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

Texas Alliance for Water Conservation Project Summary 2005-2012

Submitted to the

Texas Water Development Board

June 20, 2013; Revised September 5, 2013

EXECUTIVE SUMMARY

TAWC Project Summary 2005-2012

Mission The Texas Alliance for Water Conservation mission is to conserve water for future generations by collaborating to identify 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.

Report This report summarizes major accomplishments of the project, role of decision tools for conserving water, actual and potential changes in water use and water availability, estimates of irrigation water conserved, effects of the 2011 drought, potential water savings for alternate crops, producer reactions and behavior, barriers to change, and benefits of continuing the project.

Approach There were 29 demonstration sites in Hale and Floyd counties covering 4,700 acres which were monitored closely for use of irrigation water, crop water demand, crop yields, and input costs. Calculations were made of amounts of irrigation water conserved, crop water-use efficiency, net returns, and impacts of the 2011 drought on water use and economic returns.

Major Accomplishments

- Creation of a Unique Data Set: Eight years of records on field operations, management decisions, weather, irrigation, crop yields, and purchased inputs have been collected. These data allow thorough examination of water use and returns in relation to practices and climate.
- Economic Evaluations: Profitability, costs of production, and economic efficiency were evaluated through the preparation of enterprise and system budgets. Producers have benefitted from both site-specific and whole-farm financial analyses.
- Best Management Practices: Shifting to more-efficient irrigation equipment, 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.
- Irrigation Management Tools: The *Resource Allocation Analyzer* 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. These web tools are accessed at www.TAWCsolutions.org. A new technique involving satellite remote sensing with spectral crop coefficients was shown to accurately estimate crop water use. This will improve field accuracy of the *Irrigation Scheduling* tool for tracking evapotranspiration and expand the usefulness of the web-based tool.
- Outreach and Dissemination of Results: Field days and workshops varying in location and format were frequently held to share producers' experiences with new technologies aimed at conserving water. Results presented in journals and at conferences have attracted interest among producers and water-related stakeholders from Texas and beyond.
- Project Expansion: Additional grants were awarded to expand the involvement and impact of TAWC demonstrations and test sites beyond Hale and Floyd counties.

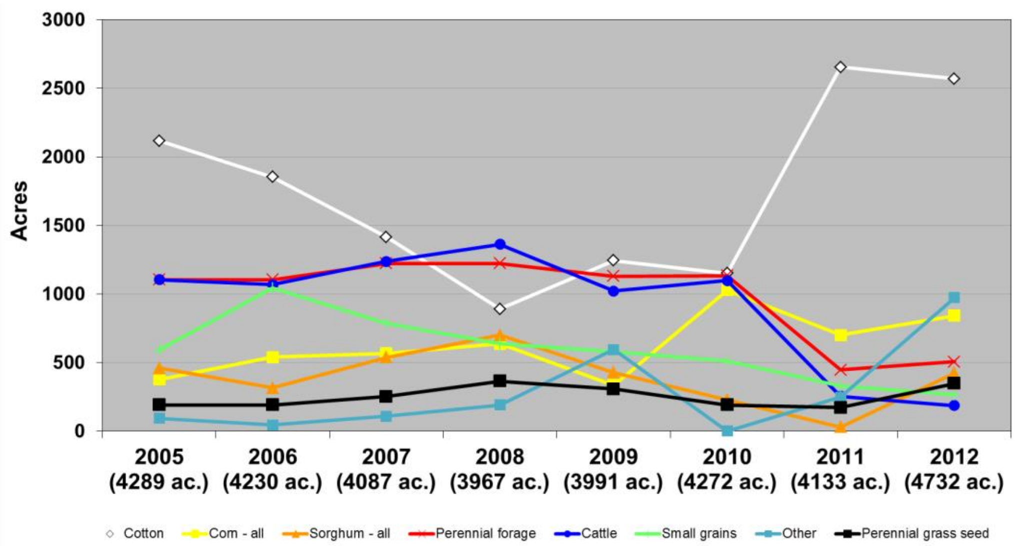
Water Availability

From the beginning of 2005 through the end of 2012, water storage in the Ogallala aquifer under Hale and Floyd counties declined by 1.82 milliot acre-feet, or 13.9%. 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 was calculated as the difference between the amount of irrigation used and the amount of irrigation necessary to meet total crop water demand at 100% of potential evapotranspiration (ET). When irrigation was less than that needed to meet 100%, that difference is considered a positive water conservation. The estimated amount of water conserved from 2006-2012 averaged 569 acre-feet per year across all sites.

The acreages of crops grown varied by year according to anticipated prices, weather conditions, and water availability for irrigation. Cotton acreage varied the most.



Crop Water Use Efficiency and Irrigation Efficiency

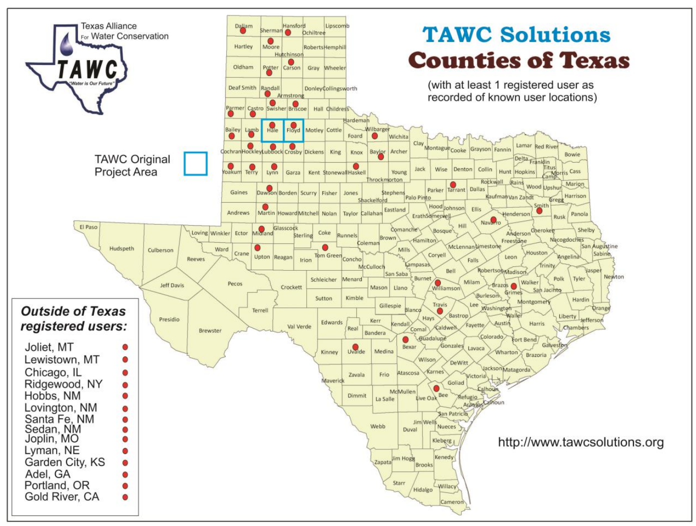
Expressed as pounds of grain yield per acre-inch of irrigation applied, grain sorghum had somewhat greater crop water use efficiency than corn (761 vs. 610). When calculated per acre-inch of irrigation plus growing-season rainfall, corn water use efficiency was modestly greater than that of grain sorghum (381 vs. 333). 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 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.

Economic Impact of 2011 Drought State-wide losses in agriculture in 2011 amounted to $7.62 billion, but is undetermined for the South Plains region. Across the TAWC sites, 30% of the total system acres were abandoned or fallowed, and crop yields per harvested acre were down from previous years. The percentage lost by crop was 30%, 45%, and 69% for cotton, corn, and wheat, respectively. The amount of irrigation applied to the primary crops was 74% greater than the average of previous years. Crop insurance indemnities were crucial in maintaining producer income. High cotton lint prices kept gross margins fairly stable, but corn margins were much reduced. Producers replaced more corn acres with grain sorghum in 2012 to save on irrigation.

What More Can Be Achieved?

- Expand the number of producer demonstration sites beyond Hale and Floyd counties so that producer-collaborators can have a direct influence over a wider region.
- Incorporate the use of the Fieldprint Calculator from the Keystone Alliance for Sustainable Agriculture to measure energy and carbon footprints, and add metrics for a water footprint feature. Documentation of water-saving practices could increase product marketability.
- Measure the economic benefits of sustaining long term water use from the aquifer beyond the farm gate and on to the municipalities and industries. Demonstration of economic impacts illustrates TAWC as a model for use across Texas and other semi-arid regions.
- Enhance the web-based tools (*Resource Allocation Analyzer* and *Irrigation Scheduling*), to achieve higher field-level precision and to enable wider applicability and use with added crops and dryland options. See Figure below for current impact.

Map at right shows locations where at least one person has registered to use the TAWC web tools (total of 417). Further tool enhancement would greatly extend the precision, commodity applications, ease of operation, and geographic usefulness of these tools.



Producer Responses and Barriers to Overcome for Wide-Scale Adoption

- The project increased farmer understanding of water availability and improved irrigation management practices by their own monitoring of soil probes, water meters and crop yield.
- Farmers can be segmented by their different approaches to using TAWC data. Adopting water-conservation practices necessitates multiple strategies for encouraging change.
- Understanding personal networks among the farmers and their willingness to adapt is crucial to increasing adoption of water conservation strategies and technologies.
- High cost of installing new technology and equipment and limited time to learn their operations are major barriers to adopting new, water-conserving technologies.
- Incomplete knowledge by crop consultants of new irrigation technologies slows adoption.
- Negative perception exists that involvement in TAWC promotes stricter water restriction policies.

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Texas Alliance for Water Conservation Project Summary 2005-2012

Introduction

The Texas Alliance for Water Conservation (TAWC) has worked directly with producers in Hale and Floyd counties in the Southern High Plains since 2005. Demonstrations of profitable farming systems that incorporate technologies, genetics, and management practices are working to conserve the region's most precious natural resource—water. To achieve this outcome, there are currently 29 demonstration sites covering over 4,700 acres representing monoculture, multi-crop, and integrated crop-livestock systems that also incorporate the full spectrum of irrigation systems including 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.

This summary report is based on previously reported results of the demonstration project in Hale and Floyd counties from 2005 to 2012 (some analyses through 2011). Outlined in this report are the major accomplishments of the project, changes in water availability due to declining aquifer levels, estimates of irrigation water conserved, producer reactions to multi-year catastrophic droughts, potential water savings for alternate crops, and the benefits of continuing the project.

Major Accomplishments of TAWC Project

1. Establishment of an Integrated Water Management Project. This project is a unique mix of field verification, education, and communication activities that are directed by the end user—the producer. 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.

2. Creation of a Comprehensive Data Set: A wide range of observations and field records has been collected from the TAWC sites from 2005 through 2012. These observations include crop yields, irrigation application rates, precipitation received, soil moisture, and crop water demand based on evapotranspiration (ET) estimates. In addition, data for cultivation practices, varieties, fertilizer applications, and chemical applications have also been collected. These observations have been compiled into a unique dataset that encompass all aspects of farm level management.

3. Economic Evaluation. Profitability, costs of production, and economic efficiency have been evaluated through the preparation of enterprise and system budgets. These budgets have been 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.

4. Best Management Practices. Best management practices relating 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 (LESA and MESA) have gradually been replaced by modes that cause less evaporative losses (LEPA and SDI), resulting in a greater proportion of the pumped water reaching the crops' roots. Crops irrigated under LEPA mode had greater crop yields and profits per acre. For example on one site in 2011, cotton yielded 1,001 lbs/acre using LEPA and 879 lbs/acre using LESA, indicating 122 lbs greater yield and $103.70 greater profit per acre. Millet produced under LEPA made 1,950 lbs/acre and 1,721 lbs/acre using LESA, resulting in 230 lbs more yield and $69.00 more profit per acre. In 2012, cotton produced with LEPA yielded 1,057 lbs/acre compared to 896 lbs/acre using LESA, indicating 161 lbs more yield and $108 greater profit per acre. In all these examples, the paired comparisons were made in the same center-pivot field and received the same amount of water. This suggests that shifting from spray modes will result in greater efficiency of water use.

TAWC data from the AquaSpy™ capacitance probes has shown that LEPA leaves greater subsoil moisture availability and dries out slower than spray mode. Figure 1 shows that the rate of soil water depletion between cotton bloom and maturity was slower with LEPA than with the spray mode when comparing two adjacent cotton fields receiving the same amount of water.

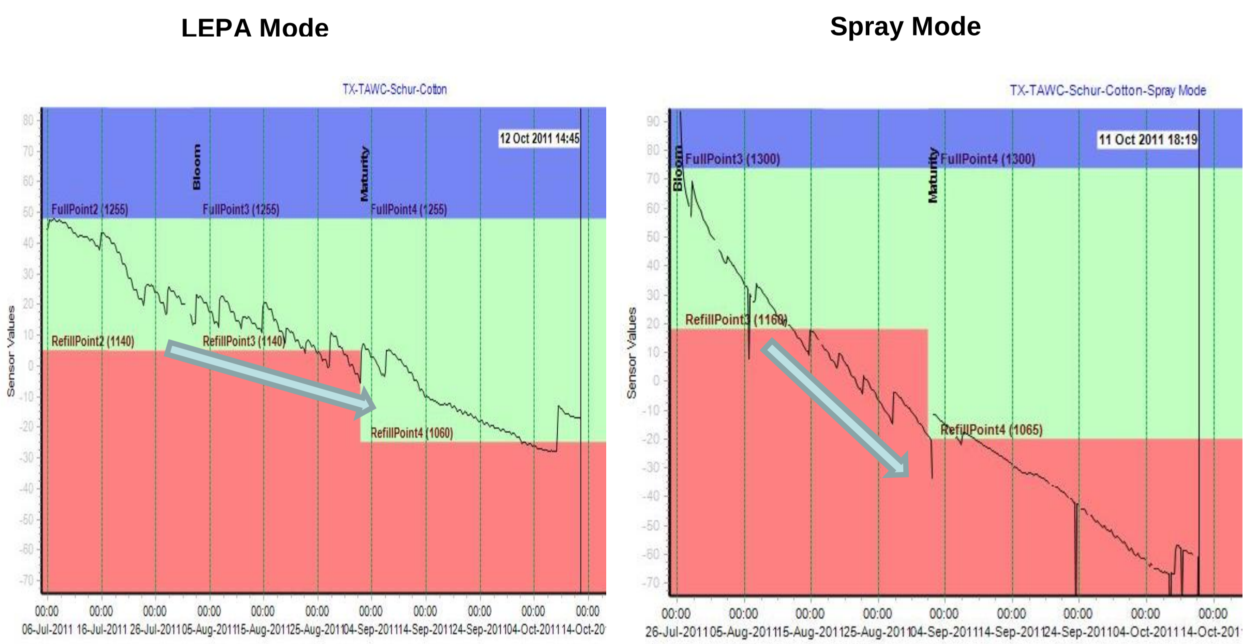

Figure 1. Comparison of LEPA and spray modes of irrigation on cotton in 2011. The x-axis denotes time during the growing season, and the y-axis denotes an index of soil water content using AquaSpy™ sensors, averaged over a 48-inch soil profile. The arrows track the rate of soil water depletion.

Another best management practice is to slow down the rate of pivot rotation to allow deeper water penetration into the plant root zone. Figure 2 shows soil water content trends at different soil depths using AquaSpy™ capacitance probes when subjected to different irrigation schedules. At relatively fast pivot rotation rates of 5 and 4-days per cycle, irrigation only reached a depth of 8 inches. Then when pivot rotation was slowed to a 7-days per cycle, applied water reached a depth of 16 inches, therefore allowing greater delivery of water to rooting zone.

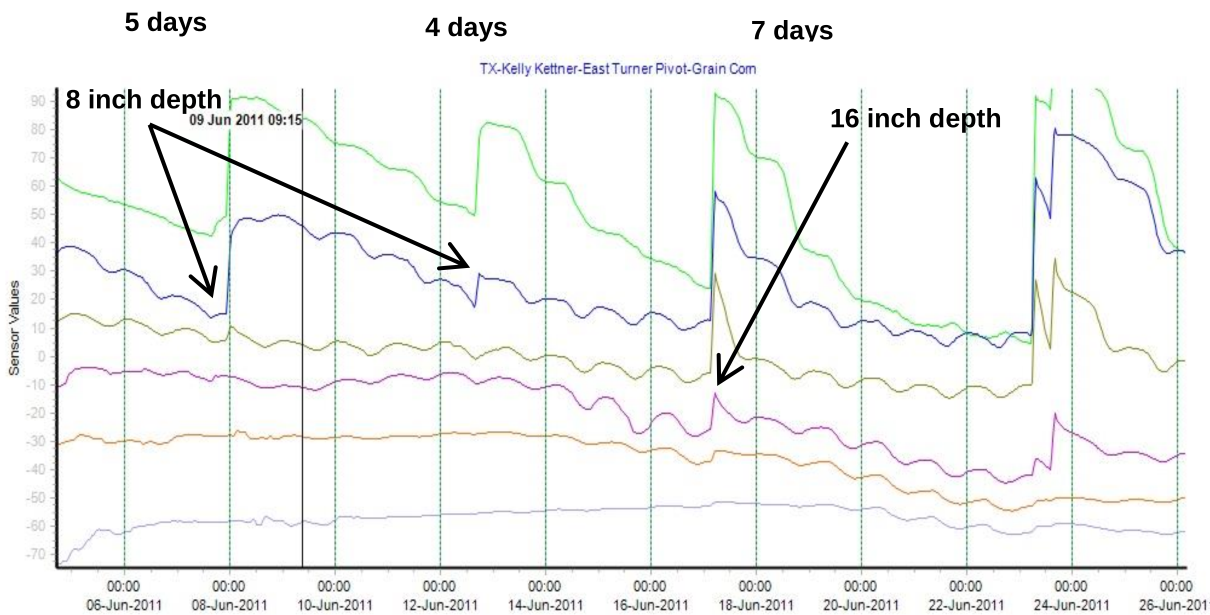

Figure 2. Depth of penetration of irrigation water with 5, 4, and 7-days per pivot cycle, showing how slowing the pivot rotation allowed deeper infiltration of water to the deeper root zone. Y-axis scale is the sensor values for the AquaSpy™ probe.

A third best-management practice is the fine-tuning of irrigation scheduling to match the replacement of evapotranspiration (ET). More producers are monitoring ET frequently, giving them a quantitative 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 initially included in the project: Smart Field and Smart Crop (2008); Net Irrigate (2008); AquaSpy (2010); Eco1st (2010); John Deere Field Connect (2012); and PivoTrac (2012). The TAWC provides an unbiased evaluation of these tools within overall crop management systems; identifying the best management practices for irrigation management. The results have illustrated the effectiveness,

efficiency, 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 professed an increased awareness of water use and conservation practices through their use of irrigation-system and soil-moisture monitoring technologies demonstrated on the TAWC sites. Information gathered and provided to producers from the project includes analysis of water use efficiency (Table 5) and amounts of irrigation water applied (Table 9). Producer Ed Teeter of Lockney stated, "I've benefitted from installing the soil moisture monitors 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.

Results of the TAWC demonstration project have also been disseminated beyond project borders through educational workshops conducted in Texas and New Mexico, trade show displays, and demonstrations that include farm shows in Amarillo, Lubbock, cotton ginner meetings in Lubbock, and the Beltwide Cotton Conference in San Antonio. Presentations have also been made at related stakeholder meetings including bankers, crop consultants and industry-related corporate meetings. Research presentations made at water conferences such as University Council on Water Resources (UCOWR) and the American Water Resources Association (AWRA). In fact, TAWC was a finalist in the Texas Environmental Excellence Awards in 2011, received the Water Conservation Advisory Council Blue Legacy Award in 2012 and will be presented with the AWRA Integrated Water Resources Management award in November, 2013. Presentations have also been made at conferences on agricultural communications, agricultural economics, agricultural education, and crop and soil science. Articles have been published in the magazines *Hay and Forage Grower*, *Crop, Soil & Agronomy News*, and the National Sorghum Producer's *Sorghum Growers*. 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 .

8. Irrigation Management Tools. Two decision-making tools have been developed for producers from project research results 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/.

Figure 3. Screen shot of the TAWC Solutions website with drop-down menu showing the choice of decision-aid tools.

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 (Figure 3). Figure 4 displays the *Resource Allocation Analyzer*. The *Irrigation Scheduling* tool (Figure 5) allows the user to track and manage crop water balance at each production site. Figure 5 displays the criteria for setting up a new crop water balance. The TAWC has also provided users with a basic irrigation calculator and a contiguous acre-inch calculator used for water resource allocation (not shown).

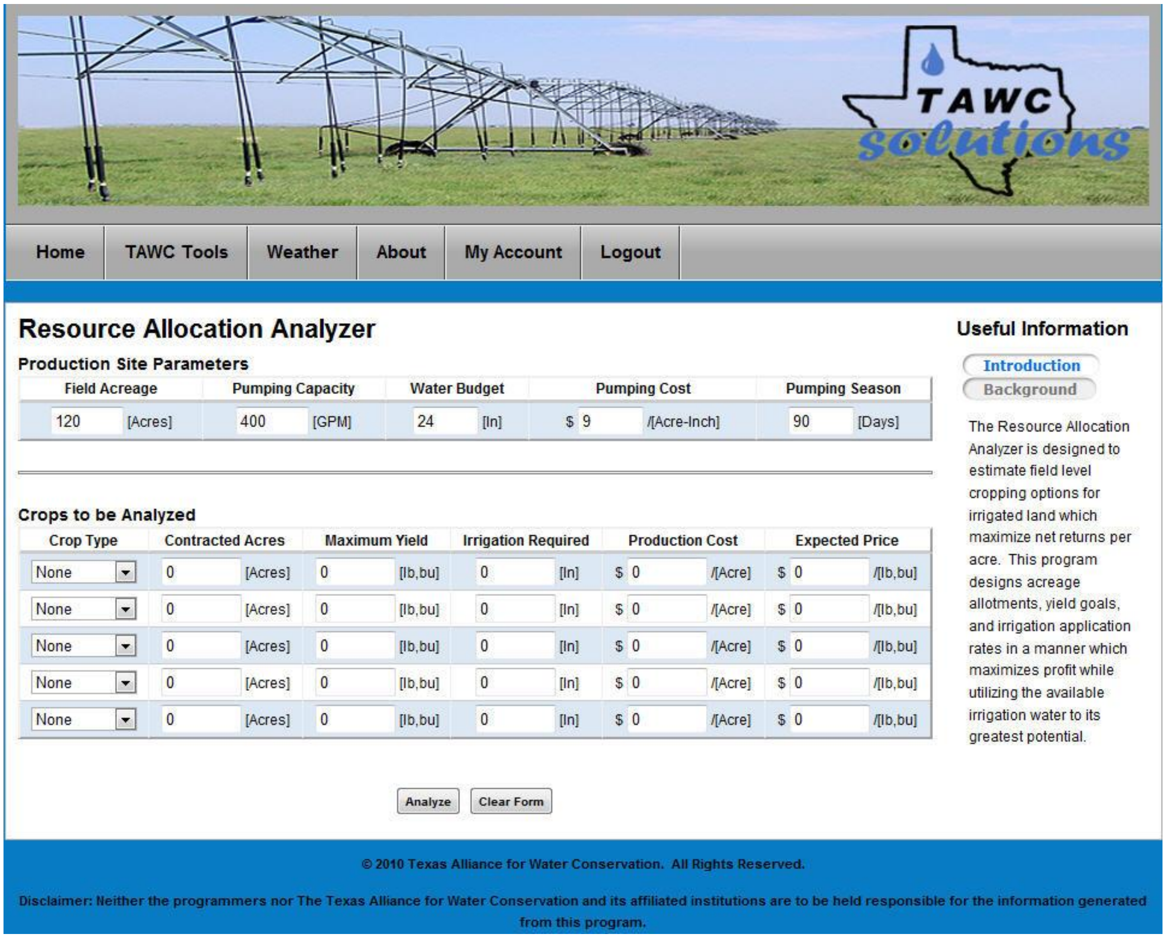

Figure 4. Screen shot of TAWC Resource Allocation Analyzer.

The *Resource Allocation Analyzer* allows producers to evaluate their crop production alternatives with the objective to maximize profitability given a specified level of available irrigation water. Producers provide cost and return information for alternative enterprises in the input screen (Figure 4), yield expectations, and irrigation availability to create and evaluate numerous scenarios. The user can choose 1 to 5 crops to analyze.

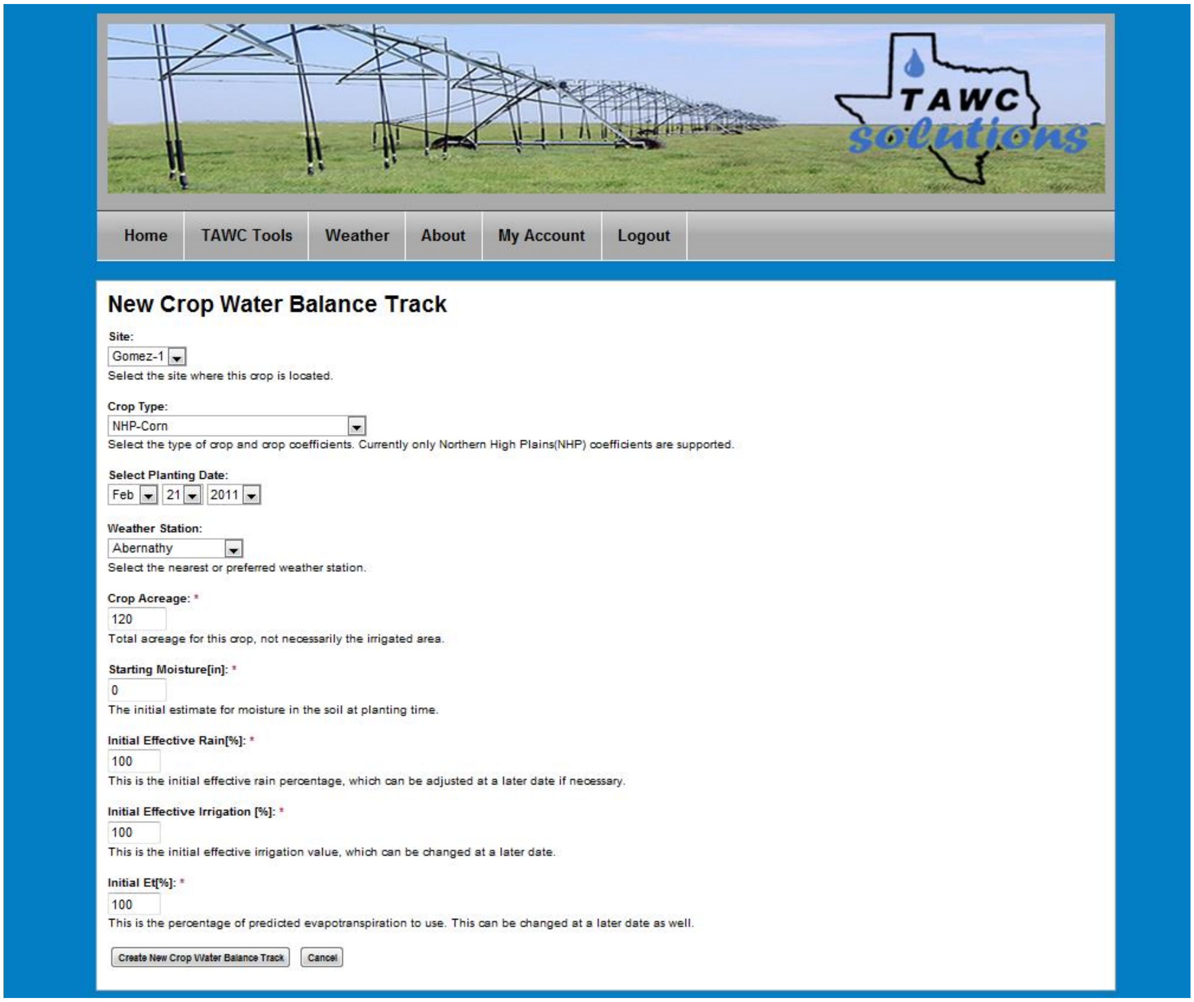

Figure 5. Screen shot of TAWC Irrigation Scheduling tool.

The *Irrigation Scheduling* 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, stage of crop development) to match their operation. Users outside the West Texas Mesonet region currently must input their own weather data. A future 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.

As of May 6, 2013, 417 users have registered online to access the tools. The distribution of registered users within Texas by county is shown in Figure 6. The wide geographic range of registered users indicates a high level of interest in this program.

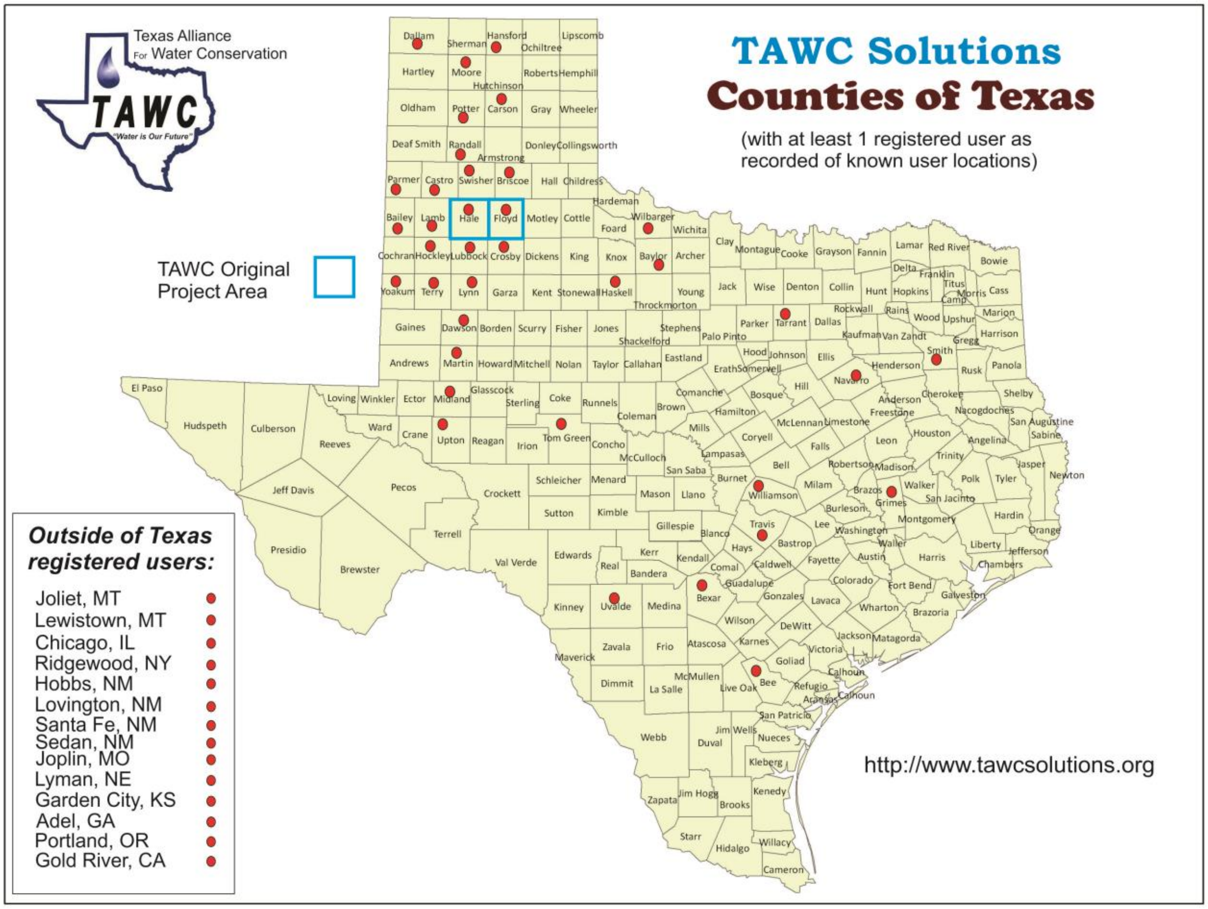

Figure 6. Counties in Texas with at least one registered user of the TAWC Solutions irrigation management tools.

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. The Texas State Legislature has approved continuation of the TAWC project for an additional six years through 2019.

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 High Plains Underground Water Conservation District No. 1 (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). To achieve the 50/50 management goal the

District adopted rules that restrict annual pumping to 1.75 acre-feet per contiguous acre for 2012 and 2013; 1.5 acre-feet for 2014 and 2015; and 1.25 acre-feet starting in 2016.

Producers in the region will be faced with declining water availability in the future, whether from depletion of the aquifer or from regulatory pumping limits. The irrigation management tools and outreach efforts to disseminate information through TAWC can assist producers in adopting water conserving management practices to meet the challenge of declining water availability.

Water Availability

The High Plains Underground Water Conservation District annually measures the saturated thickness of the aquifer from observation wells throughout the District. These data are used to estimate the available water in the aquifer and changes over time. The District publishes county level aquifer data on an annual basis. Figure 7 represents the TAWC project area with identification of the demonstration sites. Water in storage was calculated for this area (97,900 acres) in addition to the county level calculations.

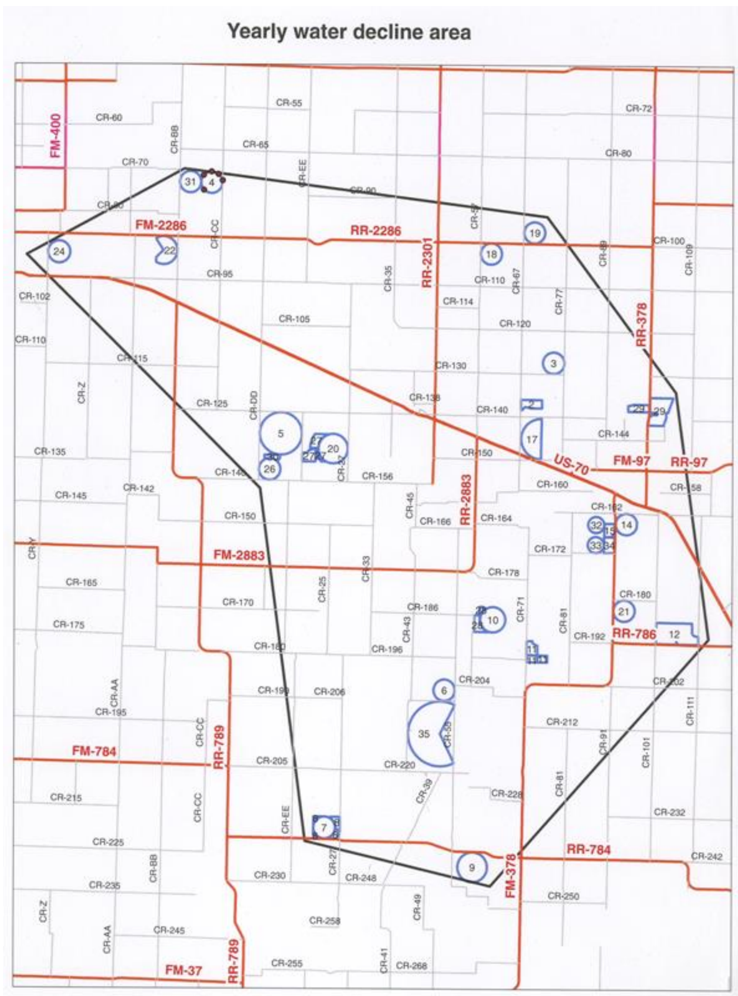

Figure 7. TAWC project area for determining water in storage (area encompassed within solid black line; 97,900 total acres) and cooperator demonstration sites (areas in blue symbols).

Table 1 shows the estimated water in storage in the Ogallala aquifer from January 2005 to January 2013 for Hale and Floyd counties and the TAWC project area. Table 2 shows the year-to-year percentage change of water in storage from 2005 to 2013 in Hale and Floyd counties and the TAWC project area.

Table 1. Water in storage† in the Ogallala aquifer for Hale and Floyd counties and in the TAWC project area estimated each year on January 1 of 2005 to 2013.

Area	2005	2006	2007	2008	2009	2010	2011	2012	2013	Total change
	------------------------------- million acre-feet --------------------------------									
Hale County	6.67	6.59	6.43	6.39	6.18	6.05	6.00	5.73	5.49	-1.18
Floyd County	6.39	6.36	6.25	6.31	6.26	6.14	6.15	5.90	5.75	-0.65
TAWC area	1.73	1.72	1.69	1.69	1.67	1.63	1.62	1.55	1.50	-0.23

Table 2. Percentage annual change in water in storage from January 1 of the year previous to that shown, through January 1, 2013.

Area	2006	2007	2008	2009	2010	2011	2012	2013	Total change
	-------------------------------- % of previous year --------------------------------								
Hale County	-1.17	-2.47	-0.59	-3.20	-2.12	-0.96	-4.40	-4.20	-17.63
Floyd County	-0.52	-1.61	0.89	-0.80	-1.97	-0.14	-3.95	-2.66	-10.10
TAWC area	-0.59	-2.02	0.04	-0.95	-2.54	-0.53	-4.32	-3.23	-13.37

The droughts of 2011 and 2012 accelerated the decline in water storage. The total decline in water storage for both counties over 8 years was estimated at 1.82 million acre-feet (-13.94% change). Of this 8-year change, half of the decline (0.91 million acre-feet) occurred in the last 2 years (-0.52 million acre-feet over 2011 to 2012, and -0.39 over 2012 to 2013). The percentage change in the TAWC area (-13.37%, or 232,000 acre-feet) was near the total change of the two counties.

<u>Estimated Water Conservation</u>

Potential water savings in irrigation is difficult to determine because of the many factors that influence crop water demand and therefore the amount of irrigation applied. The general approach to estimating water savings within the project has been to measure the level of crop ET provided by irrigation relative to total crop water demand (100% of ET). If irrigation is less than 100% of ET, then the difference is considered a potential savings in irrigation based on the assumption that irrigation in excess of 100% ET would not enhance yield.

Estimated annual irrigation water conserved (acre-feet) for the project years 2006 to 2012 and average depth of irrigation applied (inches) are given in Table 3.

Table 3. Estimated annual irrigation water conserved and irrigation applied on the irrigated-only TAWC sites.

	2006	2007	2008	2009	2010	2011	2012	Mean
	------------------------------- acre-feet -----------------------------							
Irrigation conserved†	1606	-778	130	804	416	886	919	569
	------------------------------- inches -------------------------------							
Average irrigation/site§	14.0	9.8	12.5	11.8	8.1	20.9	13.9	13.0

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

§ Averaged across fields within sites, then averaged across sites.

This method of measuring water conservation showed extreme variation over time, with no clear trend toward increased irrigation conserved. There are inherent limitations to this method because the actual amounts of irrigation applied depend on many factors that override the simple relationship between irrigation need and crop water demand (defined as 100% ET): the amount, timing and effectiveness of rainfall; temperature; wind speed; humidity; the fact that excess irrigation is sometimes used to deliver fertilizer; season differences in soil water storage; and variations in water demands per crop species. Note for example the results for 2010 and 2011. The 2010 crop year had significantly above-average precipitation, which reduced the level of irrigation applied (average of 8 inches). In the 2011 crop year precipitation was significantly below average, which increased the level of irrigation applied to 19 inches. The record drought and heat in 2011 led to high ET and caused crop water demand to increase substantially. Ironically, 2011 showed a greater level of irrigation conserved even though more than twice as much irrigation was applied. The year-to-year variation in environmental conditions and the irregular ability of the field sites to meet irrigation needs necessitate additional metrics to evaluate water savings. The final report covering 2005-2013 will include a more thorough analysis of the estimates of irrigation conserved.

Crop Water Demand

A number of factors influence crop water demand and the potential to conserve irrigation water. Crop selection influences crop water demand; for example, corn requires more water to achieve an economic yield than cotton. Economic factors such as market and global production factors generally impact crop selection from year to year as one crop may be more profitable than another. Environmental factors such as precipitation, temperature, and humidity also influence crop water demand within a given year. Precipitation is an important factor in crop production in the Texas High Plains, particularly during the growing season. Table 4 gives the average precipitation received at the project sites annually and for the growing season (April through September). Over the period of the project there has been a wide range of precipitation received.

Table 4. Precipitation received at project sites 2005 to 2012.

Precipitation	2005	2006	2007	2008	2009	2010	2011	2012	Mean
	---------------------------------- inches ----------------------------------								
Annual	15.0	15.5	27.2	21.6	15.2	28.9	5.3	10.0	17.3
Growing season †	14.9	10.7	19.8	21.5	12.7	24.0	3.0	8.3	14.4

†April through September only. 102-year mean is 18.5 in. annual and 13.2 in. April-Sept.

While the TAWC has demonstrated several enterprise options for producers using irrigation, cotton and corn are the predominant irrigated crops. Over the period 2006-2011, 96 cotton and 38 corn observations were collected. Figures 8 and 9 show the relationship between crop yield and the percentage of crop water demand provided by irrigation, precipitation, and soil moisture for cotton and corn, respectively. Irrigation and precipitation (using 70% effective precipitation during the growing season) were supplied at greater than 100% of crop ET needs in 40% of cotton and 29% of corn observations. These graphs indicate that providing enough irrigation to meet 70% to 90% of crop ET needs for cotton and corn production resulted in yields that were no 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 lacking tools to track crop water demands tended to over-irrigate in wet years. In summary, there are opportunities for producers to use irrigation management tools to reduce irrigation while attaining maximum crop yield.

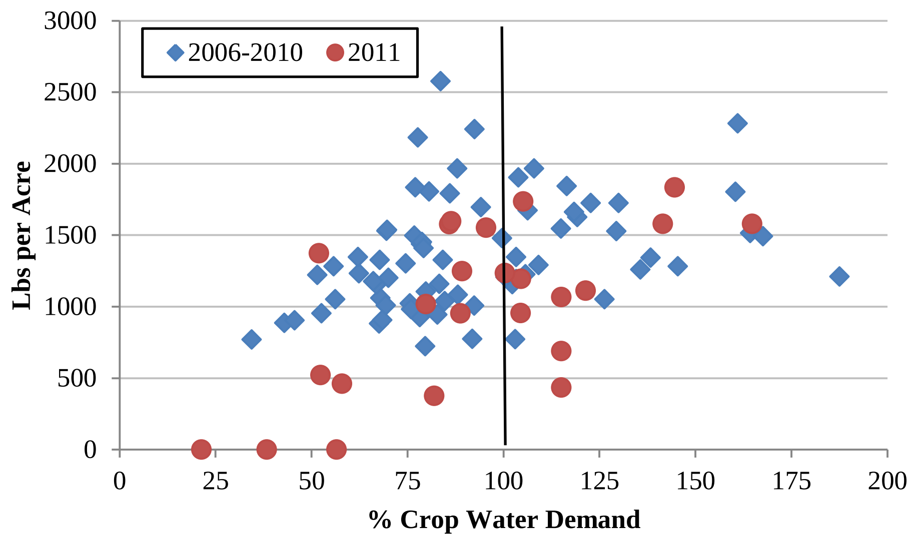

Figure 8. The relationship between cotton yield and percentage crop water demand provided by irrigation and precipitation for 2006 to 2011. Precipitation is calculated as 70% of that received in the growing season.

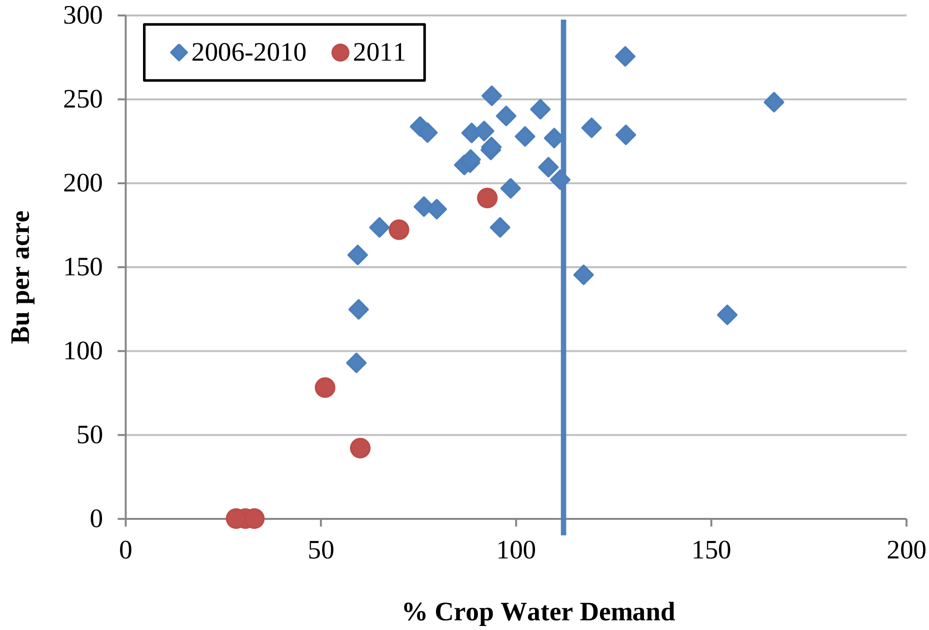

Figure 9. The relationship between corn yield and percentage crop water demand provided by irrigation and precipitation for 2006 to 2011. Precipitation is calculated as 70% of that received in the growing season.

The 2011 crop year was an extreme drought year with record high temperatures and a record low amount of rainfall. Observations for 2011 are identified in Figures 8 and 9 to illustrate the effects of the drought on crop water management. There were three fields of cotton and three fields of corn that were abandoned (zero yields) in 2011 due to the inability to meet crop water demands sufficiently to merit the harvest costs. Additionally, there were two fields of corn and one field of cotton that were harvested but qualified for crop insurance payout as a result of low yields.

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 10). 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.

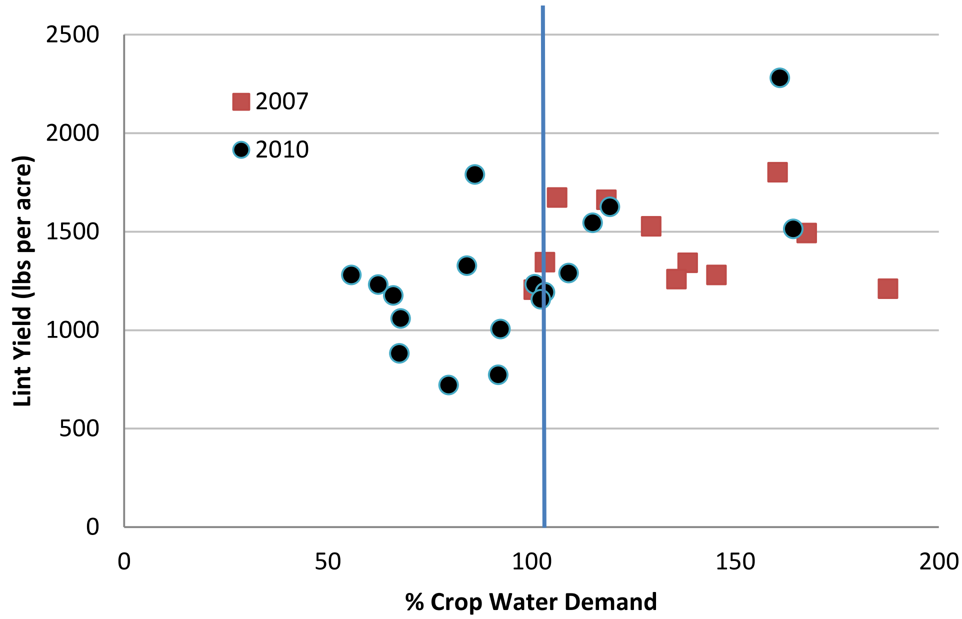

Figure 10. A comparison of the relationship between cotton yield and percentage crop water demand provided by irrigation and precipitation in two relatively high rainfall seasons, 2007 and 2010. Precipitation is calculated as 70% of that received in the growing season.

Crop Water Use Efficiency

Crop yield per unit of water applied from irrigation and total water received is a measure of crop production efficiency or water use efficiency for crop production. Table 5 gives the yield per acre-inch of irrigation applied for selected crops. This measure of efficiency tends to be highest when precipitation is highest (see 2007 and 2010) and decreases when precipitation is lowest (see 2011). Crop yield per unit of total water (irrigation plus 70% of growing-season precipitation) received was lowest in 2011, the driest year (Table 6).

Table 5. Water use efficiency for selected crops averaged across sites in pounds of yield per acre-inch of total irrigation (pre-season plus growing-season irrigation).

Crop	2005	2006	2007	2008	2009	2010	2011	2012	Mean
	---------------------------------- lbs/acre-inch ------------------------------------								
Grain sorghum	1148	704	1403	562	837	1044	43	344	761
Corn grain	768	422	992	636	674	878	125	382	610
Corn silage	3496	2381	4612	-	3159	3295	1240	2740	2989
Cotton	147	103	148	116	122	199	46	81	120

Table 6. Water use efficiency for selected crops averaged across sites in pounds of yield per acre-inch of total water, i.e. total irrigation plus growing-season precipitation†.

Crop	2005	2006	2007	2008	2009	2010	2011	2012	Mean
	-------------------------------- lbs/acre-inch --------------------------------								
Grain sorghum	428	379	445	270	442	377	40	284	333
Corn grain	504	327	523	343	490	431	116	312	381
Corn silage	2385	1887	2649	-	2498	1715	1204	2018	2053
Cotton	72	68	67	56	71	66	42	59	63

† For precipitation calculation, growing season for grain sorghum is May-September, corn is April-August, and cotton is May-October. Growing-season precipitation was multiplied by 0.70 to reflect estimated 70% effectiveness, based on TAWC management team consensus. Amounts and changes in soil water storage were not considered in the calculations of water use efficiency.

The type of irrigation technology affects crop water use efficiency. Tables 7 and 8 show average production per acre-inch of irrigation and total water for cotton and corn, respectively. Cotton grown with subsurface drip irrigation (SDI) had the highest yield (1,585 lbs per acre) and crop water use efficiency from irrigation (125 lbs per acre-inch). Furrow irrigation was the least efficient, and LEPA and Spray were of intermediate efficiency in their use of water. The spray irrigation system also had the highest corn yield (10,375 lbs) and production per acre-inch of irrigation (662 lbs, Table 8); however, the SDI system did not differ significantly from the spray system (statistical analysis not shown).

Table 7. 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 2012.

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 †	22	15.0	23.7	1,585	125	68.2
LEPA §	30	14.7	22.9	1,349	110	59.5
Spray #	66	11.7	18.8	1,148	114	61.0
Furrow	11	14.1	23.0	1,058	97	47.4

† Subsurface drip irrigation

§ Low-energy precision application

Low-elevation spray application and mid-elevation spray application

Table 8. 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 2012.

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 †	9	17.6	26.3	10,152	653	391
LEPA §	13	18.7	25.8	8,667	497	315
Spray #	26	18.5	27.8	10,375	662	383

† Subsurface drip irrigation

§ Low energy precision application

Low-elevation spray application and mid-elevation spray application

Crop water use efficiency can also be improved by avoiding excessive irrigation early in the growing season. Bordovsky et al. (2012) measured cotton lint yield in low, medium, and high irrigation treatments at the Texas A&M AgriLife Research Station at Halfway, TX. The authors found that irrigating early in the season caused more water loss due to evapotranspiration and reduced irrigation water value compared to irrigating later in the growing season.

Economic Impacts of the 2011 drought

State-wide impacts of the 2011 drought in Texas on agricultural production were approximately $7.62 billion, compared to the $4.1 billion loss in 2006 and $3.6 billion loss in 2009 (Fannin, 2012). The estimated impact on the Texas economy (businesses, cotton gins, elevators, grocery stores, etc.) was $12.5 billion (Guerrero, 2012). Production losses incurred in the Texas High Plains amounted to $2.7 billion, and regional economic impacts were approximately $4.8 billion. During 2011, scorching temperatures coupled with record low precipitation resulted in the worst drought the Texas High Plains has seen since the 1930's. Analysis of the impact of the 2011 drought on producers in the TAWC demonstration sites has shown that producers made in-season crop management decisions to mitigate the effects of drought, which also impacted their 2012 crop mixes.

In-season Management

Across the TAWC sites, 30% of the total system acres were abandoned or fallowed, primarily affecting 790.4 acres of cotton, 161.1 acres of corn, 61.5 acres of wheat, and 19.3 acres of grass seed production. The percentage lost by crop was 30%, 45%, and 69% for cotton, corn, and wheat, respectively. Corn yields per harvested acre averaged 121 bushels; 58% less than the average of previous years. Cotton lint yield was 1,166 pounds per harvested acre, or 90% of the previous six-year average. Thirteen out of the 29 sites collected an average of $406 per acre in crop insurance.

Irrigation Applied

The intensity of the heat and lack of rainfall in 2011 caused a 74% increase in the amount of irrigation applied to the primary crops (cotton, corn grain, corn silage, grain sorghum and wheat) over the average of previous years. The previous six-year average of precipitation was 20.5 inches. In contrast, total precipitation averaged across all TAWC sites in 2011was 5.3 inches, of which only 1 inch occurred during the April-September growing season. The timing of precipitation can determine the success or failure of a crop. The difference between the precipitation received in the 2005 crop year and the drought experienced in 2006 was only 0.5 inches; however, the rainfall received in 2005 came at critical times in the growing season for crop yield formation, and therefore caused less yield damage.

In 2010, producers had the greatest amount of net returns and highest precipitation of all years. Results comparing the variability in a very wet year (2010) that had 28.9 inches of rain to the 2011 drought are staggering. Table 9 shows the comparison of applied irrigation for 2010, 2011 and the 8-year average (2005-2012) for selected crops in the project. The irrigation applied for cotton (averaged over 19 sites) was 23.2 inches in 2011 compared to 7.4 inches in 2010, resulting in a 214% increase in applied irrigation water compared to 2010 and an increase of 81% compared to the seven-year average. The irrigation applied to corn for grain (averaged over 4 sites) was 27.1 inches in 2011; a 112% increase compared to 2010 and a 44% increase from the 7 year average. Comparisons are also given for corn silage, grain sorghum and wheat.

Table 9. Comparison of 2010 versus 2011 for applied irrigation by crop and 8-year (2005-2012) average.

Crop	Irrigation 2010	Irrigation 2011	Change 2010 to 2011	8-year average
	----- inches -----		%	inches
Grain sorghum	6.1	27.8	354	10.9
Corn grain	12.8	27.1	112	17.7
Corn silage	18.0	34.7	93	22.0
Cotton	7.4	23.2	214	13.5
Wheat	2.6	11.3	335	6.0

Producer Profitability

The drought heavily impacted producer profitability from production. Indemnities from crop insurance were vital in maintaining producer's incomes during 2011. Seven cotton fields received insurance indemnities that averaged $340 per acre. Average gross margin (cash income less cash expenses) over the 35 cotton fields in 2011 was $428 per acre, which included crop insurance indemnities. This compares to $531 per acre in 2010, and $296 per acre for the six years 2005-2010. It should be noted that the higher gross margins for 2010 and 2011 compared to the six-year average were due to higher cotton lint prices received in those years.

Corn profitability was more severely diminished by the drought than was cotton. Average gross margins for the eight corn fields in 2011 was $154 per acre, compared to $473 per acre in 2010, and $455 per acre for the six years 2005-2010. Of the eight corn fields in 2011, five received insurance indemnities that averaged $422 per acre.

Potential Water Savings of Alternate Crops

Over the course of this project, the mix of acres among crop types fluctuated. Figure 11 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 2012. In 2005, producers in the TAWC started with a relatively high acreage 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 in 2012. Pasture area for cattle declined strongly in 2011, partly as a result of severe drought. Relative profitability among crops has been the primary driver of species choices in cropping systems.

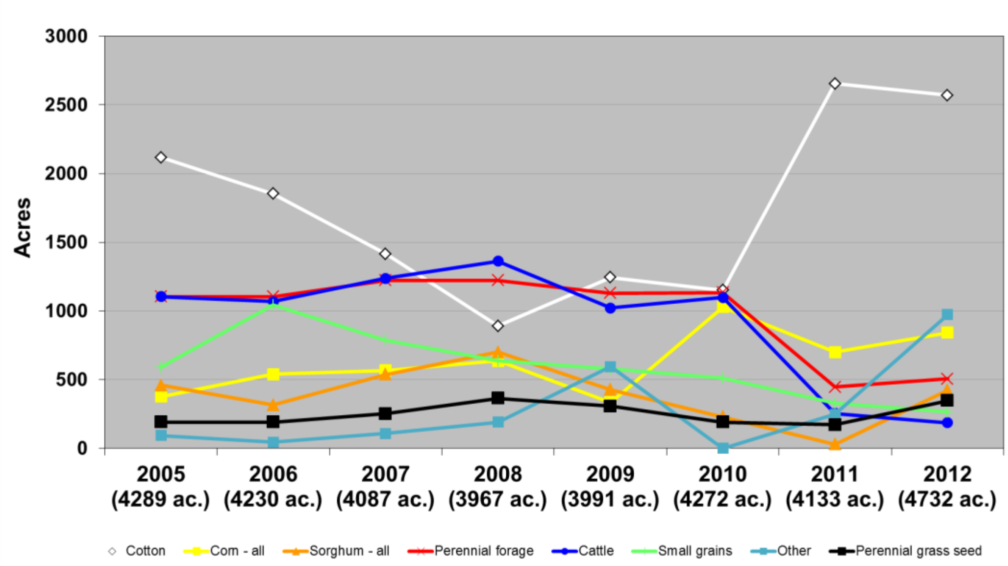

Figure 11. Acres of crops, forages, and pasture (cattle) grown on TAWC sites. Crops in the "Other" category include sunflower and peanut.

Table 10 compares two alternative crops to cotton: corn and grain sorghum, which differ in their productivity and water use efficiency. Corn had higher yields per acre than grain sorghum with 214 and 115 bushels per acre, respectively, and achieved a higher profit per acre. Grain sorghum used 56% less irrigation water than corn at 7.9 and 17.4 inches of water applied per acre, respectively. Although corn produced higher yields per acre, grain sorghum yielded 26% more bushels per inch of applied irrigation water at 17.4 compared to 13.8 for corn. Sorghum also had 19% more profit per inch of water than corn with $37.80 per inch compared to $31.80 per inch for corn.

Table 10. Comparison of corn and grain sorghum as alternative crops to cotton for irrigation efficiency and economic returns, averaged over 2005 to 2011.

Crop	Yield	Irrigation applied	Irrigation efficiency	Return on land	Return on water
	bu/acre	inches	bu/acre-inch	profit/acre	profit/inch
Corn	214	17.4	13.8	$479.40	$31.80
Sorghum	115	7.9	17.4	$248.30	$37.80

<u>Producer Responses and Barriers to Overcome for Wide-scale Adoption</u>

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. These farmers likely represent other farmers in the region who would be the most likely to be early adopters of change in their agriculture water management practices. To encourage honesty in their responses, the identity of the individual farmers was known only to the TAWC management team interviewer and was not shared with other members in the TAWC project, except in summary form. The interviews identified common themes that emerged from each conversation, which are summarized below.

- Participating farmers increased their understanding of agricultural water management practices and technologies as a result of their involvement in the TAWC project.
- West Texas farmers and ranchers are not a homogeneous population in terms of influencers on decision-making. Three population segments exist: (a) those individuals who focus solely on economic-related information that maximizes profitability; (b) those who consider multiple factors (economic resources, water availability, and personal and family goals) even if the decision is not the most economically profitable; and (c) those driven by production traditions of their operation and local cultural norms to guide their decisions. This diversity necessitates multiple strategies for disseminating research results and best practices.
- The majority of participating farmers professed that the most influential factor for change in their production systems was their personal network of other farmers.
- When questioned about the new technologies and production-related practices tested in the TAWC project, the producers generally saw their demonstration as helpful but complex and, at times, overwhelming. Most often cited as a barrier to adoption were the total costs related to the technology, and the personal time necessary to learn the nuances of each technology.
- Those seeking to adopt new water management technologies were increasingly looking to their crop consultants for assistance in dealing with greater technology complexity and time constraints for them to personally learn the new technologies.

- The final barrier to adoption is likely the most difficult to overcome—the fear of change in what was commonly linked to individual water rights. Furthermore, negative perception exists that involvement in TAWC promotes irrigation restriction policies.

What More Can Be Achieved?

1. Continued Development of Tools. The *Irrigation Scheduling* tool and *Resource Allocation Analyzer* have been developed and made available to area producers in a web-based format through the web site www.TAWCsolutions.org. The *Irrigation Scheduling* tool uses ET calculations to measure crop water demand based on standard crop water-use coefficients and local weather data. The team has recently developed a method to calculate a more accurate crop ET using satellite imagery to determine crop ground cover as it changes over the season. This method results in "field specific" crop water-use coefficients that factor in drying soil conditions, as opposed to assuming ideal soil water conditions. Incorporating this remote sensing method would enhance the current TAWC ET calculation used in the *Irrigation Scheduling* tool and allow localized crop information to make accurate irrigation decisions. This enhanced tool would be made available to area producers once the necessary programing is completed. A further enhancement to the *Irrigation Scheduling* tool will include recommendations to the user on adjustments to irrigation schedules that match the changing needs of the crop during the growing season.

The *Resource Allocation Analyzer* allows producers to evaluate crop selection decisions based on available irrigation capacity and alternative crop choices. Currently the choices included in the program are limited to the major crops in the region (cotton, corn, and sorghum). Additional crops (including lower water-use crops such as sesame and safflower, and perennial forages) and dryland options for current crops need to be included to broaden the scope of the tool. In addition, it may be possible to incorporate variability of yield and price into the solutions to allow for risk.

The TAWC *Resource Allocation* and *Irrigation Scheduling* tools have been popular outcomes of the TAWC Project. Building on this initial success, further development, enhancement, and expansion of the tools are planned to increase their utility for users in the Southern High Plains.

2. Expansion of the TAWC Area. The TAWC Project has concentrated on demonstration sites in Hale and Floyd Counties of Texas. However, the findings of the project are applicable across the Southern High Plains. The project and the region would benefit by expansion to include additional producers and cropping systems. Counties in the High Plains, such as Castro and Parmer, have greater levels of saturated thickness, and therefore provide additional potential to conserve aquifer reserves. Other counties, such as Hockley and Terry, have reached critically low aquifer levels and provide opportunity to demonstrate techniques and strategies to manage under reduced irrigation availability.

3. Intensified Outreach and Education. Information transfer and demonstration activities will be diversified and intensified in response to what was learned from the interviews with producers. While continuing the web sites, fact sheets, field days, and field walks, we will add emphasis on frequent communication with the agricultural community and more 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. Participating TAWC producers will receive one-on-one training in the same technologies as they relate to their demonstration sites. Frequent radio announcements will provide updates and tips on water conservation for efficient crop production. These efforts are designed to overcome diverse barriers to change, and to reach producers with diverse motivations for adopting conservation practices.

4. Sustainable Crop and Livestock Production. Field To Market: The Keystone Alliance for Sustainable Agriculture is a diverse initiative that joins producers, agribusinesses, food companies, and conservation organizations seeking to create sustainable outcomes for agriculture. The Keystone Alliance is associated with the Keystone Center (https://www.keystone.org), a non-profit organization involved in collaborative decision-making processes for environment, energy, and health policy issues.

Field To Market defines sustainable agriculture as "meeting the needs of the present while improving human health; and improving the economic and social well-being of agricultural communities" (http://www.fieldtomarket.org/). Their Fieldprint Calculator is a tool to analyze decisions related to sustainability, such as to measure the energy and carbon footprints for crop production. The TAWC is working with the National Cotton Council in a pilot project to provide field-level analysis based on the data collected from the TAWC sites over the eight-year time frame of the current project. The current configuration of the Fieldprint Calculator analyzes each crop year separately with regard to direct and indirect energy use and carbon emissions from production inputs, but does not consider water conservation as a metric in sustainability. We have initiated discussions with Field To Market on extending the scope of the calculator to include impacts of cropping systems on soil health and soil erosion through the crop residue management across years, and to develop metrics for water conservation. This would entail enhancing Field To Market calculator to include residue management as a practice and a dynamic multi-year analysis. This addition to the current calculator would expand the use of the analysis with regard to sustainability and potentially provided producers with much needed information to expand markets for their products and meet future regulatory demands.

5. Regional Economic and Social Assessments. One of the objectives of TAWC has been to assess the economic impacts of the choice of cropping systems that favor water conservation for individual producers. However, when such choices are implemented on the regional scale, the economic impacts can go well beyond the immediate users. The impacts can affect the entire regional community, particularly in rural communities that are strongly tied to local agriculture. **Implementation of water-conserving practices on a regional scale can prolong the usable**

life of the aquifer, allowing agriculture-related activity to extend farther into the future. This should have beneficial impacts on the economic and social aspects of the communities in this region. TAWC can conduct studies to evaluate these potential benefits, thereby expanding our understanding of the impact of the results of the TAWC Project.

Concluding Remarks

This report addresses the progress of TAWC in its mission to demonstrate cost-effective methods and develop decision tools for conserving irrigation water. It is clear that water savings can be accomplished by using the planning tools developed by TAWC for a combination of strategic and tactical decision making. Strategic planning is aided by the *Resource Allocation Analyzer* for pre-season selection of cropping and marketing plans that match up with the available water supplies, while tactical (in-season) planning is aided by the *Irrigation Scheduling* tool to avoid irrigating beyond the crop's demand for water. Producers need access to easily understood programs that are time-efficient and accurate for their specific field location. They also depend on a variety of sources, including their own peer network, to gain information and confidence about investing in new technologies that support water monitoring and conservation. Many producers value the assessments of new technologies by TAWC, which relieve them of some guesswork in how they invest in improvements. The TAWC group expects to extend the usability and precision of the online tools, expand the geographic range of participating farmers, train crop consultants in the use of the enhanced tools, and hold frequent field demonstrations of water conservation techniques across the greater Texas High Plains region.

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Note: Data in all Tables and Figures are subject to change pending thorough multi-year analysis at the end of the 2013 growing season.

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