AN INTEGRATED APPROACH TO WATER CONSERVATION FOR AGRICULTURE IN THE TEXAS SOUTHERN HIGH PLAINS

Texas Alliance for Water Conservation

Agricultural Water Conservation Grant Contract No. 0503580014

Final Report - Phase 1 - 2005-2013

Submitted to the

Texas Water Development Board

http://www.TAWC.us

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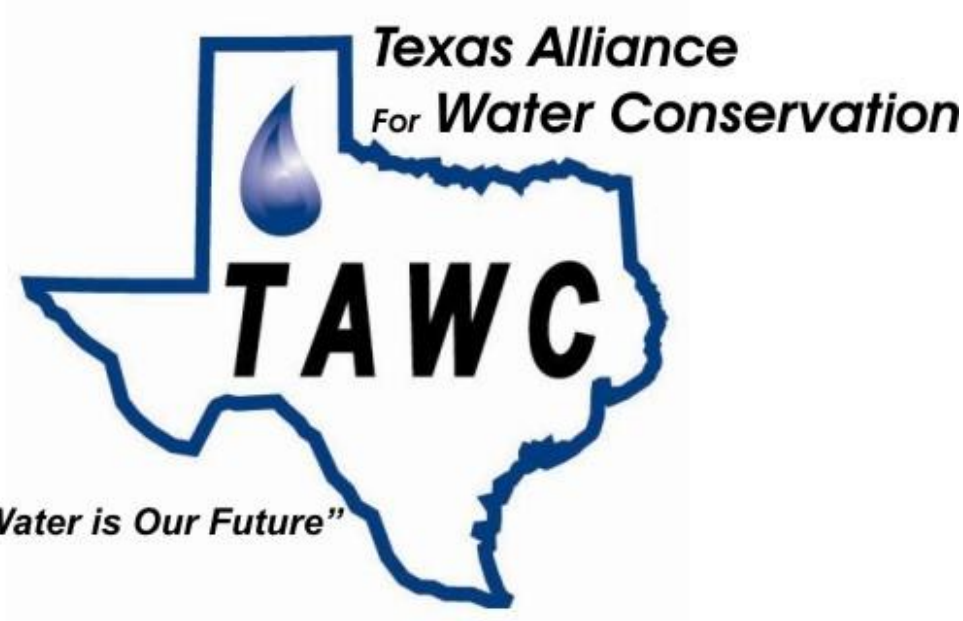

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EXECUTIVE SUMMARY

TAWC Final Report Phase 1, 2005-2013

Mission

The Texas Alliance for Water Conservation (TAWC) mission is to conserve water for future generations by identifying those agricultural production practices and technologies that, when integrated across farms and landscapes, will reduce the depletion of groundwater while maintaining or improving agricultural production and economic opportunities. Information and technologies demonstrated by TAWC on efficient production of irrigated crops have relieved growers of much of the guesswork in how they manage water. Such investments aid in sustaining the future of the Texas High Plains as an agricultural economic powerhouse while preserving our natural and human resources.

Report

Declining ground water supply, pumping limitations, variable precipitation, and fluctuating commodity prices form the background against which agricultural producers make decisions on crop plantings, irrigation rates, and adoption of new technologies. This report summarizes accomplishments of the project since its inception in 2005 with emphasis on annual changes in producers' decisions, efficiency of water use, economic returns of the cropping and irrigation systems, the creation of decision aid tools, and communication efforts to expand the usage of water-efficient technologies. Reports were submitted annually which included information on weather, task leaders' presentations, publications and data collected, soil and crop descriptions of farm sites, and calculations of water use and profitability by cropping system and irrigation technology. Results of all sites and years are tabulated in the Appendix of this final report.

Approach

There were 29 demonstration sites in Hale and Floyd counties covering 4,700 acres. Each site represented a particular cropping system (e.g. single-crop monoculture, multiple cropping, forage for livestock). The sites were managed by 20 different producers, who were chosen by a producer board to reflect a realistic range of management styles. All management decisions were made independently of the project leaders. The project collected production data and provided information to aid in producer decisions. The crops were monitored for use of irrigation water, water demand, yields, and input costs. Calculations were made of amounts of irrigation water conserved, crop water-use efficiency, and net returns. A survey revealed barriers to change and factors that motivate changes in management.

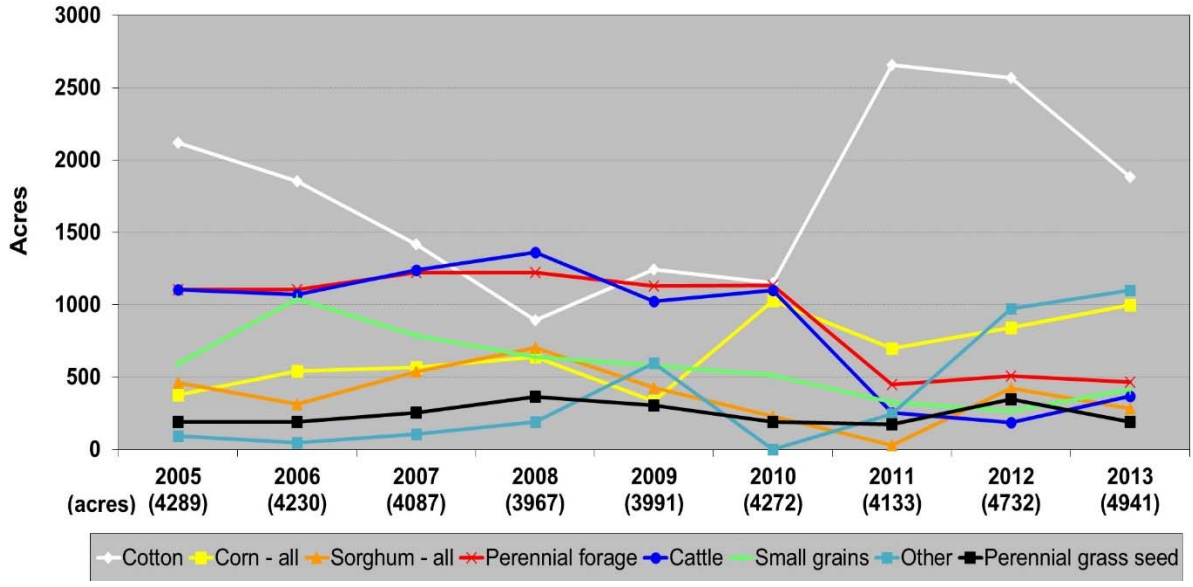
Major Accomplishments

- Creation of a Unique Data Set: Nine years of records of all costs, practices, and inputs to crop production and crop yield outputs were compiled over a range of rainfall conditions. Results indicate water savings are most effectively achieved by irrigating at levels of 70-80% of potential evapotranspiration, a level which can allow near maximum crop yield and high economic efficiency.
- Economic Evaluations: Profitability, costs of production, and economic efficiency were evaluated through the preparation of enterprise and system budgets. We identified 12 sites which attained relatively high gross return per acre ($300 or more) and low annual irrigation (15 inches or less).
- Best Management Practices: Shifting to more-efficient irrigation methods, scheduling of irrigation based on evapotranspiration, and diversification of crop species has resulted in more applied water reaching the root zone, less evaporation losses, and higher crop yields.

- Field-Based Testing of Emerging Technologies: TAWC has tested the effectiveness of new equipment for irrigation system management and for sensing soil moisture and crop stress and provided unbiased evaluations to aid purchasing decisions by producers.
- Web-based Irrigation Management Tools (www.TAWCsolutions.org): The *Resource Allocation Analyzer* helps identify and evaluates crop production alternatives to maximize profitability for a specified level of water availability. The *Irrigation Scheduling* tool uses evapotranspiration estimates and crop water-use coefficients to assist producers in irrigation scheduling decisions. As of the end of 2014, these web tools have been accessed by over 5,300 active users since the tools were brought online with over 2,850 new registered and active users within the last year. A new technique involving satellite remote sensing with spectral crop coefficients was shown to accurately estimate crop water use and soil water content. This new technology will improve field accuracy of the *Irrigation Scheduling* tool and expand its usefulness to more producers.
- Outreach and Dissemination of Results: Information has reached producers, crop consultants, extension agents, commercial technical representatives, agricultural finance officers, and various stakeholders interested in safeguarding the water supply for agriculture. TAWC has produced 12 YouTube videos, 8 TV showings, 7 technical fact sheets, displayed a booth at 25 trade shows, and has 179 followers on Facebook and 405 followers on Twitter. "Field Talk" was broadcast on two radio stations to over 1,000 listeners daily in 2013 to announce updates on crop water demand and management tips on water conservation. Annual conferences attract 70-150 attendees per year, and Field Walks attract 20-30 persons per event, of which at least half are producers or consultants. We estimate that TAWC accessed over 10,000 persons with a stake in agricultural water conservation over nine years.
- Project Expansion: Additional grants were received to expand the involvement and impact of TAWC demonstrations and test sites beyond Hale and Floyd counties.

Diversity of Crops Produced

The acreages of crops grown varied by year according to anticipated prices, weather conditions, and water availability for irrigation (see following figure). Cotton acreage varied the most. Forage and cattle (pasture) production dropped steeply during the 2011 drought and has not recovered yet.



Water Availability

From the beginning of 2005 through the beginning of 2014, water storage in the Ogallala Aquifer under the area delineated by the TAWC perimeter declined by 24%, for an average of 2.5% per year, and 3.3% between 2007 and 2014. Close to one-half of that decline occurred during 2011 and 2012, two years of severe drought and high water extraction.

Estimated Water Conservation

The amount of irrigation water conserved at the producer sites was calculated as the amount of irrigation used that was less than that necessary to meet total crop water demand at 100% of potential evapotranspiration. The amount conserved from 2006-2013 averaged 616 acre-feet per year when summed across all sites. The amount conserved in the last three years of the project averaged 918 acre-feet per year, indicating progress in the latter years, or 2.3 inches per year. Those amounts include discretionary conservation and deficit due to lack of well capacity to meet the crops' needs.

Crop Water Use Efficiency and Irrigation Efficiency

Expressed as pounds of grain produced per acre-inch of irrigation applied, grain sorghum had somewhat greater crop water use efficiency than corn (729 vs. 604). When calculated per acre-inch of irrigation plus growing-season rainfall, corn water use efficiency was greater than that of grain sorghum (380 vs. 329). Grain sorghum yield per acre averaged one-half of corn yield, but received around 40% less irrigation than corn. Grain sorghum is a profitable alternative crop to corn where irrigation supply has declined below levels needed for high corn yield. Efficiency of irrigation (pounds of crop yield as lint or grain per acre-inch applied) was generally greater for cotton and corn when delivered by subsurface drip than by spray or low-elevation precision application. Gains in irrigation efficiency can be achieved by a combination of selecting water-efficient crop varieties, using newer irrigation techniques, and precise irrigation scheduling.

This report summarizes the progress of TAWC during Phase 1 of its mission to demonstrate cost-effective methods, develop decision tools for conserving irrigation water, and set reachable goals for area farmers. The online planning tools and field demonstrations are concrete benefits toward water-smart agriculture. Less concrete, but of continuing impact, are the myriad messages of benefits to durable agricultural production. These benefits have relieved producers of much of the guesswork in how they invest in improvements. Readers are urged to consult the Appendix Tables and previous annual reports for comprehensive details on TAWC activities and data collected.

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Texas Alliance for Water Conservation Final Report 2005-2013

Introduction

Agriculture in the High Plains of West Texas owes much of its high value to the irrigation water supplied by the Ogallala Aquifer, for which strong conservation efforts are required to extend its useful life. The Texas Alliance for Water Conservation (TAWC) was initiated in 2004 to promote water conservation for future generations by identifying production practices and technologies that will reduce the depletion of groundwater while maintaining or improving agricultural production and economic opportunities. The background to this effort is the steady decline in the amount of groundwater in the aquifer, which is forcing many producers to concentrate the irrigation onto fewer acres while improving the precision in amount and timing of water application on those acres. The High Plains Underground Water Conservation District (HPWD) is implementing restrictions on water extraction, an action which puts legal impetus on reducing pumping for irrigation. A core group of interested producers was assembled in 2004 to work with Texas Tech University and other agencies to set up a long term demonstration and education project. The Producer Board identified cooperating producers who represented the current range of irrigation techniques and crop types to take part in the project. The TAWC project collected water-use data for nine years (2005-2013, Phase 1) on cooperators' farms and demonstrated techniques to make precise application of water in relation to crop needs.

Phase 1 involved 29 demonstration sites covering over 4,700 acres representing monoculture, multi-crop, and integrated crop-livestock systems. Irrigation technologies included subsurface drip irrigation (SDI), low energy precision application (LEPA), low and mid elevation spray application (LESA and MESA), and furrow, as well as dryland or non-irrigation practices. The sites were all located in Hale and Floyd Counties, an area chosen for its economic vulnerability to the steady decline in the saturated thickness of the Ogallala Aquifer. Results from these counties apply to production systems across the Southern High Plains.

This report summarizes the major accomplishments and findings of the project and the lessons learned about choices producers make in coping with groundwater declines. Nine-year trends in water supply, cropping decisions, and water use efficiencies are also summarized in relation to economic returns and adaptations by producers.

Major funding for the TAWC was provided by the Texas Water Development Board. Annual reports can be found online at http://www.twdb.texas.gov/conservation/agriculture/demonstration/.

Major Accomplishments of TAWC Project

1. Establishment of an Integrated Water Management Project. This project combined field verification, education, and communication activities guided by the needs expressed by the Producer Board. The initial project partners included area agricultural producers, industry, university, groundwater district, and extension leaders. Interest in the project has grown over time resulting in an expansion of the project's partners to now include major commodity groups and commercial enterprises involved in current and emerging irrigation technologies and crop genetics. The success of Phase 1 has resulted in new funding to support Phase 2 of the project for the 2014-2018 cropping seasons. Phase 2 will comprise 34 sites spread over eight counties. The TAWC project has been leveraged to attract additional funding from state, federal, and industry sources interested in integrating research and education to improve water use efficiency.

2. Creation of a Comprehensive Dataset: A wide range of observations and field records has been collected from the TAWC sites from 2005 through 2013, covering the extremes of wet and dry years. These observations include crop choices, crop yields, irrigation application, precipitation, soil moisture changes, and crop water demand based on evapotranspiration (ET) estimates. In addition, data for cultivation practices, varieties, fertilizer applications, and chemical applications were collected. These observations are useful for tracking producer decision-making and their adoption of new technologies. We found that excess irrigation was applied in average-rainfall to wetter-than-average years, but that severe drought made water conservation very difficult to achieve. Producers learned that using soil moisture sensors and irrigation scheduling during average to wetter years to reduce unneeded irrigations provided the best opportunity to conserve groundwater.

3. Economic Evaluation. The types of crops and irrigation equipment used by the cooperating producers were representative of those used in the South Plains. The type of crop grown in a particular field, either making up the entire field (monoculture) or with more than one crop per field (multi-cropping), was considered a cropping system whose results could be scaled up regionally. Profitability, costs of production, and economic efficiency were evaluated through enterprise and system budgets. These budgets were prepared for each demonstration site for each year of the project and returned to the respective farmer for use in subsequent production decisions. As such, producers have benefitted from both site and whole-farm financial analyses. The summarized results are useful for all producers with similar cropping systems to estimate their input costs, water needs and returns on water use.

4. Best Management Practices. Best management practices related to irrigation system management, irrigation scheduling, soil fertility, and crop selection have been identified in this project. In the Southern High Plains, spray modes of irrigation (low elevation spray application, LESA; and mid elevation spray application, MESA) have gradually been replaced by modes that cause less evaporative losses (low energy precision application, LEPA, and subsurface drip irrigation, SDI), resulting in a greater proportion of the pumped water reaching the crops' roots. Side-by-side comparisons of irrigation methods reveal how water efficiency leads to economic gain. For example, at one site in

LEPA

2011, cotton yielded 1,001 pounds per acre using LEPA and 879 pounds per acre using LESA, indicating 122 lbs greater yield and $103.70 per acre greater profit when receiving the same amount of water.

The use of soil moisture sensors has shown that LEPA leaves more crop-available subsoil moisture and dries out slower than spray mode. Another best management practice is to slow down the rate of pivot rotation to allow deeper water penetration into the plant root zone. At relatively fast pivot rotation rates of 5 and 4-days per cycle, irrigation only reached a depth of 8 inches. When pivot rotation was slowed to 7-days per cycle, applied water reached 16 inches deep, therefore allowing greater delivery of water to the rooting zone.

Another best management practice is the fine-tuning of irrigation scheduling to match the replacement of ET. More producers are monitoring ET frequently, giving them an objective basis for scheduling irrigation when needed, thus resulting in less applied water evaporating from the soil or less waste of water from over-irrigation. Finally, some producers have diversified their cropping patterns, shifting from the historic pattern of continuous cotton monoculture to more diverse cropping systems that leave more crop residue, thereby conserving soil and water and improving soil structure and fertility.

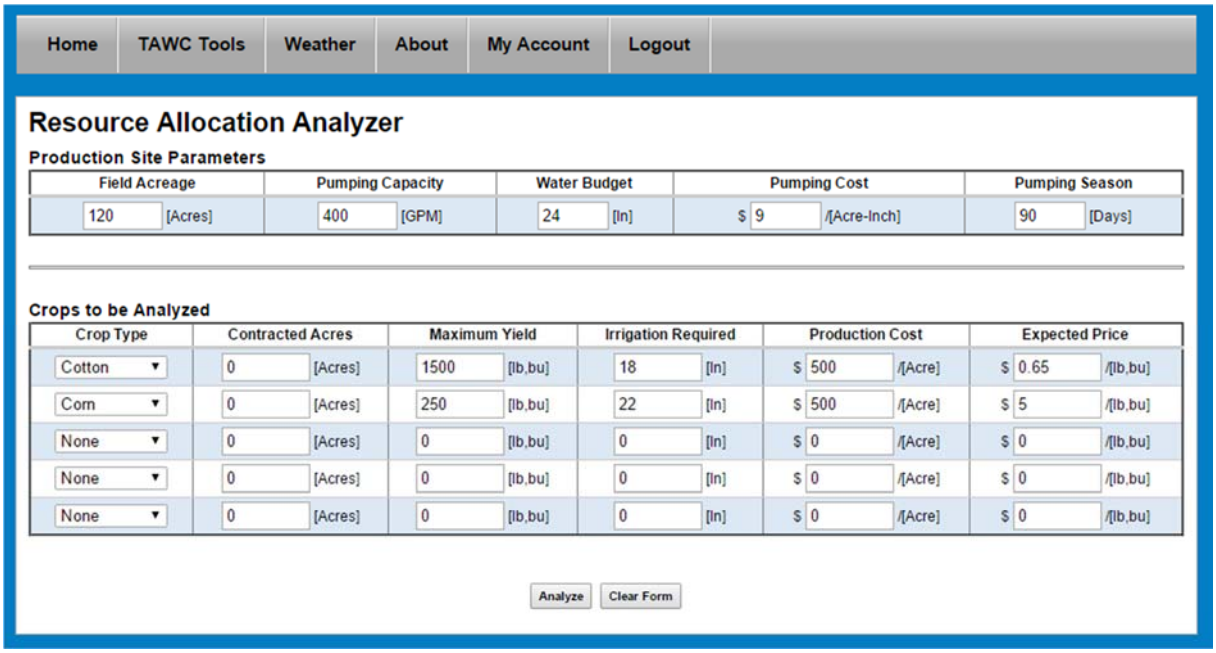
5. Emerging Technologies and Field-Based Testing. Various new irrigation and crop management technologies have been demonstrated on project sites. These technologies include soil moisture sensors, crop stress sensors, and irrigation system management equipment. The following are specific technologies demonstrated and the year they were initiated into the project: Smart Field and Smart Crop (2008), NetIrrigate (2008), AquaSpy (2010), Eco1st (2010), John Deere Field Connect (2012), AquaCheck (2012), and PivoTrac (2012). The TAWC provides an unbiased evaluation of these tools within overall crop management systems. The results have illustrated the effectiveness and compatibility of each technology, thereby assisting producers across the region in their decisions regarding potential adoption.

6. Increased Water Use Awareness. Producers participating in the demonstration project have stated an increased awareness of water use and conservation practices through their use of irrigation-system meters and soil-moisture sensors demonstrated on the TAWC sites. Information gathered and provided to producers from the project includes analysis of water use efficiency and amounts of irrigation water applied. Producer Ed Teeter of Lockney stated, “We’re using my fields to show other producers how to keep from overwatering.” Glenn Schur of Plainview said, “The TAWC project has helped me discover the new

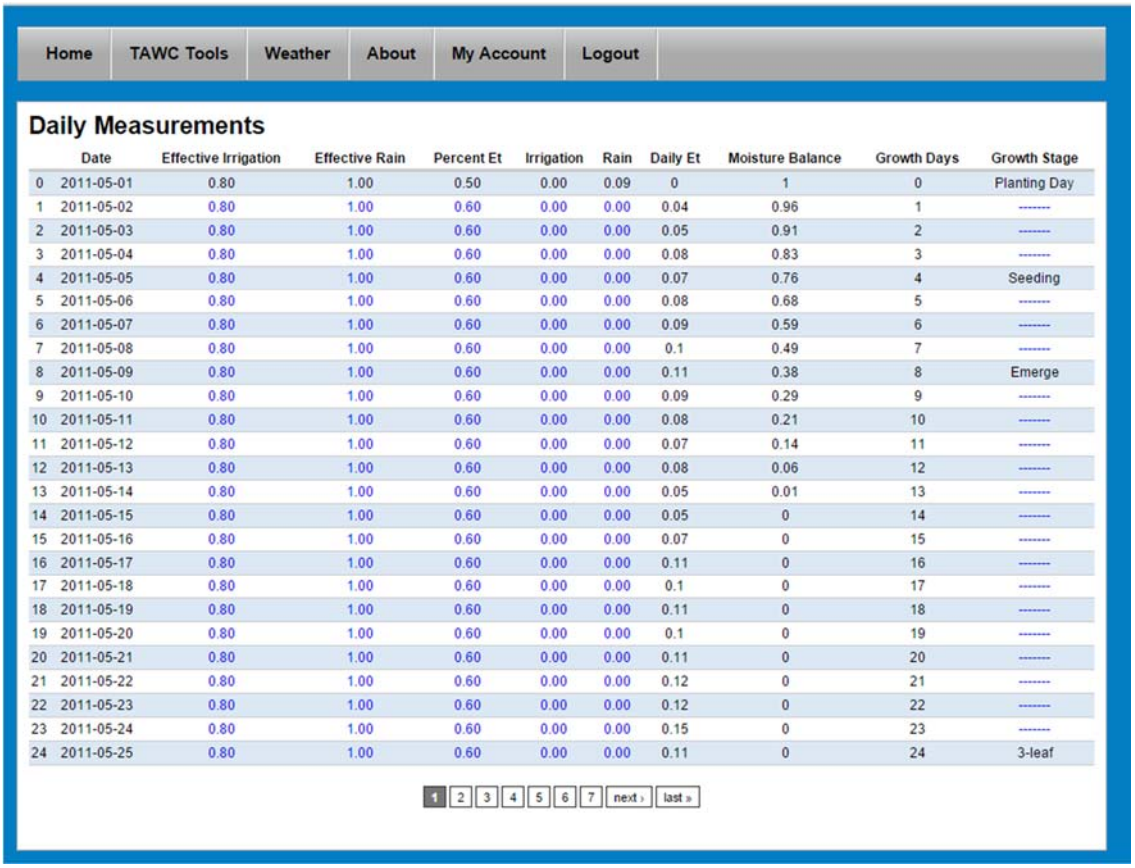
technologies available for crop requirements at various growth stages, and I've learned to manage the water so I can irrigate as effectively as possible."

7. Project Exposure and Dissemination of Results. Field days have been held in the winter and summer within the project area since 2006. The focus of the field days has been to disseminate results from the project and provide information from researchers and industry regarding irrigation and crop and livestock systems management. The summer field days have included visits to demonstration sites to illustrate specific irrigation technologies and management practices shown to be effective in increasing profitability while conserving water resources. Information has reached producers, crop consultants, extension agents, commercial technical reps, ag finance officers, and various stakeholders interested in safeguarding the water supply for agriculture. TAWC has produced 12 YouTube videos, 8 TV showings, 7 technical fact sheets, displayed a booth at 25 trade shows, and has 179 followers on Facebook and 405 followers on Twitter. "Field Talk" was broadcast on two radio stations to over 1000 listeners daily in 2013 to announce updates on crop water demand and management tips on water conservation. Annual conferences attract 70-150 attendees per year, and Field Walks attract 20-30 persons per event, of which at least half are producers or consultants. There have been 270 presentations over the nine years, not counting the 165 daily radio talks and recordings in 2013. In addition, over 2500 save-the-date cards are mailed to announce annual conferences. There have been 62 scientific publications, 70 popular publications, and 18 graduate student theses resulting from the Phase 1 TAWC efforts.

8. Irrigation Management Tools. Two decision-making tools have been developed for producers resulting from research efforts and have been provided in a web-based format to producers across the region at no charge. The tools are available on the TAWC Solutions web site at: http://www.TAWCsolutions.org/. Over 5,300 users have active accounts.



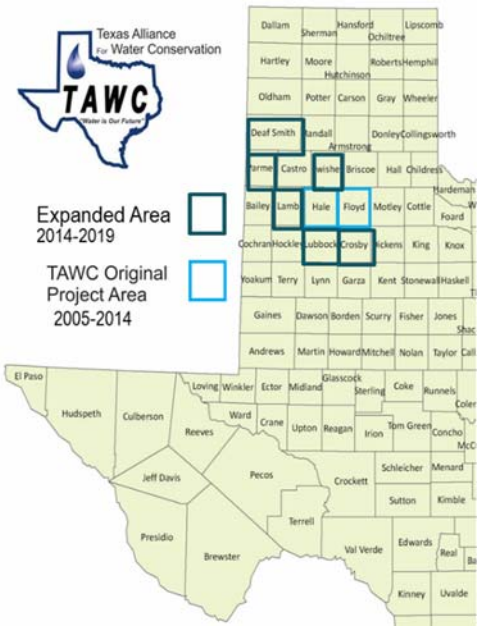
The TAWC *Resource Allocation Analyzer* and *Irrigation Scheduling* tools can be accessed by selecting the "TAWC Tools" drop-down menu on the TAWC Solutions website. For example, the *Resource Allocation Analyzer* allows producers to compare various crop options with the aim to maximize profitability given a specified level of available irrigation water. Producers input cost and return information for alternative enterprises, yield expectations, and irrigation availability to create and compare numerous scenarios. The user can choose up to five crops to analyze in a single field. The *Irrigation Scheduling* tool allows the user to track and manage crop water balance at each production site. The tool estimates actual crop water use by multiplying the calculated ET (or reference ET) by a crop coefficient that is specific to that crop species and its stage of development. The tool assists



producers in deciding when to irrigate as the crop develops by tracking soil water balance in relation to crop water demand and precipitation from the nearest West Texas Mesonet station (http://www.mesonet.ttu.edu). Producers can specify and modify various crop parameters (e.g. crop type, planting date, water applied, stage of crop development) to match their operation. Users outside the West Texas Mesonet region currently must input their own weather data. A new version of the tool using crop growth factors derived from satellite imagery will improve the accuracy of calculating ET for specific fields and provide irrigation recommendations. The new tool will be able to use weather data from other networks, assuming they grant access to their data and the data are compatible with our models to calculate water use. The rollout of the advanced tool will occur in 2015.

9. Project Expansion. The initial project success has led to additional grants facilitating the expansion of the TAWC in sites, technologies tested, and outreach. The TAWC project has increased its scope by adding additional sites across West Texas through a Conservation Innovation Grant funded by the

USDA-NRCS (Natural Resources Conservation Service). Grants from the USDA-SARE (Sustainable Agriculture Research and Education) have expanded research activity within the project. Corporate contributions to TAWC have helped to support and expand outreach and educational efforts. As stated above, Phase 2 of TAWC was funded to further expand technology evaluation and communications of improved irrigation management.



Diversity of Crop Selection over Time

Over the course of this project, the mix of acres among crop types fluctuated. Figure 1 shows the acreages devoted to cotton, corn, sorghum, perennial forages (including hay and seed crops), cattle grazing pasture, small grains, and other crops within the producer systems from 2005 to 2013. In 2005, producers in the TAWC started with relatively high acreages of cotton. A decline in cotton acreage in 2006-2008 was offset by increases in grain sorghum, forage/pasture and other crops. Cotton acreage spiked in 2011 in response to high prices, then declined by 2013. Perennial forage crops and acres devoted to cattle production declined strongly in 2011, largely as a result of severe drought and the sell-off of cattle. Recovery in cattle operations since the 2011-2012 drought had not yet occurred by 2013. Anticipated profitability has been the primary driver of species choices in annual cropping systems, but cattle operations cannot respond quickly to changing markets. See Appendix Table 10 for crop prices.

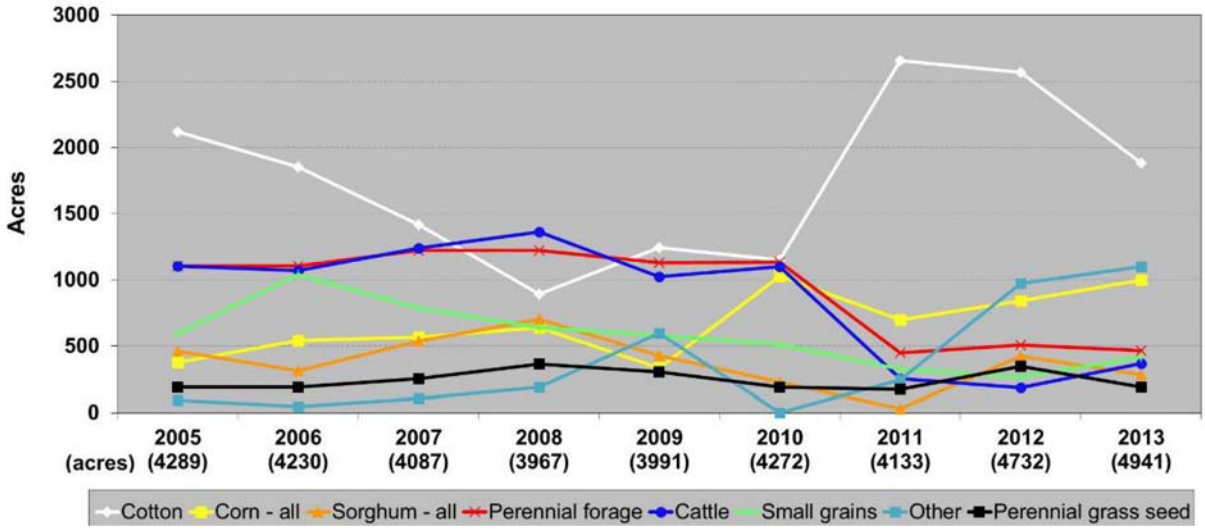


Figure 1. Acres of crops, forages, and pasture (cattle) grown on TAWC sites. Crops in the "Other" category include sunflower and peanut.

Water Availability

The High Plains Underground Water Conservation District No. 1 (District) annually measures the depth to the aquifer from observation wells and publishes the data in its annual water level report

(http://www.hpwd.org/data/). These data were used to calculate the changes in the amount of groundwater in storage and available for pumping since 2003 in the 97,900-acre area that encompassed the TAWC demonstration sites (Figures 2 and 3).

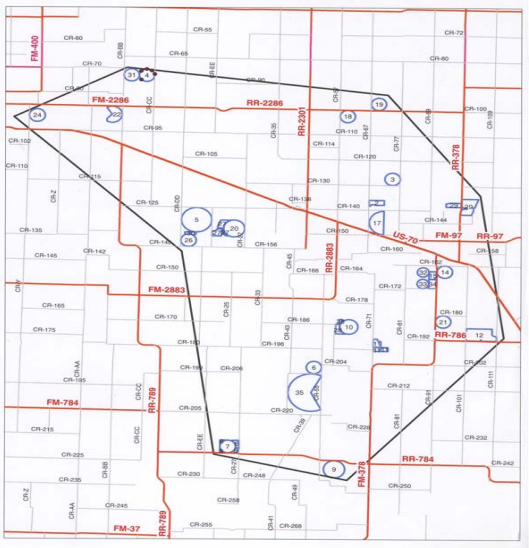


Figure 2. TAWC project area within black line for determining water in storage (97,900 acres) and 29 field sites (blue symbols), in Hale and Floyd counties.

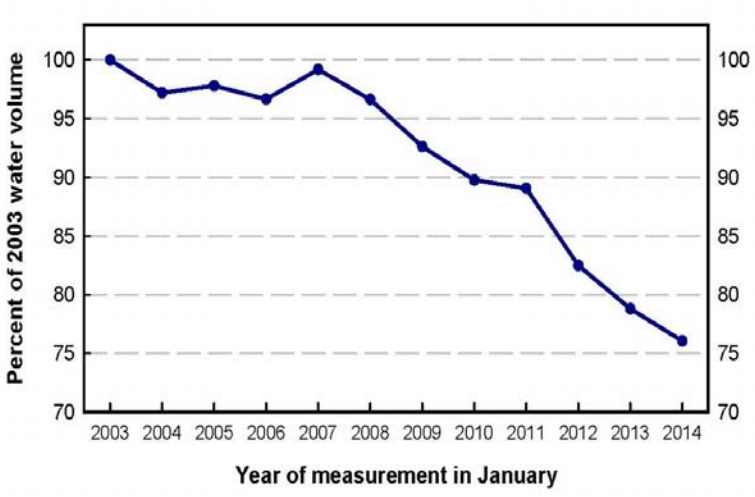


Figure 3. Change in water storage in TAWC project area from 2003 to 2014 expressed as percentage of the volume in 2003 (1,748,630 acre-feet).

The volume of water in storage declined by 24% from 1,748,630 acre-feet in January 2003 to 1,329,740 acre-feet in January 2014. The rate of decline from 2007 to 2014 averaged 3.3% per year, with the largest drop occurring during the severe drought of 2011. Water availability declined in eight years out of nine of the TAWC project years (January 2005 through end of 2013). The drought seasons of 2011 and 2012 resulted in noticeable declines in well output, which have motivated producers to seek new ways to stretch the water supply. The highest impact practice demonstrated to growers by TAWC to mitigate the drop in water supply is to curb irrigation back to 70-80% of crop water demand (or potential ET) rather than irrigating at 100+% of potential ET. Local vendors of soil moisture sensors declare that sales have picked up since the 2011 drought.

Regulatory Pumping Limits

House Bill 1763 enacted by of the 79th Texas Legislature session required Groundwater Management Areas (GMA) to establish Desired Future Conditions (DFC), which are defined as the desired quantified conditions of groundwater resources at a specified time in the future (Mace et al., 2008). The District, as part of GMA 2, adopted a DFC of 50% of the 2010 saturated thickness remaining in the aquifer in 50 years (Ground Water Management Area #2, 2010). The District will implement a new rule on January 1, 2015, limiting the annual amount of water produced from a well to 1.50 acre-feet per contiguous acre (Rule 5.3; www.hpwd.org/rules/). The TAWC irrigation management tools and outreach efforts to disseminate information assist producers in choosing water-conserving practices to meet restrictions on pumping while maintaining profitability.

Crop Water Demand

A number of factors influence crop water demand and the potential to conserve irrigation water. For example, corn requires more water to achieve an economic yield than cotton. Economic factors such as market prices and production costs impact crop selection from year to year as producers seek maximal returns and a better work load. Environmental factors such as precipitation, temperature, and humidity also influence crop water demand within a given year. Over the period 2006-2013, 137 cotton and 54 corn observations were collected. Figure 4 shows crop yield and the percentage of crop water demand provided by irrigation, precipitation, and soil **moisture for cotton and corn.**

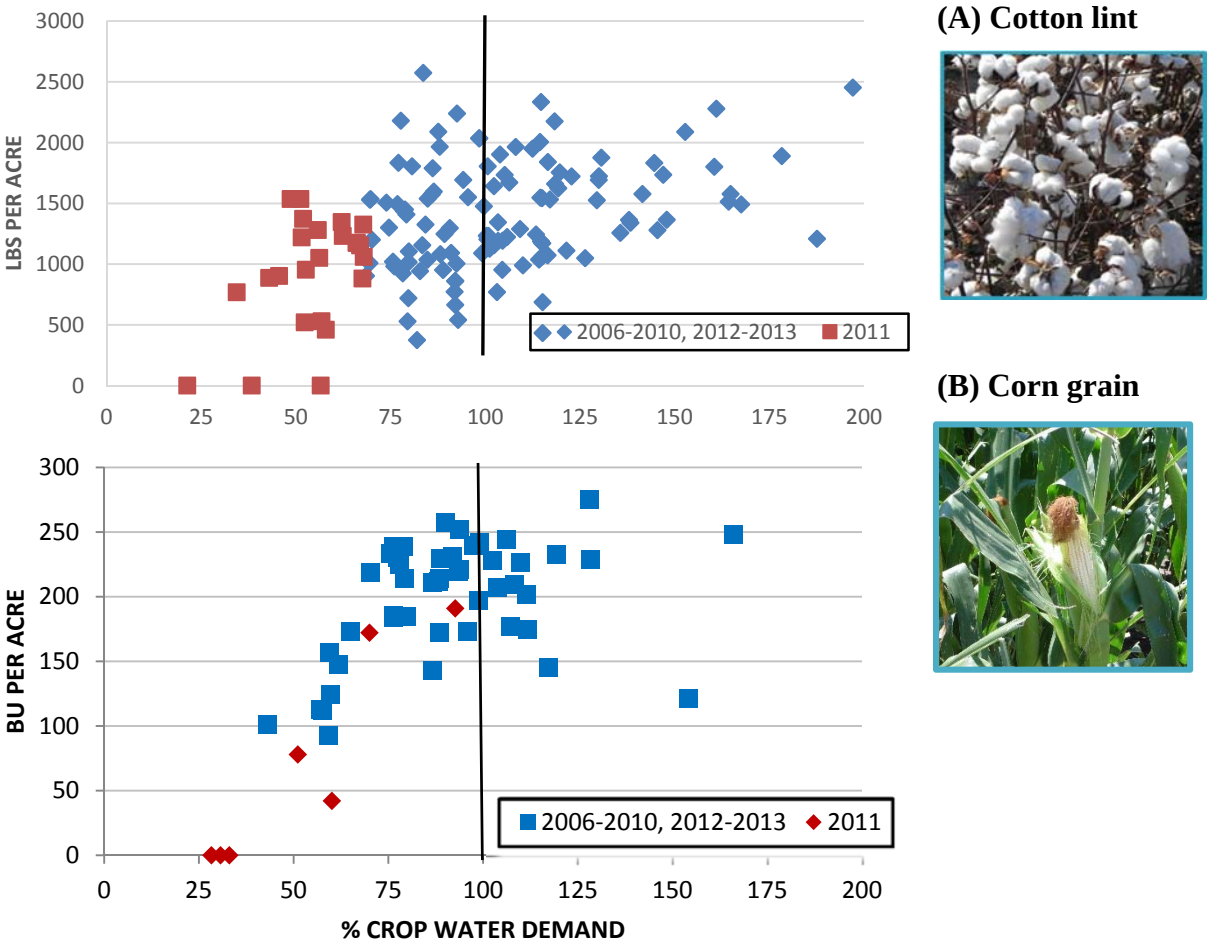


Figure 4. Relationships between cotton (A) or corn (B) yield and percentage crop water demand provided by irrigation and precipitation for 2006 to 2013. 100% equals accumulated growing-season potential evapotranspiration.

Irrigation and precipitation (using 70% effective precipitation during the growing season) were supplied at greater than 100% of crop ET needs in 45% of cotton and 26% of corn observations. Providing irrigation to meet 70% to 80% of total crop water demand based on 100% ET needs resulted in yields that were not statistically different from those of crops receiving water at or above 100% of ET. Observations where water received was greater than 100% ET often occurred in years with higher rainfall, indicating that producers who lacked tools to track crop water demands tended to over-irrigate in wet years. Irrigating above 100% ET is a form of risk

management; however, precise tracking of crop and soil water status is a water-conserving method of managing risk. Education at TAWC events stressed the opportunities for producers to use soil moisture monitoring and irrigation scheduling tools to reduce irrigation to below 100% of ET while attaining maximum crop yield. The red symbols in Figure 4 refer to data from 2011. Their low yields indicate the difficulty of providing adequate water during severe drought, and that no yield was harvested from some fields.

Estimated Water Conservation

Producers have responded to declines in water availability in various ways, for example by targeting irrigation to partial circles and leaving the rest in dryland, and by staggering peak irrigation times to different crops in the circle. Another method recommended by TAWC has been to reduce water use by not irrigating crops beyond which the crop needs to replace the water spent by evapotranspiration (ET). That reduction was termed "water conserved." We have estimated the aggregate volume of water conserved each year across the demonstration sites. The approach was to measure the level of crop ET provided by irrigation relative to total crop water demand (100% of ET). If irrigation was less than 100% of ET, then the difference was considered a potential savings in irrigation based on the assumption that irrigation in excess of 100% ET would not enhance yield. This expression implies that the difference represents discretionary conservation. The estimates of annual irrigation water conserved (acre-feet) for the project years 2006 to 2013 and average depth of irrigation applied (inches) are given in Table 1.

Table 1. Estimated annual irrigation water conserved (sum of all sites), irrigation applied on the irrigated-only fields averaged across sites, and precipitation. Data in 2005 were insufficient to calculate water conserved.

	2006	2007	2008	2009	2010	2011	2012	2013	Mean
	---------- acre-feet ----------								
Irrigation conserved†	1606	-778	130	804	416	886	919	948	616
	---------- inches ----------								
Average irrigation/site§	13.0	9.5	11.9	11.5	8.3	19.1	15.3	15.7	13.0
Annual precipitation	15.5	27.0	21.8	15.8	28.5	5.3	9.9	13.2	17.1
Seasonal precipitation#	7.7	19.8	17.0	12.1	22.7	1.0	7.5	10.2	12.2

† Values do not factor in changes in soil water content.

§ Averaged across fields within sites.

Growing season, April-September.

This method of estimating water conserved showed extreme variation in the early years (attributed to lack of adequate instrumentation), then stabilized at around 900 acre-feet in the latter years, or about 2.3 inches per year over the 4,700 acres. This estimate is very approximate because the actual amounts of irrigation applied depend on many factors that override the simple relationship between irrigation need and crop yield such as: well capacity, the amount, timing and effectiveness of rainfall; atmospheric fluctuations affecting ET; the fact that excess irrigation is sometimes used to deliver needed fertilizer; seasonal differences in soil water storage; and variations in water demands with different crop species and varieties. Note for example the

results for 2010 and 2011. The 2010 crop year was wetter than average, which reduced the amount of irrigation applied to 8.3 inches and suggested a good opportunity for water conservation. In the 2011 crop year, record drought and heat boosted the amount of irrigation applied to 19.1 inches, suggesting a poor opportunity. In fact, 2011 showed a greater volume of irrigation conserved even though more than twice as much irrigation was applied. The reason was that producers were pumping all they could while still falling way short of crop water demand, thereby inflating the estimate of "water conserved." The calculated amount of water conserved was negative in 2007, a wet year, because many producers were over-irrigating.

Plotting cotton lint yield in response to irrigation level relative to crop water demand in two high-rainfall years (2007 and 2010) provides evidence of progress among producers in reducing excessive irrigation (Figure 5). Virtually all cotton fields in 2007 (early in the TAWC project) received a total supply of water equal to or exceeding crop water demand; however, in 2010 most fields received 90% or less of crop ET demand.

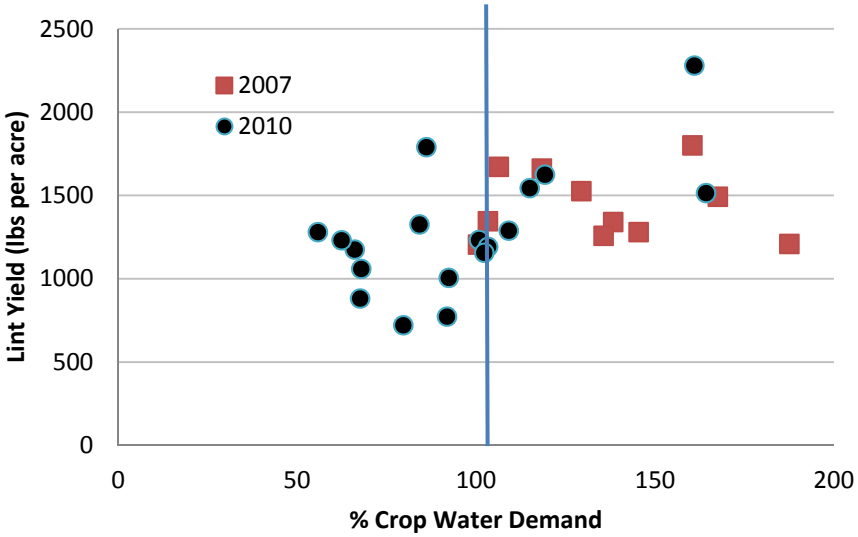


Figure 5. A comparison of the relationship between cotton yield and percentage crop water demand provided by irrigation and precipitation in two relatively high rainfall seasons, 2007 and 2010. Precipitation is calculated as 70% of that received in the growing season.

Crop Water Use Efficiency

Table 2 compares crops by irrigation efficiency (production per acre-inch of irrigation), gross margin ($ per acre), and return per acre-inch of irrigation (see Appendix for summary of assumptions and calculations of gross margin and net return). Cotton had the highest return per acre-inch of irrigation at $30.90, which was 37% higher than corn for grain. Corn had nearly double the grain yield of sorghum, and achieved a higher profit per acre. Grain sorghum used 46% less irrigation than corn. The net result was that sorghum for grain had 10% more profit per acre-inch of water than corn for grain. Even though corn production was more profitable per acre, the economic advantage of grain sorghum per unit of water used may become more

important in producers' future crop choices as water supply diminishes and becomes more expensive.

Table 2. Comparison of crops for irrigation efficiency and economic returns, averaged over 2005 to 2013.

Crop	Yield	Unit	Irrigation applied	Irrigation efficiency	Gross margin	Return on water
	Production per acre		Inches	Production per acre-inch	$/acre	$/acre-inch
Corn-Grain	9946	lbs	18.9	526	426.6	22.6
Corn-Silage	28.0	tons	23.9	1.2	423.5	17.8
Gr. Sorghum-Grain	5326	lbs	10.1	527	252.0	24.9
Gr. Sorghum-Silage	17.3	tons	9.8	1.8	228.5	23.3
Haygrazer - Hay	3.1	tons	10.8	0.3	122.9	11.4
Wheat-Grain	2430	lbs	5.1	474	88.9	17.4
Cotton-Lint	1,204	lbs	12.3	98.2	378.4	30.9

Water Use and Profitability

Patterns are emerging with respect to profitability in relation to irrigation applied. This is important because of the constant need to increase water use efficiency by the crops and prolong the groundwater supply, while maintaining profitability of agricultural production in the High Plains. To assess opportunities for achieving good profitability at relatively low water use, we constructed a graph of the distribution of gross margin per site-acre vs. inches of irrigation, including four dryland sites (Figure 6). We arbitrarily defined two sets of benchmarks:

1) maximum of 15 inches of irrigation and minimum of $300 gross margin per acre (black box in Figure 6) to represent high profitability at a currently common level of water availability;

2) maximum of 10 inches of irrigation and minimum of $100 gross margin per acre (dashed box) to represent modest profitability at a low level of water availability, which will be faced by more growers in the future.

Please note that these levels were selected only to identify whether certain sites and cropping systems consistently performed within those benchmarks and not to relate system performance to pumping restrictions nor to state a minimum amount of revenue required for economic viability.

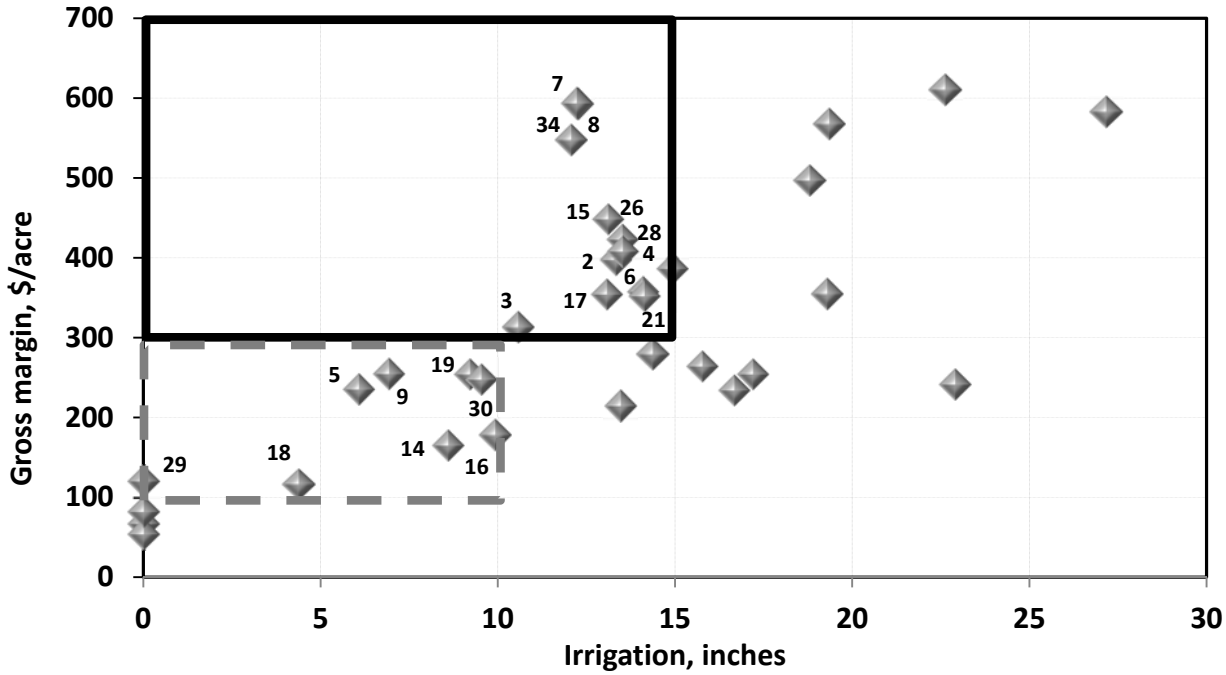


Figure 6. Gross margin per acre in relation to inches of applied irrigation averaged over 2005 to 2013. Each point represents one site. The solid black box brackets those sites which averaged 15 inches irrigation or less and $300 minimum gross margin per acre. The dashed box brackets 10 inches of irrigation or less and $100 gross margin per acre or more. Numbered sites are described in Tables 3 (black box) and 4 (dashed box).

Table 3. Description of cropping systems used in 2005-2013 and irrigation types used in 2013 for sites plotted in Figure 6 which met benchmarks of 15 or fewer inches of irrigation and $300 or more gross margin per acre (black box in Figure 6).

Site	Cropping system†	Irrigation type
2	Cotton/corn grain rotation	Subsurface drip
3	Cotton/grain sorghum	Mid elevation spray application
4	Multi-crop with cotton, alfalfa, cattle	Low energy precision application
6	Multi-crop, cotton/wheat	Low elevation spray application
7	Continuous sideoats grama grass seed	Low elevation spray application
8	Continuous sideoats grama grass seed	Subsurface drip
15	Cotton	Subsurface drip
17	Multi-crop corn, sunflower, cow-calf	Mid elevation spray application
21	Multi-crop corn, wheat, forage sorghum	Low energy precision application
26	Multi-crop rotations, corn, wheat	Low elevation spray application
28	Cotton in 2013, with corn in 2012	Subsurface drip
34	Multi-crop corn, sunflower (2 years only)	Low elevation spray application

† For a complete summary of performance of cropping systems, see the 9th Annual Report 2005-2014 at http://www.depts.ttu.edu/tawc/research_summaries.html. Annual reports are also available at http://www.twdb.texas.gov/conservation/agriculture/demonstration/texas-southern-high-plains.asp.

Twelve sites met the benchmarks of 15 or fewer inches of irrigation and $300 or more gross margin per acre, when averaged over 2005-2013 (Figure 6, Table 3). Five sites that met the $300 gross margin per acre benchmark but with average irrigation over 18 inches (points located to the right of the black box in Figure 6) were cotton/corn rotations. Inclusion of corn in multi-cropping systems can produce high gross margins, but requires more irrigation than cotton. Sites 2, 17, 21, 26, 28, and 34 all included corn in the rotations and met the double benchmarks of 15 inches and $300 per acre, indicating that inclusion of corn in the cropping system can result in high return at low water use, averaged over years.

Table 4. Description of cropping systems used in 2005-2013 and irrigation types used for sites plotted in Figure 6 which met benchmarks of 10 or fewer inches of irrigation and $100 or more gross margin per acre (dashed box in Figure 6).

Site	Cropping system	Irrigation type
5	Integrated crop-livestock	Low elevation spray application
9	Integrated crop-livestock	Mid elevation spray application
14	Multi-crop and cotton	Low elevation spray application
16	Cotton monoculture, 2 years	Low elevation spray application
18	Multi-crop (7 years), fallow (2 years)	Mid elevation spray application
19	Multi-crop and cotton	Low energy precision application
29	Multi-crop and cotton	Dryland
30	Cotton, corn, sunflower	Subsurface drip

Eight sites met the benchmarks of 10 or fewer inches of irrigation and $100 or more gross margin per acre, when averaged over 2005-2013 (Figure 6, Table 4). Sites 5 and 9 involved cattle in the system, either spatially as part of the land-use mix within years, or temporally as part of a rotation between pasture and cropland. These sites received 6 and 7 inches per year, respectively, of irrigation and rendered around $250 gross margin per acre annually. As some producers face declining well outputs, converting at least some of their cropland to high quality pastures for beef production is a viable option that can produce more than $200 per acre. Two other relatively profitable, low-irrigation sites were numbers 19 and 30, which both involved multi-species cropping and monoculture cotton, depending on the year. One dryland site (no. 30) had gross margin of $120 per acre, but other dryland sites were below $100 per acre.

Results in Figure 6 indicate that all but 6 sites irrigated at less than the 2015 regulatory pumping limit of 18 inches (1.5 acre-feet per contiguous acre per year). Those irrigating at more than 18 inches have options to reduce irrigation through a combination of precise irrigation scheduling to not exceed 70-80% of crop water demand and use of high-efficiency systems such as LEPA and subsurface drip.

The type of irrigation technology can affect crop water use efficiency. Tables 5 and 6 show average production per acre-inch of irrigation and total water for cotton and corn, respectively. Normally crop water use efficiency is greater with subsurface drip irrigation (SDI) than with other irrigation types because of precise delivery of water near the roots

with minimal evaporation losses from the soil surface, and in most years that occurred. When averaged over the 9 years, SDI did tend to have the highest lint yield, irrigation efficiency, and total-water efficiency; however, SDI efficiencies were not significantly different from Spray.

Table 5. Cotton lint production per acre-inch of irrigation and total effective water (irrigation + 70% of growing-season precipitation) by irrigation technology averaged over the period 2005 to 2013.

Irrigation technology	Number of site-years	Irrigation applied	Total water	Lint yield	Irrigation efficiency	Total water efficiency
	no.	---- inches ----		lbs/acre	---- lbs/acre-inch ----	
SDI †	32	15.9	24.5	1,642	125	69
LEPA §	37	15.4	23.7	1,415	109	61
Spray #	79	12.8	20.1	1,268	122	66
Furrow	27	14.4	23.1	1,059	96	47

† Subsurface drip irrigation
§ Low-energy precision application
# Low-elevation spray application and mid-elevation spray application

In corn, SDI and spray irrigation systems had similar yields and water use efficiencies, with Spray tending to be higher for both measurements (Table 6).

Table 6. Corn grain production per acre-inch of irrigation and total effective water (irrigation + 70% of growing-season precipitation) by irrigation technology averaged over the period 2005 to 2013.

Irrigation technology	Number of site-years	Irrigation applied	Total water	Grain yield	Irrigation efficiency	Total water efficiency
	no.	---- inches ----		lbs/acre	---- lbs/acre-inch ----	
SDI †	15	18.0	26.7	10,303	630	389
LEPA §	13	20.4	28.4	10,460	576	372
Spray #	30	20.0	28.7	10,645	615	384

† Subsurface drip irrigation
§ Low energy precision application
# Low-elevation spray application and mid-elevation spray application

In both the cotton and corn cases above, LEPA did not result in higher irrigation efficiency than spray, even though controlled experiments generally show LEPA to deliver a greater proportion of its output to the root zone (higher application efficiency) than spray. For example, a trial by Dr. Stephan Maas, one of the TAWC co-investigators, demonstrated that application efficiency of LEPA exceeded 90% versus 70-80% for LESA (spray) (see Task 5 report in TAWC 2014 annual report, p. 226-231). The data in Tables 4 and 5 are summaries across many years and locations of different commercial farm situations without holding soil type, fertilization, crop variety, or amount of water input equal across comparisons, so by chance the LEPA was associated with low-efficiency sites. A controlled comparison was done on one center-pivot field using data from 61 acres of cotton during the 2011-2013 cropping seasons (Yates and Pate, 2014). One span of the pivot was run in LESA (spray) mode and seven spans in LEPA mode. All cotton was on the same soil type and received equal amounts of water and all other inputs. The LEPA mode averaged 15% greater lint production per acre-inch of irrigation and $123 greater net return per acre than the LESA mode. The Texas A&M AgriLife Extension FARM Assistance program projected that the LEPA mode would provide positive returns over a 10-year scenario, whereas the LESA mode would likely yield negative returns.

Producer Responses and Barriers to Overcome for Wide-scale Adoption

We conducted one-on-one interviews with TAWC producers to better understand the challenges that will need to be overcome to achieve wide-scale adoption of more efficient and effective water management practices and technologies. The interviews identified common themes that emerged from views expressed, which are summarized below.

- Participating producers increased their understanding of and interest in water management technologies as a result of their involvement in the TAWC project.

- The main factors influencing producers' decisions on adopting water-conserving technologies vary from solely maximizing profits to mixtures of economic, family situations, traditional goals, or

simply water availability. This diversity requires multiple approaches for reaching producers with information on best practices.

- The most influential factor inciting change for most producers was what they heard and observed from their personal network of other producers.
- Concerning the new technologies and practices tested in the TAWC project, the producers generally saw such demonstrations as helpful but complex and, at times, overwhelming. Most often cited as a barrier to adoption were the costs related to the technology, and the personal time necessary to learn the nuances of each technology.
- Producers seeking to adopt new water management technologies were increasingly seeking help from crop consultants in handling the complexity and time constraints in keeping up with interpreting and responding to the information flow.

Impact of TAWC

TAWC activities have been much more than putting numbers in tables and graphs. TAWC cooperator and Producer Board member, Eddie Teeter, said it best when looking back over the project and the role of TAWC in helping him and others conserve their irrigation water.

"In eight years we've had excessively wet years and we've had excessively dry years and we've had one or two normal years," Teeter said. "So we've been able to put together data to help farmers know how much water it takes to produce a pound of crop. And with the water table leaving us and our water level going down, we're having less water to work with. It's very important information that we're putting together."

Another TAWC producer, Berry Evans of Kress, Texas, said, “The TAWC project has done a great job of putting usable data and resources together and in the hands of producers. With declining irrigation water, this project is going to become more and more valuable and needed in the future.”

TAWC has used early-adopter farmers like Teeter, and Evans to lend credibility to the messages of irrigation planning tools and soil water sensors to prevent over-irrigating by better timing of irrigation events and

application amounts. They have hosted field walks and spoken at producer meetings where they have amplified the TAWC messages of crop water management. Producers have shown project personnel how they have monitored their water use more precisely thanks to what they've seen demonstrated in the field. TAWC personnel have projected the improved technologies beyond Hale and Floyd Counties through educational workshops conducted in Texas and New Mexico, trade show displays, and demonstrations that include farm shows in Amarillo, Lubbock, San Antonio, cotton ginner meetings in Lubbock, and the Beltwide Cotton Conference. Presentations have also been made at meetings for bankers, crop consultants, commodity groups, and agricultural industries.

TAWC was a finalist in the Texas Environmental Excellence Awards in 2011, won the award in 2015, received the Water Conservation Advisory Council Blue Legacy Award in 2012 and won the AWRA Integrated Water Resources Management award in November, 2013. Articles about TAWC impacts have been published in various national magazines such as the National Sorghum Producer's *Sorghum Growers*, *Progressive Farmer*, and *Southwest Farm Press*. Interviews have been given with Bloomberg News (New York) and Voice of America (Washington, D.C.). In addition, the National USDA SARE program commissioned a video that was released in 2012 to highlight this overall program effort of research and demonstration and was titled "The Ogallala Aquifer of the Texas High Plains: A Race Against Time". URL: http://www.sare.org/Learning-Center/Multimedia/Videos-from-the-Field/The-Ogallala-Aquifer-of-the-Texas-High-Plains-A-Race-Against-Time .

The main points we have learned are that:

1) Producers are hungry for information and techniques that will keep them in business, now with a closer eye on fine-tuning the timing and amount of irrigation;

2) Producers respond well to what they hear from a trusted neighbor concerning the use of water-conserving techniques;

3) There is a great need for educating crop consultants in the latest technologies which they can manage for their clients because agriculture is becoming very data-intensive and increasingly complex;

4) Recent droughts and fear of the next drought are forcing many producers to diversify their farming operations and seek out low-irrigation and dryland options to manage their risk. Adoption of new technologies aimed at making crop water use more efficient is a gradual process. The technologies and information made available to producers in the South Plains serve to buffer the farm economy from the gradual decline in available groundwater and from the shock of future droughts.

Phase 2 of the TAWC project began in 2014 and will extend through the 2018 cropping season. Activities are designed to intensify delivery of technical information and expand the geographic range of demonstration sites as follows:

- Further Development of Online Tools. The team will implement a feature that calculates a more accurate crop ET using satellite imagery based on field-specific crop development. This method results in precise crop water-use coefficients that factor in actual soil conditions, and is another step toward precision water management. Additional crops choices and dryland options will be included in the *Resource Allocation Analyzer* to broaden the scope of this strategic planning tool.

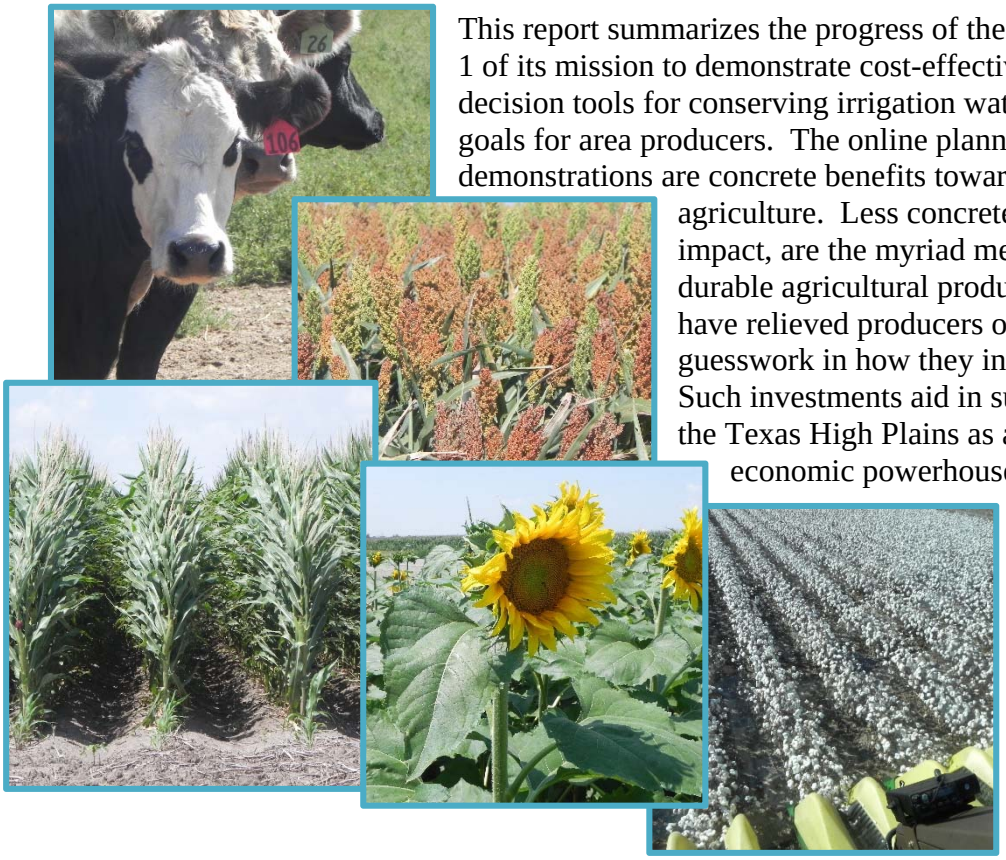
- Expansion of the TAWC Area. The TAWC project is expanding beyond the original two counties of Hale and Floyd to include Crosby, Deaf Smith, Lamb, Lubbock, Parmer, and Swisher counties. This will multiply the opportunities to demonstrate and communicate improved crop and irrigation management techniques.

- Intensified Outreach and Education. Information transfer and demonstration activities will be intensified to overcome diverse barriers to change, and to reach producers with diverse motivations for adopting conservation practices. We will add emphasis on communicating directly with individuals who influence decision-making. For example, workshops will focus on training crop consultants on the use of the enhanced web-based tools and soil-water monitoring sensors.

- Sustainable Crop and Livestock Production. TAWC is working with the National Cotton Council in a pilot project to collect data from the demonstration sites to extend the scope of the Fieldprint Calculator. The enhanced tool will include ways to analyze water conservation in crop production. This is designed to aid cotton producers in expanding markets and meeting future regulatory demands.

- Regional Economic and Social Assessments. TAWC will analyze how crop and irrigation choices made on individual farms result in broader economic and social impact when implemented on a regional scale. This effort underscores the importance of continually improving the adoption of crop water use for the health of rural communities.

Conclusion



This report summarizes the progress of the TAWC during Phase 1 of its mission to demonstrate cost-effective methods, develop decision tools for conserving irrigation water, and set reachable goals for area producers. The online planning tools and field demonstrations are concrete benefits toward water-smart agriculture. Less concrete, but of continuing impact, are the myriad messages of benefits to durable agricultural production. These benefits have relieved producers of much of the guesswork in how they invest in improvements. Such investments aid in sustaining the future of the Texas High Plains as an agricultural economic powerhouse while preserving our natural and human resources.

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APPENDIX

Economic Summaries of Results from Monitoring Producer Sites in 2005-2013.

Appendix Table 1. Summary of results from monitoring 26 producer sites during 2005 (Year 1).

System	Site no.	Acres	Irrigation type[1]	System inches	$/system acre	Gross margin per inch irrigation
Monoculture systems						
Cotton	1	61	SDI	11.7	84.02	7.19
Cotton	2	68	SDI	8.9	186.94	21.00
Cotton	14	125	CP	6.8	120.9	17.91
Cotton	16	145	CP	7.6	123.68	16.38
Cotton	21	123	CP	6.8	122.51	18.15
Cotton	11	95	Fur	9.2	4.39	0.48
Cotton	15	98	Fur	4.6	62.65	13.62
Multi-crop systems						
Cotton/grain sorghum	3	125	CP	8.3	37.79	4.66
Cotton/grain sorghum	18	120	CP	5.9	16.75	2.84
Cotton/grain sorghum	25	179	DL	0	67.58	Dryland
Cotton/forage sorghum	12	250	DL	0	36	Dryland
Cotton/pearl millet	19	120	CP	9.5	186.97	19.12
Cotton/corn	22	148	CP	15.3	166.63	10.90
Cotton/corn	24	129	CP	14.7	149.87	9.96
Cotton/corn	26	123	CP	10.5	192.44	18.34
Cotton/sunflowers	23	110	CP	5.4	270.62	47.07
Cotton/alfalfa	4	123	CP	5.5	110.44	19.06
Cotton/wheat	13	315	DL	0	47.37	Dryland
Cotton/corn silage/grass	17	223	CP	10.5	188.44	17.91
Corn/wheat/sorghum silages	20	220	CP	21.5	-48.6	-2.16
Crop-Livestock systems						
Cotton/wheat/stocker cattle	6	123	CP	11.4	162.63	9.04
Cotton/grass/stocker cattle	9	237	CP	6.5	298.14	46.17
Cotton/grass/cattle	10	175	CP	8.5	187.72	22.06
Forage/beef cow-calf	5	630	CP	1.23	125.89	93.34
Forage/grass seed	7	61	SDI	9.8	425.32	37.81
Forage/grass seed	8	130	CP	11.3	346.9	35.56

[1]SDI – Subsurface drip irrigation; CP – center pivot; Fur – furrow irrigation; DL – dryland

Appendix Table 2. Summary of results from monitoring 26 producer sites during 2006 (Year 2).

System	Site no.	Acres	Irrigation type[1]	System inches	$/system acre	$/inch water	Gross margin per inch irrigation
Monoculture systems							
Cotton	1	135	SDI	21	225.9	10.76	15.77
Cotton	2	61	SDI	19	308.71	16.25	22.56
Cotton	27	46	SDI	18	417.99	23.22	29.89
Cotton	3	123	CP	10	105.79	10.58	18.44
Cotton	6	123	CP	13.6	321.79	23.64	29.42
Cotton	14	124	CP	6.2	44.81	7.20	19.84
Cotton	16	143	CP	12.2	71.08	5.81	8.43
Cotton	11	93	Fur	16.9	88.18	5.22	9.37
Multi-crop systems							
Cotton/grain sorghum	15	96	Fur	11.2	161.89	14.51	20.78
Cotton/forage sorghum	12	284	DL	0	-13.72	Dryland	Dryland
Cotton/forage sorghum/oats	18	122	CP	12	-32.31	-2.69	3.86
Cotton/pearl millet	19	120	CP	9.8	95.28	9.77	17.83
Cotton/corn	22	149	CP	22	285.98	12.98	16.55
Cotton/corn	24	130	CP	19.4	68.17	3.51	8.34
Cotton/corn	26	123	CP	16	243.32	15.22	21.08
Cotton/corn	23	105	CP	14.8	127.39	8.59	13.90
Cotton/alfalfa/wheat/forage sorghum	4	123	CP	26.7	312.33	11.69	14.75
Cotton/wheat	13	320	DL	0	-33.56	Dryland	Dryland
Corn/triticale/ sorghum silages	20	233	CP	21.9	242.79	10.49	15.17
Crop-Livestock systems							
Cotton/stocker cattle	21	123	CP	16.4	94.94	5.79	10.22
Cotton/grass/stocker cattle	9	237	CP	10.6	63.29	6.26	13.87
Cotton/corn silage/ wheat/cattle	17	221	CP	13	242.21	14.89	20.64
Forage/beef cow-calf	5	628	CP	9.6	150.46	15.62	22.31
Forage/beef cow-calf	10	174	CP	16.1	217.71	13.52	18.40
Forage/grass seed	7	130	CP	7.8	687.36	88.69	98.83
Forage/grass seed	8	62	SDI	10.1	376.36	48.56	64.05

[1]SDI – Subsurface drip irrigation; CP – center pivot; Fur – furrow irrigation; DL – dryland

Appendix Table 3. Summary of results from monitoring 26 producer sites during 2007 (Year 3).

System	Site no.	Acres	Irrigation type[1]	System inches	$/system acre	$/inch water	Gross margin per inch irrigation
Monoculture systems							
Cotton	1	135	SDI	14.60	162.40	11.12	19.34
Cotton	2	61	SDI	12.94	511.33	39.52	48.79
Cotton	6	123	CP	10.86	605.78	55.78	63.02
Cotton	11	93	Fur	14.67	163.58	11.15	15.92
Cotton	14	124	CP	8.63	217.38	25.19	34.30
Cotton	22	149	CP	11.86	551.33	46.49	53.11
Corn	23	105	CP	10.89	325.69	29.91	37.12
Corn	24	130	CP	15.34	373.92	24.38	31.46
Perennial grass: seed and hay	7	130	CP	13.39	392.59	29.32	35.19
Perennial grass: seed and hay	8	62	SDI	15.67	292.63	18.67	26.33
Multi-crop systems							
Cotton/grain sorghum/wheat	3	123	CP	13.25	190.53	14.38	20.31
Cotton/grain sorghum	12	284	DL	0.00	265.71	Dryland	Dryland
Cotton/wheat	13	320	DL	0.00	105.79	Dryland	Dryland
Cotton/grain sorghum	15	96	Fur	10.50	191.68	18.26	24.92
Grain sorghum/wheat	18	122	CP	5.34	13.91	2.60	13.62
Cotton/pearl millet	19	121	CP	7.57	318.61	42.10	52.49
Corn/sorghum/triticale silages	20	233	CP	24.27	371.14	15.29	19.76
Corn/peren. grass: seed and hay	21	123	CP	8.35	231.60	27.75	37.16
Corn silage	27	62	SDI	13.00	194.40	14.95	24.18
Crop-Livestock systems							
Wheat: cow-calf, grain/cotton/alfalfa hay	4	123	CP	8.18	183.72	22.47	33.30
Perennial grass: cow-calf, hay	5	628	CP	3.56	193.81	54.38	72.45
Perennial grass, rye: stocker cattle/grain sorghum	9	237	CP	4.19	48.89	11.65	30.00
Perennial grass: cow-calf, hay/corn silage	10	174	CP	6.80	27.84	4.09	14.74
Perennial grass: cow-calf, seed, hay/cotton/wheat for grazing	17	221	CP	8.31	181.48	21.83	33.06
Pearl millet: seed, grazing/corn	26	123	CP	11.34	378.61	33.39	41.65

[1]SDI – Subsurface drip irrigation; CP – center pivot; Fur – furrow irrigation; DL – dryland

Appendix Table 4. Summary of results from monitoring 25 producer sites during 2008 (Year 4).

System	Site no.	Acres	Irrigation type[1]	System inches	$/system acre	$/inch water	Gross margin per inch irrigation
Monoculture Systems							
Sunflowers	2	60.9	SDI	6.89	147.83	21.46	43.23
Perennial grass: seed and hay	7	130.0	CP	9.88	295.43	29.90	40.89
Perennial grass: seed and hay	8	61.8	SDI	6.65	314.74	47.33	69.89
Cotton	14	124.2	CP	8.97	-2.12	-0.24	11.87
Corn	22	148.7	CP	24.75	720.10	29.09	34.49
Corn	24	129.8	CP	24.70	513.54	20.79	26.20
Corn	28	51.5	SDI	8.20	591.15	72.09	93.43
Multi-crop systems							
Cotton/Wheat/Grain sorghum	3	123.3	CP	14.75	53.79	3.65	11.01
Cotton/Corn	6	122.9	CP	17.35	411.02	23.68	29.94
Cotton/Grain sorghum	11	92.5	Fur	10.86	176.14	16.22	25.43
Sorghum silage/fallow wheat	12	283.9	DL	0.00	-17.89	Dryland	Dryland
Cotton/Wheat	15	95.5	Fur/SDI	11.22	132.15	11.78	21.57
Cotton/Wheat silage/Grain sorghum hay & silage	18	122.2	CP	10.67	186.42	17.47	27.64
Cotton/Seed millet	19	120.4	CP	7.01	121.40	17.33	32.83
Wheat grain/Grain sorghum grain & silage/hay	20	233.4	CP	27.61	513.56	18.60	22.54
Barley seed/forage sorghum hay/per. grass: seed & hay	21	122.7	CP	10.13	387.20	38.24	48.96
Cotton/Sunflowers	23	105.1	CP	14.93	-50.54	-3.38	4.60
Cotton/Corn grain	27	108.5	SDI	20.69	291.15	14.07	22.01
Cotton/Wheat/fallow	29	221.6	DL	0.00	34.06	Dryland	Dryland
Crop-Livestock systems							
Wheat: cow-calf, grain/cotton/alfalfa hay	4	123.1	CP	14.51	154.85	10.68	17.00
Perennial grass: cow-calf, hay	5	628	CP	4.02	107.14	26.65	49.02
Perennial grass: stocker cattle/Cotton	9	237.8	CP	7.26	11.63	1.60	16.25
Perennial grass: cow-calf, hay/Grass seed/Corn	10	173.6	CP	14.67	64.80	4.42	0.00
Perennial grass: cow-calf, seed, hay/cotton/wheat for grazing	17	220.8	CP	15.00	309.34	20.62	28.68
Pearl millet: seed, Grain sorghum/Corn: grazing, hay	26	125.2	CP	14.65	279.69	19.09	27.36

[1]SDI – Subsurface drip irrigation; CP – center pivot; Fur – furrow irrigation; DL – dryland

Appendix Table 5. Summary of results from monitoring 26 producer sites during 2009 (Year 5).

System	Site no.	Acres	Irrigation type[1]	System inches	$/system acre	$/inch water	Gross margin per inch irrigation
Monoculture Systems							
Cotton	2	60.9	SDI	10.50	-52.29	-4.98	9.31
Perennial grass: seed and hay	7	129.9	CP	15.70	597.23	38.04	44.96
Perennial grass: seed and hay	8	61.8	SDI	13.80	365.46	26.48	37.35
Cotton	15	102.8	Fur/SDI	12.96	72.15	5.57	12.39
Cotton	22	148.7	CP	14.73	56.35	3.83	11.20
Cotton	28	51.5	SDI	10.89	187.72	17.24	31.01
Sunflower	30	21.8	SDI	9.25	8.13	0.88	17.10
Multi-crop systems							
Cotton/Grain Sorghum	3	123.3	CP	5.89	158.51	26.91	45.35
Cotton/Corn	6	122.9	CP	10.43	182.14	17.52	28.49
Cotton/Rye	9	237.8	CP	3.17	-11.71	-3.69	30.52
Cotton/Grain Sorghum	11	92.5	Fur	13.24	53.67	4.05	11.60
Sorghum silage/Wheat	12	283.9	DL	0.00	-8.81	Dryland	Dryland
Wheat grain/Cotton	14	124.2	CP	10.57	37.15	3.52	13.79
Wheat grain/Cotton	18	122.2	CP	3.53	44.88	12.71	43.47
Wheat grain/Cotton	19	120.3	CP	5.26	-4.88	-0.93	19.71
Corn silage/Cotton	20	233.3	CP	23.75	552.08	23.25	28.35
Wheat grain/Hay/perennial grass	21	122.6	CP	17.75	79.79	4.50	10.61
Oats/Wheat/Sorghum – all silage	23	105.2	CP	15.67	53.80	3.43	10.36
Corn/Sunflower	24	129.7	CP	13.09	172.53	13.18	22.42
Corn/Cotton	27	108.5	SDI	23.00	218.72	9.51	16.63
Wheat grain/Cotton	29	221.6	DL	0.00	73.79	Dryland	Dryland
Crop-Livestock systems							
Wheat/haygrazer; contract grazing, grain sorghum/cotton/alfalfa hay	4	123.1	CP	9.03	119.85	13.28	25.67
Perennial grass: cow-calf, hay	5	626.4	CP	6.60	53.76	8.15	21.79
Perennial grass: contract grazing, /Cotton	10	173.6	CP	6.04	-83.25	-13.79	4.20
Perennial grass: contract grazing, /sunflower/WW-BDahl for seed and grazing	17	220.8	CP	7.09	71.37	10.07	25.39
Corn/Sunflower, contract grazing	26	125.2	CP	14.99	316.22	21.09	29.16

[1]SDI – Subsurface drip irrigation; CP – center pivot; Fur – furrow irrigation; DL – dryland

Appendix Table 6. Summary of results from monitoring 26 producer sites during 2010 (Year 6).

System	Site no.	Acres	Irrigation type[1]	System inches	$/system acre	$/inch water	Gross margin per inch irrigation
Monoculture systems							
Corn	2	60.9	SDI	14.04	107.81	7.68	22.99
Perennial grass: seed and hay	7	130	CP	2.37	460.56	194.33	253.40
Perennial grass: seed and hay	8	61.8	SDI	3.25	498.82	153.48	207.33
Cotton	15	102.8	Fur/SDI	3.98	489.46	122.85	166.77
Corn	22	148.7	CP	16.10	370.88	23.04	34.22
Corn	24	129.7	CP	17.90	271.50	15.17	25.22
Cotton	28	51.5	SDI	6.24	298.35	47.81	75.86
Corn	30	21.8	SDI	11.90	563.63	47.36	65.43
Multi-crop systems							
Cotton/Grain Sorghum/Wheat	3	123.3	CP	9.15	191.55	20.93	38.10
Alfalfa/Cotton/Wheat/Hay	4	123	CP	11.11	365.89	32.92	45.99
Cotton/Corn	6	122.8	CP	9.88	323.38	32.72	48.88
Cotton/Grain Sorghum	11	92.5	Fur	4.41	6,9,10	38.93	67.25
	12	283.9	DL	0.00	0.00	Dryland	Dryland
Wheat grain/Cotton	14	124.2	CP	4.30	73.13	17.02	49.59
Wheat grain/Cotton	18	122.2	CP	1.11	78.24	70.66	197.11
Wheat grain/Cotton	19	120.3	CP	4.31	134.55	31.21	63.69
Corn/Triticale silage/Cotton	20	233.4	CP	16.69	817.74	49.01	59.80
Cotton/Corn	21	122.6	CP	10.45	246.09	23.54	38.85
Triticale/Corn Silage	23	121.1	CP	20.70	-7.64	-0.37	8.33
Corn silage/Cotton	27	108.5	SDI	14.70	565.29	38.46	51.59
Grain sorghum/Cotton	29	221.6	DL	0.00	235.29	Dryland	Dryland
Crop-Livestock systems							
Perennial grass: cow-calf, Hay	5	628	CP	5.15	44.47	8.63	31.08
Perennial grass: contract grazing, /Cotton	9	237.8	CP	2.19	129.12	58.98	122.93
Perennial grass: contract grazing, /Corn	10	173.6	CP	12.00	140.43	25.32	57.36
Perennial grass: contract grazing, /Corn	17	220.8	CP	8.94	6.82	0.76	18.62
Wheat/Cotton/Corn, contract grazing	26	125.2	CP	10.73	416.76	38.85	53.75

[1]SDI – Subsurface drip irrigation; CP – center pivot; Fur – furrow irrigation; DL – dryland

Appendix Table 7 Summary of results from monitoring 29 producer sites during 2011 (Year 7).

System	Site No.	Acres	Irrigation Type[1]	System inches	$/system acre	$/inch water	Gross margin per inch irrigation
Monoculture systems							
Cotton	2	60.9	SDI	16.61	122.37	7.37	17.90
Cotton	3	123.3	CP/MESA	9.30	-102.89	-11.07	3.99
Perennial grass: seed and hay	7	130	CP/LESA	20.50	370.64	18.08	24.91
Perennial grass: seed and hay	8	61.8	SDI	20.04	93.50	4.67	13.40
Cotton	12	283.9	DL	0.00	230.29	Dryland	Dryland
Cotton	14	124.2	CP/MESA	17.80	-226.26	-12.71	-4.85
Cotton	19	120.3	CP/LEPA	19.90	141.92	7.13	14.17
Cotton	22	148.7	CP/LEPA	25.20	538.44	21.37	26.92
Cotton	28	51.5	SDI	18.80	319.90	17.02	26.32
Cotton	29	221.6	DL	0.00	194.89	Dryland	Dryland
Fallow	30	21.8	SDI	0.00	-215.00	Fallow	Fallow
Corn	32	70	CP/LEPA	37.00	-866.35	-23.41	-18.55
Corn	33	70	CP/LEPA	12.00	-67.05	-5.59	9.41
Multi-crop systems							
Alfalfa/Cotton/Wheat /Haygrazer	4	123	CP/LEPA	25.32	519.67	20.53	26.26
Cotton/fallow	5	487.6	CP/LESA	3.71	162.53	43.82	81.56
Cotton/Corn	6	122.8	CP/LESA	18.94	179.82	9.49	17.40
Cotton/Grain sorghum	11	92.5	Fur	27.80	-81.18	-2.92	1.58
Corn/Cotton	15	102.8	SDI	19.31	346.96	17.97	27.95
Wheat grain/Cotton	18	122.2	CP/MESA	0.93	31.02	33.35	183.89
Corn/Triticale silage/Cotton	20	233.4	CP/LEPA	52.08	250.23	4.80	8.26
Cotton/Corn	21	122.6	CP/LEPA	17.91	157.78	8.81	17.75
Triticale/Corn silage	23	121.1	CP/LESA	33.85	112.64	3.33	8.65
Corn grain/Cotton	24	129.7	CP/LESA	26.54	537.36	20.25	26.27
Corn/Cotton	26	125.2	CP/LESA	16.57	433.62	26.16	35.81
Corn silage/Cotton	27	108.5	SDI	38.20	229.80	6.02	11.17
Cotton/Seed millet	31	121	CP/LEPA	27.90	12.26	0.44	5.46
Crop-Livestock systems							
Perennial grass: contract grazing, /Cotton	9	237.8	CP/MESA	8.45	72.39	8.56	25.12
Perennial grass: contract grazing, /Cotton	10	173.6	CP/LESA	30.02	592.02	19.72	24.38
Perennial grass: contract grazing, /Cotton	17	220.8	CP/MESA	22.00	116.96	5.32	11.68

[1]SDI – Subsurface drip irrigation; CP – center pivot; Fur – furrow irrigation; DL – dryland

Appendix Table 8. Summary of results from monitoring 29 producer sites during 2012 (Year 8).

System	Site no.	Acres	Irrigation type[1]	System inches	$/system acre	$/inch water	Gross margin per inch irrigation
Monoculture systems							
Cotton	3	123.3	CP/MESA	8.40	822.71	97.93	114.60
Cotton/fallow	5	484.1	CP/LESA	10.53	-55.06	-5.23	5.71
Corn grain/fallow	6	122.7	CP/LESA	17.29	-76.28	-4.41	2.52
Perennial grass: seed and hay	7	130	CP/LESA	20.60	696.38	33.80	40.60
Perennial grass: seed and hay	8	61.8	SDI	17.30	712.46	41.18	51.30
Cotton (No data)	12	283.8	DL	0.00	0.00	Dryland	Dryland
Cotton/fallow	19	120.4	CP/LEPA	7.33	177.03	24.16	40.50
Cotton	22	148.7	CP/LEPA	19.50	918.83	47.12	54.30
Cotton	30	21.8	SDI	13.60	-53.60	-3.94	8.93
Corn grain	33	70	CP/LEPA	18.70	-298.65	-15.97	-6.34
Multi-crop systems							
Cotton/Corn grain	2	60	SDI	12.06	545.42	45.23	61.73
Alfalfa/Cotton/Wheat/ Seed sorghum	4	123	CP/LEPA	15.54	320.03	20.59	26.24
Cotton (failed)/Grain sorghum	11	92.5	Fur	12.00	463.87	38.66	49.07
Cotton/Wheat	14	124.1	CP/MESA	6.51	-99.71	-15.31	6.19
Cotton (failed)/Grain sorghum	15	101.1	SDI	27.43	591.80	21.57	27.95
Perennial grass: contract grazing, /Cotton/Corn grain	17	220.7	CP/MESA	17.40	890.46	51.18	59.23
Wheat/Cotton (No data)	18	122.2	CP/MESA	0.00	0.00	0.00	0.00
Corn/Triticale Silage/Cotton	20	233.3	CP/LEPA	29.53	609.85	20.66	26.08
Wheat/Haygrazer/ Cotton	21	122.6	CP/LEPA	19.41	542.88	27.97	35.19
Corn grain/Cotton	24	129.7	CP/LESA	19.94	788.27	39.53	47.55
Sunflowers/Cotton	26	125.1	CP/LESA	14.95	235.53	15.75	25.12
Corn silage/Cotton	27	108.4	SDI	16.98	953.77	56.17	66.40
Cotton (hail)/Corn grain	28	51.5	SDI	19.6	-138.03	-7.04	1.89
Cotton/Grain sorghum	29	221.6	DL	0.00	9.39	Dryland	Dryland
Cotton/Seed millet	31	121.9	CP/LEPA	20.36	167.05	8.21	15.08
Cotton (hail)/Corn grain	32	70	CP/LEPA	21.50	194.39	9.04	17.41
Cotton (hail)/Corn grain	34	726.6	CP/LESA	10.00	358.39	35.84	51.84
Crop-Livestock systems							
Perennial grass: contract grazing, /Cotton	9	237.8	CP/MESA	11.46	391.18	34.14	46.35
Perennial grass: contract grazing, /Cotton	10	173.6	CP/LESA	23.02	29.08	1.26	8.22

[1]SDI – Subsurface drip irrigation; CP – center pivot; Fur – furrow irrigation; DL – dryland

Appendix Table 9. Summary of results from monitoring 29 producer sites during 2013 (Year 9).

System	Site no.	Acres	Irrigation type[1]	System inches	$/system acre	$/inch water	Gross margin per inch irrigation
Monoculture systems							
Perennial grass: seed/hay	7	130	CP/LESA	10.3	403.68	39.19	52.78
Perennial grass: seed/hay	8	61.8	SDI	14.1	983.54	69.75	82.17
Cotton	11	92.5	FUR	12.0	-18.10	-1.51	8.91
Cotton – No data	12	283.8	DL	0	0.00	Dryland	Dryland
Cotton (2 in 2 out)	14	124.1	CP/LESA	7.5	371.85	49.58	58.92
Cotton	15	101.1	SDI	17.65	858.11	48.62	58.54
Fallowed	18	122.2	CP/MESA	0	0.00	0.00	0.00
Cotton (2 in 2 out)	19	120.3	CP/LEPA	12.0	199.93	16.66	22.49
Cotton	22	148.7	CP/LEPA	24.5	424.35	17.32	23.03
Cotton	28	51.4	SDI	17.5	163.36	9.33	19.33
Cotton (failed, collected ins.)	29	221.6	DL	0	3.79	Dryland	Dryland
Corn	30	21.8	SDI	13	-30.84	-2.37	14.17
Corn	32	70	CP/LEPA	20.6	196.45	9.54	18.27
Corn	33	70	CP/LEPA	26.8	188.99	7.05	13.77
Multi-crop systems							
Cotton/Corn grain	2	59.9	SDI	21.0	262.95	12.54	21.79
Cotton/Grain sorghum	3	123.3	CP/MEPA	16.2	334.56	20.59	29.21
Wheat/Millet/Cotton/Sunflower	5	484.1	CP/LESA	10.3	454.87	44.37	58.03
Wheat/Cotton	6	122.7	CP/LESA	17.0	149.62	8.78	17.00
Dahl/Corn/Sunflower	17	220.7	CP/MESA	12.2	118.60	9.76	21.27
Trit silage/Corn silage/Cotton	20	233.3	CP/LEPA	27.3	704.25	25.78	31.65
Wheat/Haygrazer/Corn	21	122.6	CP/LEPA	19.9	286.14	14.38	21.16
Corn grain/Sunflower	24	129.7	CP/LESA	17.2	392.45	22.78	32.07
Wheat/Corn	26	125.1	CP/LESA	11.9	157.18	13.20	26.62
Corn silage/Cotton	27	108.4	SDI	36.3	673.31	18.55	23.98
Cotton/Seed millet	31	121.9	CP/LEPA	20.0	469.53	23.52	30.53
Corn/Sunflower	34	726.6	CP/LESA	14.1	445.30	31.58	40.94
Grain sorghum/Corn/Cotton	35	229.3	SDI	20.0	403.82	20.22	27.70
Crop-Livestock systems							
Alfalfa/Cotton/Wheat/Seed Sorghum	4	122.9	CP/LEPA	18.3	420.87	23.05	31.01
Perennial grass: contract grazing/cotton	9	237.7	CP/MESA	8.7	277.95	31.89	47.96
Perennial grass: contract grazing/cotton	10	173.6	CP/LESA	18.5	242.86	13.14	21.80

[1]SDI – Subsurface drip irrigation; CP – center pivot; FUR – furrow irrigation; DL – dryland

Appendix Table 10. Commodity prices for 2005 through 2013.

Commodity	2005	2006	2007	2008	2009	2010	2011	2012	2013
Cotton lint ($/lb)	$0.54	$0.56	$0.58	$0.55	$0.56	$0.75	$0.90	$0.90	$0.80
Cotton seed ($/ton)	$100	$135	$155	$225	$175	$150	$340	$280	$260
Grain sorghum – Grain ($/cwt)	$3.85	$6.10	$5.96	$7.90	$6.48	$9.51	$9.75	$13.10	$8.50
Grain sorghum – Seed ($/lb)	-	-	-	-	-	-	-	$0.17	
Corn – Grain ($/bu)	$2.89	$3.00	$3.69	$5.71	$3.96	$5.64	$5.64	$6.00	$5.00
Corn – Food ($/bu)	$3.48	$3.55	$4.20	$7.02	$5.00	$4.88	$7.50	$7.50	$6.80
Barley ($/cwt)	-	-	-	-	-	-	-	$14.08	$14.08
Wheat – grain ($/bu)	$2.89	$4.28	$4.28	$7.85	$5.30	$3.71	$5.75	$6.85	$6.85
Sorghum silage ($/ton)	$20.19	$18.00	$18.00	$25.00	$24.00	$24.00	$24.00	$24.00	$24.00
Corn silage ($/ton)	$20.12	$22.50	$25.00	$25.00	$42.90	$43.50	$43.50	$43.50	$45.00
Wheat silage ($/ton)	$18.63	$22.89	$22.89	$29.80	$26.59	$26.59	$26.59	$26.59	$26.59
Oat silage ($/ton) -	$17.00	$17.00	-	$14.58	-	-	-	$14.58	$14.58
Millet seed ($/lb)	$0.17	$0.17	$0.22	$0.25	-	$0.25	$0.25	$0.25	$0.38
Sunflowers ($/lb)	$0.21	$0.21	$0.21	$0.29	$0.27	-	-	$0.39	$0.38
Alfalfa ($/ton)	$130	$150	$150	$160	$160	$185	$350	$350	$250
Hay ($/ton)	$60	$60	$60	$60	$60	-	-	$60	$60
WW-BDahl hay ($/ton)	$65	$65	$90	$90	-	$60	$200	$200	$108
Haygrazer ($/ton)	-	$110	$110	$70	$110	$65	$65	$125	$104
Sideoats seed ($/lb)	-	-	$6.52	$6.52	$3.90	$8.00	$5.70	$5.70	$9.00
Sideoats say ($/ton)	-	-	$64	$64	$70	$60	$220	$220	$60
Triticale silage ($/ton)	-	-	-	-	-	-	-	$45	$45
Triticale forage ($/ton)	-	-	-	-	-	-	-	$24	$24

Economic Assumptions Of Data Collection And Interpretation

1. Although actual depth to water in wells located among the producer sites varies, a pumping depth of 303 feet is assumed for all irrigation points. The actual depth to water influences costs and energy used to extract water but has nothing to do with the actual functions of the system to which this water is delivered. Thus, a uniform pumping depth is assumed.

2. All input costs and prices received for commodities sold are uniform and representative of the year and the region. Using an individual's actual costs for inputs would reflect the unique opportunities that an individual could have for purchasing in bulk or being unable to take advantage of such economies and would thus represent differences between individuals rather than the system. Likewise, prices received for commodities sold should represent the regional average to eliminate variation due to an individual's marketing skill.

3. Irrigation system costs are unique to the type of irrigation system. Therefore, annual fixed costs were calculated for each type of irrigation system taking into account the average cost of equipment and expected economic life.

4. Variable cost of irrigation across all systems was based on a center pivot system using electricity as the energy source. Variable costs are nearly constant across irrigation systems, according to Amosson et al. (2011)[1], so this assumption has negligible effect on the analysis. The estimated cost per acre-inch includes the cost of energy, repair and maintenance cost, and labor cost. The primary source of variation in variable cost from year to year is due to changes in the unit cost of energy and repair and maintenance costs.

5. Mechanical tillage operations for each individual site were accounted for with the cost of each field operation being based on typical custom rates for the region. Using custom rates avoids the variations among sites in the types of equipment owned and operated by individuals.

Economic Term Definitions

Gross Income – The total revenue received per acre from the sale of production

Variable Costs – Cash expenses for production inputs including interest on operating loans.

Gross Margin – Total revenue less total variable costs

Fixed Costs – Costs that do not change with a change in production. These costs are incurred regardless of whether or not there was a crop produced. These include land rent charges and investment costs for irrigation equipment.

Net Returns – Gross margin less fixed costs.

[1] Amosson, L. et al. 2011. Economics of irrigation systems. Texas A&M AgriLife Extension Service. B-6113.

Assumptions of Energy Costs, Prices, Fixed and Variable Costs

1. Irrigation costs were based on a center pivot system using electricity as the energy source.

Appendix Table 11. Electricity and irrigation cost parameters for 2005 through 2013.

Item	2005	2006	2007	2008	2009	2010	2011	2012	2013
Gallons per minute (gpm)	450	450	450	450	450	450	450	450	450
Pumping lift (feet)	260	250	252	254	256	285	290	300	303
Discharge pressure (psi)	15	15	15	15	15	15	15	15	15
Pump efficiency (%)	60	60	60	60	60	60	60	60	60
Motor efficiency (%)	88	88	88	88	88	88	88	88	88
Electricity cost per kWh	$0.085	$0.085	$0.090	$0.110	$0.140	$0.081	$0.086	$0.100	$0.140
Cost of electricity per acre-inch	$4.02	$4.26	$5.06	$6.60	$3.78	$4.42	$4.69	$5.37	$8.26
Cost of maint. & repairs per acre-inch	$2.05	$2.07	$2.13	$2.45	$3.37	$3.49	$4.15	$3.83	$3.87
Cost of labor per acre-inch	$0.75	$0.75	$0.80	$0.90	$0.90	$0.90	$0.90	$1.00	$1.10
Total cost per acre-inch	$6.82	$7.08	$7.99	$9.95	$8.05	$8.81	$9.74	$10.20	$13.23