.4	10.2	0.2	-0.2	20.6			
	Average Annual ET Saved				3.5			

#5 A. Sugar Beets (Limited) B. Canola (Limited)

Crop	Irrigation (in)	Precip (in)	Soil Moisture	Drainage (in)	ET (in)	Yield	Yield Units	WUE (Yld/in)
A. Sugar Beet	10.8	8.2	0.8	-0.2	19.6	31	T/ac	1.82
B. Canola	6.0	12.3	0.0	0.0	18.3		bu/ac	
Rotation Average	8.4	10.2	0.4	-0.1	18.9			
	Average Annual ET Saved				5.1			

2010 (Continued)

#6	A. Corn (Full) B. Soybean (Full) C. Wheat (Dry) D. Canola (Full)							
Crop	Irrigation (in)	Precip (in)	Soil Moisture	Drainage (in)	ET (in)	Yield	Yield Units	WUE (Yld/in)
A. Corn	18.5	8.3	1.0	-1.6	26.1	224	bu/ac	8.57
B. Soybean	9.3	8.3	-0.2	-1.9	15.3	31	bu/ac	2.02
C. Wheat	0.0	12.3	2.3	-1.1	13.5	44	bu/ac	3.26
D. Canola	5.5	12.3	0.5	-2.7	15.6		bu/ac	
Rotation Average	8.3	10.3	0.9	-1.8	17.6			
	Average Annual ET Saved				6.4			

#7	A. Corn (Limtd) B. Soybean (Limtd) C. Wheat (Limtd) D. Canola (Limtd)							
Crop	Irrigation (in)	Precip (in)	Soil Moisture	Drainage (in)	ET (in)	Yield	Yield Units	WUE (Yld/in)
A. Corn	14.8	8.3	1.9	-0.6	24.3	175	bu/ac	7.21
B. Soybean	8.5	8.3	-0.1	-2.0	14.6	25	bu/ac	1.71
C. Wheat	1.0	12.3	2.3	-0.3	15.3	58	bu/ac	3.80
D. Canola	2.5	12.3	0.7	-1.0	14.5		bu/ac	
Rotation Average	6.7	10.3	1.2	-1.0	17.1			
	Average Annual ET Saved				6.9			

#8	A Corn (Full) B. Soybean (Full) C. Wheat (Dry) D. Triticale (Dry)							
Crop	Irrigation (in)	Precip (in)	Soil Moisture	Drainage (in)	ET (in)	Yield	Yield Units	WUE (Yld/in)
A. Corn	18.5	8.3	0.7	-2.6	24.9	235	bu/ac	9.45
B. Soybean	9.3	8.3	-0.2	-1.7	15.6	31	bu/ac	2.0
C. Wheat	0.0	12.3	2.9	-0.3	14.9	47	bu/ac	3.16
D. Triticale	0.0	12.3	0.7	0.0	12.9		T/ac	
Rotation Average	6.9	10.3	1.0	-1.2	17.1			
	Average Annual ET Saved				7.0			

#9	A. Corn (Limtd) B. Soybean (Limtd) C. Wheat (Limtd) D. Triticale (Limtd)							
Crop	Irrigation (in)	Precip (in)	Soil Moisture	Drainage (in)	ET (in)	Yield	Yield Units	WUE (Yld/in)
A. Corn	14.8	8.3	1.4	-0.9	23.5	187	bu/ac	7.96
B. Soybean	8.5	8.3	0.3	-2.0	15.0	25	lbs/ac	1.7
C. Wheat	1.0	12.3	2.0	0.0	15.2	54	bu/ac	3.55
D. Triticale	0.5	12.3	0.3	0.0	13.1		T/ac	
Rotation Average	6.2	10.3	1.0	-0.7	16.7			
	Average Annual ET Saved				7.3			