Multi-year Water Allocation: A Policy Analysis for Groundwater Management and Conservation for Irrigated Agriculture

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Abstract: Heavy withdrawals from the most dependable source of groundwater in the Texas Panhandle, the Ogallala Aquifer, create an impending need for implementing water conservation policies. This study evaluates the policy option of multi-year water allocation coupled with water use restriction in four water deficit counties of Castro, Deafsmith, Parmer and Swisher over a sixty year planning horizon. Results indicate that the water use in the study area declines with progressive restriction rates accompanied by a substantial decrease in the net present value of net returns over sixty years and therefore it is important to analyze the socio-economic effects of implementing such a policy alternative.

Key Words: Multi-year allocation, Ogallala Aquifer, Texas Panhandle, Water conservation.

Background: The economy of the Texas High plains is driven by irrigated agriculture and the most important and dependable source of groundwater for irrigation purposes in this region is the Ogallala Aquifer, which continues to decline on account of heavy withdrawals for agricultural uses. Declining levels of water in the aquifer create an impending need for the state legislature and policy makers to realize the importance of the complexity of water laws affecting usage of ground water in the Texas High Plains, and suggest policy options like water allocation and water use restriction to ensure availability of groundwater resources for future use.

Objective: The primary objective of this research is to analyze and evaluate the impacts of multi-year water allocation as a policy alternative for optimizing groundwater use from the Ogallala aquifer in the northern high plains of Texas, more specifically in four water deficit counties of Castro, Deaf smith, Parmer and Swisher. This study also aims at evaluating the impacts of allocating the use of groundwater resources over a five year period under three different scenarios (15%, 30% and 45% water use restriction from baseline year-1 water use) when compared to baseline scenario of current water use with no restriction, for each county of study.

Description of the problem and importance of the Texas water Law: The Texas law of water rights for groundwater has a complex structural framework which can be accounted for by inclusion of certain Hispanic features along with the incorporation of the traditional English common law (Handbook of Texas Online, 2009). The rule of capture is the guiding principle behind percolating groundwater and is sometimes referred to as the “law of the biggest pump”. This has been derived out of the English common law which was adopted in the year 1904 by the Texas Supreme Court, in a historical ruling which is considered as a landmark in legal doctrines on groundwater. This specific ruling has been recorded as Houston and Central Texas Railway vs. East. (Texas Water Development Board, 2004). Under this rule the owner of the overlying land can pump and use the water with few restrictions, whatever the impact on adjacent landowners or more distant water users. The Rule of Capture has been maintained as the prevailing law for groundwater in the state of Texas, ever since the East ruling and therefore it is crucial to understand various policy options that could be incorporated in the current water rights system with an objective of conserving water for future use. Several studies have been undertaken in this regard. Wheeler et al., 2008 evaluated the impacts of short-term and long-term water rights buyout policies. The results of the study suggested that the long-term buyouts were more economically efficient than shot-term buyouts.

Johnson et al., 2009, studied the impacts and economic effects of implementing ground water policies on the Ogallala Aquifer in the Southern High Plains of Texas, and concluded that a policy that restricts the quantity of groundwater pumped conserved more water over the 50-year planning horizon than implementation of a water use fee, but at a higher cost. These studies provide an insight into scope of further research regarding water policies implementation in the study area with a long term objective of water conservation in the aquifer.

Water allocation over multiple years may be of interest to the policy makers and legislature with an objective of extending the economic life of the Ogallala Aquifer in the Southern High Plains of Texas, and maintaining the viability of a regional economy which critically depends on agriculture. The North Plains Groundwater Conservation District, in its Groundwater Management Plan for the years 2008-2018, set a maximum allowable production limit of 2 acre-feet per acre per-annum on water rights tracts not to exceed 1600 acres. This was done with an objective to limit groundwater withdrawal amounts based on an allowable production limitation and a contiguous water right acres limitation (North Plains Ground Water Conservation District, 2008). Although the Rule of Capture remains in effect, the local groundwater conservation rules supercede. Because, those rules can be altered by the district, it is always possible to revert to Rule of Capture. Therefore, any allocation system advocated in the state of Texas will need to be adjusted accordingly.

A water allocation system over multiple years will potentially reduce excessive wastage of water during the allocated time period by allowing for water stock to accumulate for the judicious users, which could be rolled over into the next allocation period at an appropriate rate of the unused stock. This will also pave the way for producers to manage irrigation needs of their crops in a planned manner with better utilization of available water than previously used. The goal of the multi-year allocation policy is to allow an equitable distribution of a limited resource like water and ensure its availability in the future, given the excessive groundwater mining and associated decline in water levels from a limited water source for the area.

Data and Methods: Several steps were necessary to analyze the economic impacts of the multi-year water allocation policy coupled with restriction scenarios when compared to the baseline scenario of no restriction on water use. The study utilized the General Algebraic Modeling Systems (GAMS) for developing optimization models for each county using specific parameters. The specific model for the purpose of this study is a nonlinear dynamic model with the incorporation of crop production functions for individual crops in the study area. These crops are corn, grain sorghum, cotton and wheat. An approach that utilized non-linear dynamic programming in combination with GAMS (Brooke et al., 1998) was used in this research study to facilitate multiple runs of the model. First, hydrologic data were collected for the study counties for saturated thickness, pumping lift, hydraulic conductivity and recharge rate, which were needed to calculate the water withdrawal on an annual basis for irrigation.

Specific data were collected for five year average planted acreages of cotton, corn, grain sorghum, wheat and fallow land (2004-2008) form the Farm Service Agency of United States Department of Agriculture. Crop acreages under conventional furrow, low energy precision application (LEPA) and dry land were calculated utilizing the ratio of acreages under different irrigation systems from the TWDB Survey of Irrigation (2001). Operating costs were collected for specific crops of study, including fertilizer, herbicide, seed, insecticide, fuel, irrigation technology maintenance, irrigation, labor, and harvesting costs. The developed models estimated the optimal water requirements for irrigation and the resulting net returns from crop production for major crops in the four counties of study over a 60 -year planning horizon. A three percent discount rate was used to calculate the net present value for the 60-year period for each of the four counties.

Hydrologic Data

Saturated thickness and pump lift by county calculations were based on data from the Texas Tech University Center for Geospatial Technology website (Texas Tech University, Center for Geospatial Technology, 2010). Saturated thickness was calculated by subtracting the depth to water from the depth of the well. Pump lift was calculated as the depth from the ground surface to the water level. Recharge rate used in the model on a county wide basis was obtained from the Panhandle Water Planning Group report on adjustments of parameters to improve calibration of models of the Ogallala Aquifer (Dutton, 2004). An average estimated specific yield of 0.155 was used for the entire study area (USGS, 2010). Initial acres served per well and maximum allowable withdrawal were calculated from the TWDB Survey of Irrigation (2001). It was assumed, that as saturated thickness values for counties increase, the well yield in GPM (gallons per minute) also increased. As an example, for counties with saturated thickness above 80 feet, a well yield of 1000 GPM was assumed for modeling purpose. The well yield values assumed for modeling purpose were guided by the fact that the maximum allowable annual withdrawal for each county in acre-feet would require a minimum average well yield for satisfying the water demand. The average hydraulic conductivity used in the model for Ogallala Aquifer in Texas is estimated to be 65 feet per day (USGS, 2010). Initial acres served per well were calculated by dividing the groundwater irrigated acres by the approximate number of wells in each county.

Production functions

The production function parameters by crop for each county were calculated by using field data obtained through personal communication with farmers in the counties of study (New, 2010). The production techniques and timing of cultural practices were held constant for irrigated crops with only the irrigation water amounts changing. Maximum and minimum water applications for each crop were also incorporated in the model. Application efficiency for the LEPA and furrow irrigation systems were established as constants and the production functions were allowed to adjust with the application efficiencies in the functional form specifications for equations in the model.

Response functions were estimated from the field data using the quadratic functional form with yield per acre as the dependent variable and irrigation water applied as the independent variable. The coefficients (β_1, β_2) were estimated setting the intercept to zero or the respective dryland yield of the crop, achieved without irrigation as reported for the county. The crop-water production function thus developed established the relationship between crop yield and applied irrigation. With this function, producers and policy makers can understand and evaluate irrigation water requirements in order to achieve targeted production or, conversely, estimate the most feasible and best-fit crop production functions for fixed or limited volumes of irrigation water. The established equation was represented as follows:

(1) $Y = \beta_0 + \beta_1 X - \beta_2 X^2$

where Y represents the yield and X represents water application rate.

Commodity prices and Production costs

Prices and costs of production for corn, cotton, sorghum, and wheat were obtained from the budgets available for District -1 from Texas AgriLife Extension Service (Amosson et al., 2009) for the year 2009. Prices for the year 2009 were used in the model and these budgets were also utilized to calculate costs of production for the different crops for the year 2009. Natural gas is the main energy source for irrigation in this area and the price of natural gas was also derived from these budgets.

Model Specification

This study was conducted with an objective of finding the most optimal combination on individual county basis using optimization models to maximize net returns from production of crops over a time horizon of sixty years.

The objective function is defined as:

where *NPV* represents the net present value of net returns; *r* represents the discount rate; and NR_t represents net revenue at time *t*. The bounds of summation for the net revenue are from one to sixty years.

NR_t is defined as:

(3) $NR_t = \Sigma_i \Sigma_k \Omega_{ikt} \{ P_i Y_{ikt} [WA_{ikt}, (WP_{ikt})] - C_{ik} (WP_{ikt}, X_t, ST_t)\}$

where: *i* represents crops grown; *k* represents irrigation systems used; Ω_{ikt} represents the percentage of crop *i* produced using irrigation system *k* in time *t*, P_i represents the output price of crop *i*, WA_{ikt} and WP_{ikt} represent irrigation water application per acre and water pumped per acre, respectively. Y_{ikt} represents the per acre yield production function, C_{ikt} represents the costs per acre, X_t represents pump lift at time *t*, ST_t represents the saturated thickness of the aquifer at time *t*. The bounds of summation are 1 to 5 and 1 to 3 for *i* and *k* respectively.

The main constraints of the model are:

(4) $\mathrm{ST}_{t+1} = \mathrm{ST}_t - [(\Sigma i\ \Sigma_k\ \Omega_{ikt} * \mathrm{WP}_{ikt}) - \mathrm{ARR}]\ \mathrm{PIA/SY},$

(5) $\mathrm{X}_{t+1} = \mathrm{X}_t + [(\Sigma_i\ \Sigma_k\ \Omega_{ikt} * \mathrm{WP}_{ikt}) - \mathrm{ARR}]\ \mathrm{PIA/\ SY},$

(6) $\mathrm{GPC}_t = (\mathrm{ST}_t/\mathrm{IST})^2 * (4.42*\mathrm{WY/AW}),$

(7) $\mathrm{WT}_t = \Sigma_i\ \Sigma_k\ \Omega_{ikt} * \mathrm{WP}_{ikt},$

(8) $\mathrm{WT}_t \leq \mathrm{GPC}_t$

(9) $\mathrm{PC}_{ikt} = \{[\mathrm{EF}(\mathrm{X}_t + 2.31*\mathrm{PSI})\mathrm{EP}]/\mathrm{EFF}\}*\mathrm{WP}_{ikt},$

(10) $\mathrm{C}_{ikt} = \mathrm{VPC}_{ik} + \mathrm{PC}_{ikt} + \mathrm{HC}_{ikt} + \mathrm{MC}_k + \mathrm{DP}_k + \mathrm{LC}_k$

(11) $\Sigma_i\ \Sigma_k\ \Omega_{ikt} \leq 1$ for all t,

(12) $\Omega_{ikt} \geq (2/3)\ \Omega_{ik\,(t-1)},$

(13) $\Omega_{ikt} \geq 0$

Equations (4) and (5) update the two state variables, saturated thickness and pumping lift, *STt* and *Xt* respectively where *ARR* represents the annual recharge rate in feet, *PIA* represents the percentage of irrigated acres expressed as the initial number of irrigated acres in the county divided by the area of the county overlying the aquifer, and *SY* represents the specific yield of the aquifer. In equation (6), *GPC* represents gross pumping capacity, *IST* represents the initial saturated thickness of the aquifer in year one of the planning horizon, i.e. 2010, and *WY* represents the average initial well yield for the county in year one. Constraints (7) and (8) are the water application and water pumping capacity constraints respectively. Equation (7) represents the total amount of water pumped per acre, WT_t, as the sum of water pumped on each crop. Constraint (8) requires WT_t to be less than or equal to GPC. Equations (9) and (10) represent the cost functions in the model. In Equation (9), PC_{ikt} represents the cost of pumping, EF represents the energy use factor for electricity, EP is the price of energy, EFF represents pump efficiency, and 2.31 feet is the height of a column of water that will exert a pressure of 1 pound per square inch. Equation (10) expresses the cost of production, C_{ikt}, in terms of VPC_{ik}, the variable cost of production per acre; HC_{ikt}, the harvest cost per acre; MC_k, the irrigation system maintenance cost per acre; DP_k, the per acre depreciation of the irrigation system per year; and LC_k, the cost of labor per acre for the irrigation system.

Equation (11) limits the fractional sum of all acres of crops *i* produced by irrigation systems *k* for time period t to be less than or equal to 1. Equation (12) is a constraint placed in the model to limit the annual shift to a 33.3 % change from the previous year’s acreage. This was done with an objective of constraining the model from predicting rapid shifts towards dryland cropping. Equation (13) is a non-negativity constraint to assure all decision variables in the model take on positive values. The model works on the objective of profit maximization and finds the optimal by maximizing the 60 year NPV typically called the social planners solution.

Results and Discussion: Results were analyzed for the optimal levels of saturated thickness, annual net revenue per acre, water applied per cropland acre, cost of pumping, and net present value of net returns per acre (NPV) by county. These were derived using the non-linear dynamic optimization model for the baseline scenario of a five year water allocation policy with no restriction on water use and the three alternative scenarios of a five year water allocation policy coupled with water use restriction rates of 15%, 30% and 45% reduction rates respectively.

Results for baseline scenario

In all the four counties of study, under the baseline scenario, saturated thickness decreased from the year 2010 to 2060 on account of unrestricted water use for irrigated agriculture. The range of decrease for the four counties was: 85 feet to 7.8 feet in Castro county, 59 feet to 6.3 feet in Deafsmith County, 75 feet to 9.29 feet in Parmer county and 43 feet to 4.9 feet in Swisher county respectively. Fig 2. describes the change in saturated thickness for the four counties under baseline scenario. The decrease in saturated thickness also accounted for an increase in pump cost for successive years into the planning horizon for all the counties of study. In Castro County the pump cost increased by 24% and a similar trend was noticed for Deafsmith, Parmer and Swisher counties where the pump cost increased by 15%, 18% and 15.5% respectively.

There was an associated decrease in net returns per acre as well as water applied per cropland acre over the study period because of decrease in irrigation water availability. Net returns decreased over the sixty year planning period in a range of 80% to 28% for the study counties. The NPV of cultivated land for the four counties at the end of the sixtieth year was \$2764 for Castro County, \$1862 for Deafsmith County, \$2086 for Parmer County and \$1605 for Swisher County, respectively. Fig.1 describes the Change in percent irrigated area for four counties under baseline scenario. It is observed that there is a gradual reduction in percentage of irrigated acres from year one to year sixty for all the four counties of study.

Comparison of Water use restriction scenarios for study counties: In this section, results of specific water use restriction rates for the allocation policy are compared to the baseline for the study counties.

Scenario - A (15% reduction in water use from Baseline Year-1)

This scenario placed a constraint on the annual water use, with a 15% reduction from baseline year-1 water use and the allocation period assumed was five years, as in the baseline scenario. The results indicated that saturated thickness for Castro County declined to 7.89 feet during the 60-year period which is 1% less than the baseline scenario. For Deafsmith County, saturated thickness declined to 6.2 feet during the 60-year period which is 6% less than the baseline scenario. For Parmer and Swisher counties, saturated thickness showed no significant changes when compared to the baseline scenario. The results for changes in saturated thickness for the study counties are provided in Table 1. The net revenue per acre for the counties at the end of the sixtieth year showed varied results. While Castro, Swisher and Parmer showed no significant changes in the net revenue when compared to the respective baselines results for the sixtieth year, Deafsmith County showed an increase of 67% in net revenue per acre when compared to the sixtieth year of the baseline scenario.

Average water applied per cropland acre showed different trends for the counties at the end of the planning horizon when compared to the baseline. For Castro and Swisher counties, there was a slight increase in water applied per acre by 3% and 1% respectively from the baselines. However, Deafsmith County experienced a significant decrease of 12% from the baseline scenarios and there was no change recorded for Parmer County. The nominal pump cost showed no significant changes by the sixtieth year, when compared to the baseline scenario for the study counties. The NPV of cultivated land for the four counties at the end of the sixtieth year decreased for Castro, Parmer and Swisher counties but increased to $1,916 for Deafsmith County when compared to the respective baseline scenarios. Overall, it was concluded that the 15% restriction scenario conserved water at no significant economic cost, as there was only a slight decrease in NPV per acre in all counties except Deafsmith County, where an increase in NPV was recorded.

Scenario - B (30% reduction in water use from Baseline Year-1)

This scenario placed a constraint on the annual water use, with a 30% reduction from baseline year-1 water use and the allocation period assumed was five years, as in the baseline scenario. The results indicated that saturated thickness for Castro County declined to 8.07 feet by the sixtieth year which is 3% more than the baseline scenario. For Deafsmith County, saturated thickness declined to 7.28 feet by the sixtieth year which is 10% more than the baseline scenario. For Parmer County, saturated thickness showed no significant changes when compared to the baseline scenario and for Swisher County a 2% higher decrease in saturated thickness was observed at the end of the sixtieth year, when compared to that of the baseline. The results for changes in saturated thickness for the study counties are provided in Table 1.The net revenue per acre for the counties at the end of the sixtieth year showed varied results similar to the 15% restriction scenario. While Castro and Swisher counties showed an increase of 1% each in the net revenue when compared to the respective baselines results for the sixtieth year, Deafsmith County showed an increase of 84% in net revenue per acre when compared to the sixtieth year of the baseline scenario. There was no change in the net revenue for Parmer County when compared to the baseline results for the sixtieth year.

Average water applied per cropland acre also showed different trends for the counties at the end of the planning horizon when compared to the baseline. For Castro and Deafsmith counties, there was an increase in water applied per acre by 8% and 21% respectively from the baselines. However, Parmer County experienced no change from the baseline scenario and Swisher County experienced an increase of 4% from the baseline scenario. The nominal pump cost showed no significant changes by the sixtieth year, when compared to the baseline scenario for the study counties. The NPV of cultivated land for all the four counties at the end of the sixtieth year decreased when compared to the respective baseline scenarios.

Scenario - C (45% reduction in water use from Baseline Year-1)

This scenario placed a constraint on the annual water use, with a 45% reduction from baseline year-1 water use and the allocation period assumed was five years, as in the baseline scenario. The results for this scenario bring to light the importance of initial saturated thickness values for the study counties. It is crucial to note that the initial saturated thickness values for all the four study counties are low values and a restriction of 45% on water use will lead to significant changes in the water availability of the area. The results from the optimization models indicated some interesting findings, when the 45% restriction was imposed.

The restriction lead to no significant pumping from the aquifer and therefore the overall decrease in saturated thickness was much lower than that in the baseline scenario. The saturated thickness for Castro County declined to 8.39 feet during the 60-year period, when compared to the baseline scenario where it decreased to 7.8 feet. For Deafsmith County, saturated thickness declined to 15.89 feet during the 60-year period, when compared to the baseline scenario where it decreased to 6.62 feet. For Parmer County, saturated thickness declined to 9.6 feet when compared to baseline where it decreased to 9.29 feet. For Swisher County, the saturated thickness declined to 5.08 at the end of the sixtieth year, when compared to the baseline scenario where it decreased to 4.87 feet. The results for changes in saturated thickness for the study counties are provided in Table 1. The net revenue per acre for the counties at the end of the sixtieth year showed varied results. Castro and Swisher counties showed an increase of 3% and 2% in the net revenue when compared to the respective baselines results for the sixtieth year.

Deafsmith County showed an increase of 222% in net revenue per acre in the sixtieth year when compared to the baseline scenario, while Parmer county showed a 16% increase from the baseline scenario's sixtieth year.

Average water applied per cropland acre showed different trends for the counties at the end of the planning horizon when compared to the baseline. For Castro and Swisher counties, there was an increase in water applied per acre by 16% and 10% respectively from the sixtieth year of the baselines. Deafsmith and Parmer counties also experienced a significant increase of 193% and 7% from the baseline scenarios respectively. The nominal pump cost showed no significant changes by the sixtieth year, when compared to the baseline scenario for Castro, Parmer and Swisher counties, but decreased by 2% for Deafsmith County at the end of the sixtieth year when compared to the baseline scenario. The NPV of cultivated land for the four counties at the end of the sixtieth year decreased for all the four counties due to lesser water applied per irrigated acre over the sixty years and lower productivity per irrigated acre. The wide variability in results for water use, saturated thickness and net returns per acre, in different scenarios indicate that individual counties with different crop mix proportions will show varied results for the restriction policies.

It was generally observed that both NPV and water applied per cropland acre decrease successively with increasing water use restriction rates of 15%, 30% and 45% respectively and there is a continuous trend for decrease in water application rates and saturated thickness levels in the study counties with increasing restriction rates. It is to be realized that individual irrigators will bear the cost of water savings in the form of reduction in NPV per acre, if such a restriction is mandated by the water conservation district. It is also important to analyze for the depreciation in the value of land when converted from irrigated to dryland production. Irrigated cropland in the study area with good water has a value of $2,200 to $2,800 per acre and dry cropland values range from $350 to $500 per acre (Texas A&M Real Estate Center, 2008).Therefore, the irrigator is faced with various options and has to decide on the most profitable alternative accompanying the cost of water conservation.

Conclusions: The results from this study indicate that in all four counties, there was a reduction in NPV per acre which became more significant with each restriction scenario when compared to the baseline. Under the unconstrained baseline scenario, the counties of study show a decline in saturated thickness over a sixty year planning horizon that recommends the incorporation of water use restriction alternatives at different rates. As shown by the results, the reduction in NPV per acre becomes significantly high with increase in water use restriction rates of 15%, 30% and 45% for the counties in the study area. However for Deafsmith County, a different trend is observed for water applied, saturated thickness and net returns per acre. The net returns per acre and the water applied per cropland acre almost doubled in the 45% restriction scenario when compared to the sixtieth year of the baseline scenario. This indicates the appropriateness of a high restriction rate as a recommended strategy in this county.

While considering water conservation policy alternatives for the Ogallala Aquifer, it is crucial to realize the set of legislative norms that govern groundwater use in a particular region or state. The Rule of Capture, still being the primary law governing underground water use in the state of Texas, limits the incorporation of water policy alternatives unless suitable relaxations or changes are made as deemed necessary by the law and policy makers of the area. Therefore, it is of vital importance that studies be carried out which address these issues and analyze the suitability and feasibility of a policy like multi-year allocation in the light of legislative and political scenarios. Another interesting possibility in the research direction of this policy could be the incorporation of a moving 5 – year constraint in the model that will permit ‘carry-over’ of unused water and also take into consideration stochastic weather conditions. This will allow the researchers to achieve the possibility of finding suitable optimization scenarios to overcome production risk in a multi-year allocation model.

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Appendix

Table 1. Change in Saturated thickness (feet) for four counties (2010 - 2060)

	Castro		Deafsmith		Parmer		Swisher	
	2010	2070	2010	2070	2010	2070	2010	2070
Baseline	85.00	7.80	59.00	6.62	75.00	9.29	43.00	4.87
15% Restriction	85.00	7.89	59.00	6.23	75.00	9.29	43.00	4.89
Change from Baseline	*0%*	*1%*	*0%*	*-6%*	*0%*	*0%*	*0%*	*0%*
30% Restriction	85.00	8.07	59.00	7.28	75.00	9.29	43.00	4.94
Change from Baseline	*0%*	*3%*	*0%*	*10%*	*0%*	*0%*	*0%*	*2%*
45% Restriction	85.00	8.39	59.00	15.89	75.00	9.60	43.00	5.08
Change from Baseline	*0%*	*8%*	*0%*	*140%*	*0%*	*3%*	*0%*	*4%*

Table 2. Change in Nominal Net Returns ($/acre) for four counties (2010 - 2060)

	Castro		Deafsmith		Parmer		Swisher	
	2010	2070	2010	2070	2010	2070	2010	2070
Baseline	120.95	41.17	51.48	23.86	114.23	21.66	53.02	38.41
15% Restriction	84.82	41.37	43.89	39.93	84.81	21.66	34.35	38.48
Change from Baseline	*-30%*	*0%*	*-15%*	*67%*	*-26%*	*0%*	*-35%*	*0%*
30% Restriction	41.23	41.78	27.21	43.94	47.12	21.66	12.35	38.66
Change from Baseline	*-66%*	*1%*	*-47%*	*84%*	*-59%*	*0%*	*-77%*	*1%*
45% Restriction	-0.10	42.49	3.15	76.90	0.68	25.19	-9.74	39.16
Change from Baseline	*-100%*	*3%*	*-94%*	*222%*	*-99%*	*16%*	*-118%*	*2%*

Table 3. Change in Water applied per acre (inch) for four counties (2010 - 2060)

	Castro		Deafsmith		Parmer		Swisher	
	2010	2070	2010	2070	2010	2070	2010	2070
Baseline	10.29	0.57	5.66	1.10	10.00	1.50	4.57	0.49
15% Restriction	8.74	0.59	4.98	0.97	8.50	1.50	3.89	0.50
Change from Baseline	*-15%*	*3%*	*-12%*	*-12%*	*-15%*	*0%*	*-15%*	*1%*
30% Restriction	7.20	0.61	4.10	1.33	7.00	1.50	3.20	0.51
Change from Baseline	*-30%*	*8%*	*-28%*	*21%*	*-30%*	*0%*	*-30%*	*4%*
45% Restriction	5.97	0.66	3.22	3.22	5.50	1.60	2.61	0.54
Change from Baseline	*-42%*	*16%*	*-43%*	*193%*	*-45%*	*7%*	*-43%*	*10%*

Table 4. Change in Pump Cost ($/ac-inch) for four counties (2010 - 2060)

	Castro		Deafsmith		Parmer		Swisher	
	2010	2070	2010	2070	2010	2070	2010	2070
Baseline	6.83	8.44	7.17	8.25	7.50	8.86	5.23	6.03
15% Restriction	6.83	8.43	7.17	8.25	7.50	8.86	5.23	6.03
Change from Baseline	*0%*	*0%*	*0%*	*0%*	*0%*	*0%*	*0%*	*0%*
30% Restriction	6.83	8.43	7.17	8.24	7.50	8.86	5.23	6.03
Change from Baseline	*0%*	*0%*	*0%*	*0%*	*0%*	*0%*	*0%*	*0%*
45% Restriction	6.83	8.42	7.17	8.06	7.50	8.86	5.23	6.02
Change from Baseline	*0%*	*0%*	*0%*	*-2%*	*0%*	*0%*	*0%*	*0%*

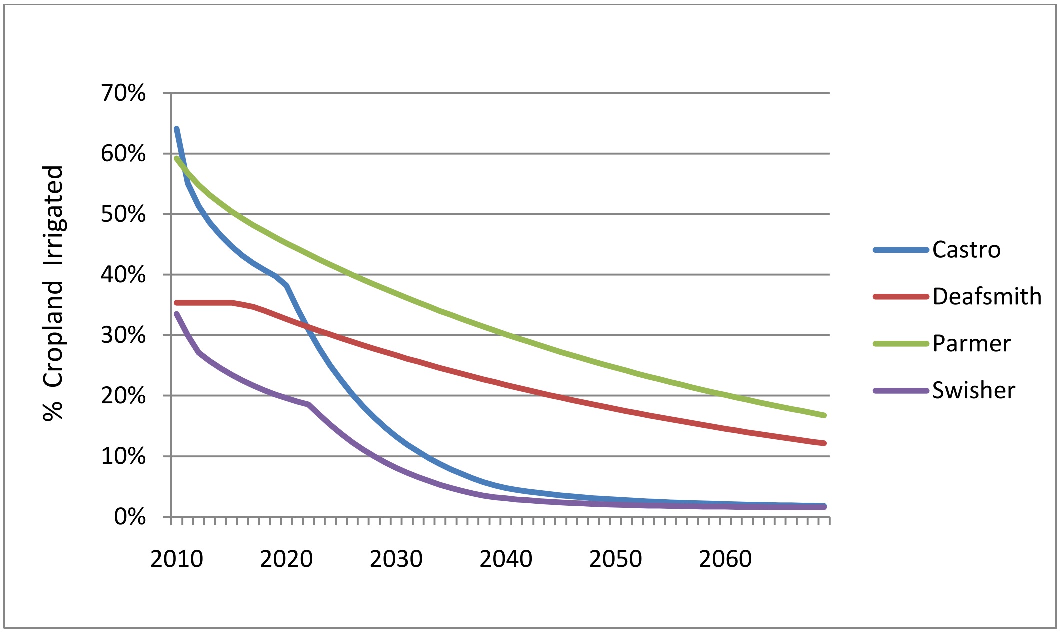

Fig 1.Change in percent irrigated area for four counties under baseline scenario

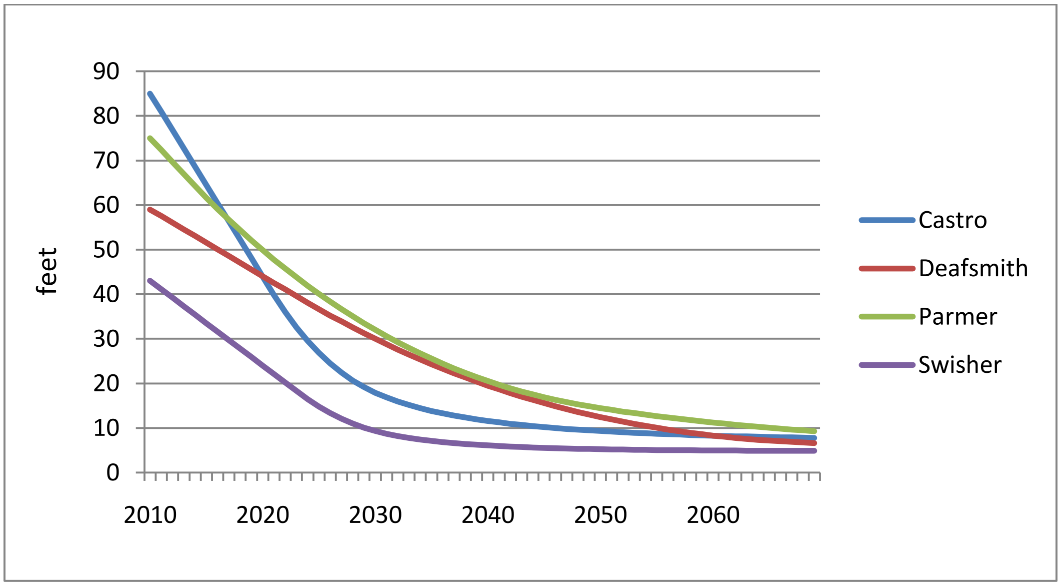

Fig 2.Change in saturated thickness for four counties under baseline scenario