Securing Food Supply for Future Generations through Groundwater Management: A Policy Analysis Approach

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Abstract

The linkages between food, water and energy are quite straightforward. Food production is dependent on water availability. Approximately 1350 liters of water is needed to produce one kilogram of wheat, 3000 liters for one kg of rice, and for meat production the water requirement is even many times more. The energy in one form or the other is needed to pump water especially in case of groundwater. More energy is required due to decrease in saturated thickness and increase in pumping lift. The rising energy costs coupled with aquifer depletion and increased pumping lift indirectly contribute towards significant increase in production costs of food and feed. Water scarcity could be considered one of the most important constraints to food and feed production. Therefore, management strategies and policy scenarios that will maintain returns while conserving water are critical to the future of Texas Panhandle economy.

Among the various policy alternatives, when compared with the baseline scenario, biotechnology option yielded the maximum socio-economic impacts. The effects were 6% higher than the baseline in terms of gross receipts, industry output, value added as well as employment generation even though the irrigated acreage a well as saturated thickness of the aquifer declined when compared to the baseline scenario. Several implications can be derived from the results of this study. First, some form of long term water use restriction (percentage per year or permanent conversion) is necessary in order to achieve any meaningful water savings. Second, accelerated adoption of improved biotechnology or irrigation technology without restrictions will not save water and, in fact, could increase water use lowering water availability in the future. However, using these strategies in combination with a water use restriction policy can negate the negative impacts to producer income and the regional economy. Finally, temporary conversion to dryland has little impact on long term water savings and should not be pursued.

Introduction: Translocation of businesses and population to the Western United States are resulting in increasing municipal and industrial water demand. However, the demand for irrigation still dominates water use in the Western United States. Irrigation is the largest single water user in the United States, often reaching 90 percent of total water consumption in the western states. Limited water supplies and increasing demand are forcing the western states to initiate long-range water planning and management to ensure that adequate supplies are available in the future.

Texas is no different from other western states in facing the water allocation dilemma. In particular, the Texas Panhandle personifies the problem. The Texas Panhandle is not only faced with an expanding urban/industrial sector, but the livestock industry has which been expanding at an impressive rate, further compounding the water allocation problem.

The area's temperate climate, sparse population and environmental conditions such as low rainfall and deep water tables favor concentrated livestock. More than 30 percent of the nation's fed beef supply is produced in the Texas Panhandle and the surrounding counties in New Mexico and Oklahoma (TCFA, 2009). The number of fed cattle in Texas has increased from 3.1 million head in 1970 to 5.7 million head in 2007 (TASS, 2007). Out of 5.7 million head fed and marketed in 2007 in Texas, 4.9 million head were from the Texas Panhandle area (TASS, 2007). Fed cattle numbers in the Texas Panhandle exploded in the late sixties and early seventies. Since then fed cattle numbers have steadily grown.

The same conditions that have brought the cattle industry to the area have recently attracting the hog industry to the region. The swine industry in this area has expanded more than tenfold during the 1990s. Growth of the swine industry has continued in the area with the opening of Texas Farms in Perryton, Texas. It is anticipated that many satellite industries will come to the area to support the expanding swine industry increasing the demand on existing water supplies. The dairy industry in the region is currently seeing a similar if not more impressive expansion.

The growing livestock industry in the region has increased the demand for feed grains in the area. In fact, the area has become a grain deficit production region resulting in premiums to be paid for feed grains. This expanding demand for feed grain has enticed area producers to increase irrigation and place more acres under cultivation. The result has been increased water demand for irrigation. Since there is no renewable surface source of irrigation water in the Panhandle and only limited recharge of the Ogallala aquifer in this area, irrigation water is a fixed supply and excessive pumping results in shortening the economic life of the aquifer and reduces the returns to the resources held by the farmer (Amosson et al. 2001).

The increased need for water conservation in the region has also led to the adoption of more efficient irrigation equipment such as the use of low-energy-application (LEPA) and low-energy-spray-application (LESA) systems (Howell, 2001). However, the efficiency improvements with the new irrigation technology have resulted in lowering the marginal cost to irrigate ($/unit of water applied). This reduced cost in turn encourages producers to continue and sometimes expand irrigation often resulting in more water use than before.

The main goal of any conservation policy is to limit the use of a resource in an effort to preserve the quantity and quality of that resource. Policies for conserving groundwater are aimed at preventing depletions of the aquifer in an effort to assure a continued supply of water for many years. This is very important when a region is rural in nature and in which the local economy is dependent on agriculture. Such is the case in the Texas Panhandle, with area municipalities also relying on the aquifer to meet as much as 50% of the water needs for other uses in addition to agriculture. In choosing an appropriate policy, the benefits (in this case decreased drawdown of the aquifer) need to be weighed against the costs (reduced producer and resource supplier revenues because of reduced irrigated crop acres).

The scope of this study is the evaluation of a baseline and five alternative policies designed to conserve groundwater in eight counties in the Texas Panhandle. These counties were selected because they showed a significant amount of water depletion in the baseline scenario during a sixty-year simulation. This study focuses on the changes in saturated thickness, water use (both in terms of acre-inches applied per acre and total water use in acre-feet), crop mix (irrigated versus dryland), and the net present value of profits in the Texas Panhandle overlying the Ogallala Aquifer over a sixty-year planning horizon. The results of the study allow a comparison between the baseline and each of the five policies in terms of water use reduction as well as the economic impacts of the policies to affected producers as well as the regional economy.

Data Collection and Research Methodology: Park (2005) and Adusumilli (2007) developed economic optimization models of the Ogallala aquifer for the Texas Panhandle and Oklahoma Panhandle, respectively. This study follows the previous groundwater studies conducted in the northern Texas High Plains but with a different approach. Dynamic programming, an optimization technique, is used to develop optimization models for each county in the study area. Dynamic programming procedure is used to determine the optimal allocation of groundwater resource to maximize the net returns from crop production. Wheeler (2006) developed the framework for the dynamic optimization models under two different irrigation systems, i.e., Low

Energy Precision Application (LEPA) and furrow for southern portion of the Ogallala aquifer in Texas and New Mexico. This study follows the same framework but with only the LEPA irrigation system taken into consideration. The model used in this study is a dynamic model that considered crop production functions. Non-linear dynamic programming with General Algebraic Modeling System (GAMS) (Brooke et al. 2005) is used to facilitate multiple runs of the model.

In order to develop a non-linear programming model, the functional relationship between yield and applied irrigation needs to be developed for major crops in the region. The Crop Production and Management Model (CroPMan) (Gerik and Harman 2003), a window based, multi-year, multi-crop, daily time step cropping system simulation model, is used to simulate the yields for the crops. Yields are simulated from CroPMan for LEPA (90% efficiency) for major crops under varying water application rates. Water response functions are estimated from the CroPMan data using the quadratic functional form and express the relationship between crop yield and total seasonal irrigation. With this function, decision makers can assess irrigation water needs to meet production targets or, conversely, estimate likely crop production for fixed volumes of water. The optimization model incorporated the production functions from CroPMan to develop a non-linear model. The developed models estimated the optimal level of water required for irrigation and the resulting net returns from crop production for major crops in the three counties over a 60-year planning period. There is considerable yield variation from year to year, especially for the lower irrigation frequencies. Although the yield simulations are revealing, conversion of these yields to net revenues gives a more complete picture of the merits of the various irrigation levels. A three percent discount rate is used to calculate the net present value for the 60-year period.

General Data Collection: Specific data are compiled for each county within the study region. The county specific data included a five-year average of planted acreage of cotton, corn, grain sorghum, and wheat, total cropland and total acreage under irrigated and dryland conditions. Operating costs associated with commonly used crop production practices including fertilizer, herbicide, seed, insecticide, fuel, irrigation technology maintenance, irrigation labor, and harvesting costs are calculated. Finally, hydrologic data including the area of each county overlying the aquifer, number of wells, and total crop acres per irrigation well, average saturated thickness of the aquifer, initial well yield, and average pump lift are collected for each county.

An estimated specific yield of 0.15 is used for the entire study area and the initial well yield by county is estimated using the methods described in the analytical study of the Ogallala aquifer in various counties. The southern portion of the Ogallala aquifer has no significant recharge. Hence, it is assumed for modeling purposes that there is no recharge of the aquifer occurring in the study area. The number of acres irrigated using groundwater and the number of wells in each county are obtained from the state reports available at the NASS website.

The GAMS models also include county-specific data such as aquifer recharge rate, acres planted in each crop and system in the base year, budgeted 2007 production and irrigation costs, actual 2007 crop prices, and a three-year average dryland yield as reported by the National Agricultural Statistics Service (NASS).

The specific policy models also include constraints for water usage, crop substitution, and dryland substitution, as well as revenue, cost, and hydrologic calculations. Saturated thickness values for each county were obtained from the Texas Tech University Center for Geospatial Technology, with the initial (2004) average saturated thickness and were used as the beginning saturated thickness for each county in the baseline and policy GAMS models.

These models were run optimizing the net present value of profits over a sixty year horizon, providing detailed results showing changes in the average saturated thickness of the aquifer, net present value for returns, the amount of water use, and the acreage planted under each crop and system (dry land or irrigated) for each county for each of the sixty years modeled. The baseline scenario assumes that no water conserving policy is implemented and producers operate in an unregulated profit maximizing manner. The only restrictions in the models for the target area are a maximum of 36 inches of irrigation allowed per crop per year, the maximum annual withdraw cannot exceed the actual 2005-07 average level of water use as reported by the Texas Water Development Board, and the saturated thickness is not allowed to fall below 20 feet.

The specific conservation scenarios were selected based on a survey by The Economics Section of the Ogallala Aquifer Project, and include the adoption of biotechnology resulting in a 1% decrease in water use while providing a 0.5% increase in yields, the adoption of irrigation technology where 1% of irrigated cropland is converted to drip irrigation until a total of 10% is reached, a mandatory water use restriction reducing water use by 1%, the temporary conversion

(TCD) of 10% of irrigated acreage to dryland production for 15 years, and the permanent conversion (PCD) of 10% of irrigated acreage to dryland production.

Model Specification: In order to estimate the economic life of the aquifer across the region, a dynamic optimization model is developed. The objective of the study is to maximize the net returns from crop production over a sixty-year planning period for a given county as a whole.

The objective function is:

$$\text{Max NPV} = \sum_{t=1}^{60} NR_t (1+r)^{-t} \qquad \text{(i)}$$

Where, NPV is the net present value of net returns, r is the discount rate, and NR_t is the net revenue at time t. NR_t is defined as:

$$NR_t = \sum_i \sum_k \Theta_{ikt} \{P_i\, Y_{ikt} [WA_{ikt}, (WP_{ikt})] - C_{ik} (WP_{ikt}, X_t, ST_t)\} \qquad \text{(ii)}$$

where i represents crop grown, k represents irrigation methods used, Θ_{ikt} is the percentage of crop i produced using method k in time t, P_i is the output price of the crop i, WA_{ikt} water applied per acre, WP_{ikt} water pumped per acre, Y_{ikt} is the per acre yield production function, C_{ik} represents costs per acre, X_t is the pump lift at time t, and ST_t is the saturated thickness of the aquifer at time t.

The constraints of the model are:

$$ST_{t+1} = ST_t - [(\Sigma_i \Sigma_k \Theta_{ikt} * WP_{ikt})]A/s, \qquad \text{(iii)}$$

$$X_{t+1} = X_t + [(\Sigma_i \Sigma_k \Theta_{ikt} * WP_{ikt})]\, A/s, \qquad \text{(iv)}$$

$$GPC_t = (ST_t/IST)^2 * (4.42*WY/AW), \qquad \text{(v)}$$

$$WT_t = \Sigma_i \Sigma_k \Theta_{ikt} * WP_{ikt}, \qquad \text{(vi)}$$

$$WT_t \leq GPC_t \qquad \text{(vii)}$$

$$PC_{ikt} = \{[EF(X_t + 2.31*PSI)EP]/EFF\}*WP_{ikt}, \qquad \text{(viii)}$$

$$C_{ikt} = VC_{ik} + PC_{ikt} + HC_{ikt} + MC_k + DP_k + LC_k \qquad \text{(ix)}$$

$$\Sigma_i \Sigma_k \Theta_{ikt} \leq 1 \text{ for all t}, \qquad \text{(x)}$$

$$\Theta_{ikt} \geq (0.9)\, \Theta_{ikt-1} \qquad \text{(xi)}$$

$$\Theta_{ikt} \geq 0. \qquad \text{(xii)}$$

Equation (iii) updates the saturated thickness variable and equation (iv) updates the pumping lift variable in the model. A is 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 s is the specific yield of the aquifer. GPC in equation (v) is the gross pumping capacity, IST represents the initial saturated thickness of the aquifer and WY represents the average initial well yield for the county. The factor 4.42 assumes 2000 hours of pumping per season and has the units AcIn/GPM. Thus, GPC unit is AcIn/GPM. Equation (vi) represents the total amount of water pumped per acre, WT_t, is the average water use on all acreage. Constraint (vii) requires WT_t to be less than or equal to GPC.

Equations (viii) and (ix) represent the cost functions in the model. In Equation (viii), PC_{ikt} represents the cost of pumping; EF represents the energy use factor for natural gas, EP is the price of natural gas, 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 (ix) represents the cost of production, C_{ikt} in terms of VC_{ik}, is 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 (x) limits the sum of all acres of crops i produced by irrigation systems k for time period t to be less than or equal to one (1). Equation (xi) is a constraint placed in the model to limit the annual shift to a 10% change from the previous year's acreage. Equation (xii) is a non-negativity constraint to assure all decision variables in the model take on positive values.

Results and Discussion: A survey of stakeholders identified five strategies to be analyzed: permanent conversion to dryland production, technology adoption, biotechnology, water use restriction, and temporary conversion to dryland production. Economic optimization models were developed to estimate changes in the aquifer, irrigated acreage and net farm income over a 60 year planning period. Socioeconomic models were utilized to evaluate impacts on the regional economy. Each conservation strategy was then evaluated with respect to the change in saturated thickness, producer income and impacts on the regional economy relative to the baseline.

The study region has a population of 388,971, average income per household of $60,682 and covers 23,292 square miles. The economy of the Texas Panhandle region is comprised of total industry output of $23 billion, value added of $10 billion, and employment of 203,689. The target area includes Castro, Dallam, Deaf Smith, Hartley, Moore, Parmer, Sherman, and Swisher counties in the Texas Panhandle. Dallam, Hartley, Moore and Sherman counties are located in the Texas Water Development Board's (TWDB) Groundwater Management Area 1 (GMA1), and are all part of the North Plains Groundwater Conservation District. Castro, Deaf Smith, Parmer, and Swisher counties are in the TWDB Groundwater Management Area 2 (GMA2), with Deaf Smith, Parmer, and Castro counties being located in the High Plains Underground Water Conservation District No. 1. The target area consists of 2,398,567 cropland acres, of which approximately 63% are irrigated. These eight counties consume approximately 2.3 million acre-feet of groundwater annually. The saturated thickness of the aquifer in this area averages 110 feet, and ranges from approximately 43 feet in Swisher County to approximately 182 feet in Sherman County. Approximately 95% of all irrigated acres in the area are under center pivot sprinkler irrigation systems. Of the total irrigated acres under all practices, approximately 38% is planted in sprinkler-irrigated corn, 30% in sprinkler-irrigated wheat, and 16% in sprinkler-irrigated cotton.

Results of the alternative water conservation policy scenarios were compared to the baseline scenario to identify the relative effect of the policy. The results of this analysis will provide the primary information that policy makers and state agencies need to assess the potential economic implications of these policy alternatives.

Baseline Scenario

The baseline scenario assumes that no water conserving policy is implemented and producers operate in an unregulated profit maximizing manner. Under these assumptions, on average, over the 60 year planning horizon the saturated thickness declines to 43.7 feet (Table 1). As saturated thickness declines, well capacity diminishes and pumping costs increase which results in total annual water use being reduced from 2,303,317 acre-feet to 754,794 acre-feet (Table 2). When water use is restricted, producers of irrigated crops respond by reducing total irrigated acres, shifting to a less water intensive crop, or converting to dryland production. As this occurs, the percent of irrigated acreage within the target area declines to 17.4% (Table 3). The net effect of this scenario is that the target area average net income per acre is reduced approximately 40.8% to $106.85 per acre (Table 4). Over the 60 year planning horizon, each cropland acre generates a net present value of $4,307.36.

The socioeconomic impacts of agricultural crop production in the region are presented in 2007 dollars (Table 5). Gross receipts of $47,622 million from crop production result in a total economic impact of $105,970 million in industry output, $48,634 million in value added and an average of 29,183 jobs over 60 years.

Biotechnology Adoption Scenario

The biotechnology adoption scenario assumes that water use is reduced at the rate of 1% per year, and crop yields increase at the rate of 0.5% per year. Under these assumptions, on average, over the 60 year planning horizon the saturated thickness declines to 49.2 feet leaving approximately 12.4% more saturated thickness by year 60 than the baseline scenario (Table 1). As saturated thickness declines, well capacity diminishes, pumping costs increase, and it takes less water to reach the profit maximizing level which results in total annual water use being reduced from 2,303,317 acre-feet to 588,155 acre-feet or approximately 22.1% less than the baseline scenario (Table 2). When water use is restricted, producers of irrigated crops respond by reducing total irrigated acres, shifting to a less water intensive crop, or converting to dryland production. As this occurs, the percent of irrigated acreage within the target area declines to 14.9% or 14.4% less than the baseline scenario (Table 3). The net effect of this scenario is that the target area average net income per acre increases over time to $225.77 per acre or 111.3% more than the baseline scenario (Table 4). Over the 60 year planning horizon, each cropland acre generates a net present value of $5,505.16 or 27.8% more than the baseline scenario.

The socioeconomic impacts of agricultural crop production in the region under the biotechnology scenario are approximately 6% higher than the baseline scenario over 60 years (Table 5). Gross receipts of $50,243 million from crop production result in a total economic impact of $111,993 million in industry output, $51,337 million in value added and an average of 30,434 jobs.

Irrigation Technology Adoption Scenario

The irrigation technology adoption scenario assumes that irrigation efficiency improves as LEPA style center pivots (95% efficient) are replaced by sub-surface drip systems (99% efficient) until 10% of the irrigated acreage is irrigated with sub-surface drip technology. Under these assumptions, on average, over the 60 year planning horizon the saturated thickness declines to 43.7 feet or approximately no change from the baseline scenario (Table 1). As saturated thickness declines, well capacity diminishes, pumping costs increase, and it takes less water to reach the profit maximizing level which results in total annual water use being reduced from 2,303,317 acre-feet to 754,609 acre-feet or approximately no change from the baseline scenario (Table 2). When per acre water use is restricted, producers of irrigated crops respond by reducing total irrigated acres, shifting to a less water intensive crop, or converting to dryland production. As this occurs, the percent of irrigated acreage within the target area declines to 17.3% or 0.3% less than the baseline scenario (Table 3). The net effect of this scenario is that the target area average net income per acre decreases over time to $105.73 per acre or 1.1% less than the baseline scenario (Table 4). Over the 60 year planning horizon, each cropland acre generates a net present value of $4,216.14 or 2.1% less than the baseline scenario.

There is very little change in socioeconomic impacts of agricultural crop production in the region under the technology adoption scenario compared to the baseline scenario over 60 years (Table 5). Gross receipts of $47,410 million from crop production result in a total economic impact of $105,509 million in industry output, $48,430 million in value added and an average of 29,026 jobs.

Water Use Restriction Scenario

The water use restriction scenario assumes that water use is reduced at the rate of 1% per year. Under this assumption, on average, over the 60 year planning horizon the saturated thickness declines to 49.2 feet or approximately 12.4% more than the baseline scenario (Table 1). As saturated thickness declines, well capacity diminishes, pumping costs increase, and it takes less water to reach the profit maximizing level which results in total annual water use being reduced to 596,510 acre-feet or approximately 21.0% less than the baseline scenario (Table 2). When per acre water use is restricted, producers of irrigated crops respond by reducing total irrigated acres, shifting to a less water intensive crop, or converting to dryland production. As this occurs, the percent of irrigated acreage within the target area declines to 14.0% or 19.6% less than the baseline scenario (Table 3). The net effect of this scenario is that the target area average net income per acre decreases over time to $99.43 per acre or 6.9% less than the baseline scenario (Table 4). Over the 60 year planning horizon, each cropland acre generates a net present value of $4,074.99 or 5.4% less than the baseline scenario.

The socioeconomic impacts of agricultural crop production in the region under the water use restriction scenario are approximately three percent lower than the baseline scenario over 60 years (Table 5). Gross receipts of $46,249 million from crop production result in a total economic impact of $103,014 million in industry output, $47,273 million in value added and an average of 28,133 jobs.

Temporary Conversion to Dryland Scenario

The temporary conversion to dryland scenario assumes that 2% of the initial irrigated acreage is converted to dryland use each year for 5 years for a total of 10%. This acreage is then allowed to re-enter irrigated production after year 15. Under these assumptions, on average, over the 60 year planning horizon the saturated thickness declines to 44.1 feet or approximately 0.8% more than the baseline scenario (Table 1). As saturated thickness declines, well capacity diminishes, pumping costs increase, and it takes less water to reach the profit maximizing level which results in total annual water use being reduced to 764,236 acre-feet or approximately 1.3% more than the baseline scenario (Table 2). When per acre water use is restricted, producers of irrigated crops respond by reducing total irrigated acres, shifting to a less water intensive crop, or converting to dryland production. As this occurs, the percent of irrigated acreage within the target area declines to 17.6% or 1.4% more than the baseline scenario (Table 3). The net effect of this scenario is that the target area average net income per acre decreases over time to $107.21 per acre or 0.3% more than the baseline scenario (Table 4). Over the 60 year planning horizon, each cropland acre generates a net present value of $4,197.53 or 2.5% less than the baseline scenario.

The socioeconomic impacts of agricultural crop production in the region under the temporary conversion to dryland scenario are two percent lower than the baseline scenario over 60 years

(Table 5). Gross receipts of $46,764 million from crop production result in a total economic impact of $104,069 million in industry output, $47,765 million in value added and an average of 28,637 jobs.

Permanent Conversion to Dryland Scenario Plan A

This permanent conversion to dryland scenario assumes that 2% of irrigated acreage is idled each year for the first 5 years for a total of 10%. This acreage then remains idled for 15 years and is then allowed to resume the production of dryland crops. Under these assumptions, on average, over the 60 year planning horizon the saturated thickness declines to 44.2 feet or approximately 1.1% more than the baseline scenario (Table 1). As saturated thickness declines, well capacity diminishes, pumping costs increase, and it takes less water to reach the profit maximizing level which results in total annual water use being reduced to 768,282 acre-feet or approximately 1.8% more than the baseline scenario (Table 2). When per acre water use is restricted, producers of irrigated crops respond by reducing total irrigated acres, shifting to a less water intensive crop, or converting to dryland production. As this occurs, the percent of irrigated acreage within the target area declines to 17.7% or 1.9% more than the baseline scenario (Table 3). The net effect of this scenario is that the target area average net income per acre decreases over time to $107.36 per acre or 0.5% more than the baseline scenario (Table 4). Over the 60 year planning horizon, each cropland acre generates a net present value of $4,187.06 or 2.8% less than the baseline scenario.

The socioeconomic impacts of agricultural crop production in the region under the permanent conversion to dryland scenario are two percent lower than the baseline scenario over 60 years (Table 5). Gross receipts of $46,650 million from crop production result in a total economic impact of $103,813 million in industry output, $47,658 million in value added and an average of 28,564 jobs.

Permanent Conversion to Dryland Scenario Plan B

This permanent conversion to dryland scenario assumes that 2% of irrigated acreage is converted to dryland production each year for the first 5 years for a total of 10%. This acreage is allowed to immediately convert to the production of dryland crops. Under these assumptions, on average, over the 60 year planning horizon the saturated thickness declines to 44.2 feet or approximately 1.1% more than the baseline scenario (Table 1). As saturated thickness declines, well capacity diminishes, pumping costs increase, and it takes less water to reach the profit maximizing level which results in total annual water use being reduced to 768,282 acre-feet or approximately 1.8% more than the baseline scenario (Table 2). When per acre water use is restricted, producers of irrigated crops respond by reducing total irrigated acres, shifting to a less water intensive crop, or converting to dryland production. As this occurs, the percent of irrigated acreage within the target area declines to 17.7% or 1.9% more than the baseline scenario (Table 3). The net effect of this scenario is that the target area average net income per acre decreases over time to $107.36 per acre or 0.5% more than the baseline scenario (Table 4). Over the 60 year planning horizon, each cropland acre generates a net present value of $4,244.23 or 1.5% less than the baseline scenario.

The socioeconomic impacts of agricultural crop production in the region under the permanent conversion to dryland scenario are one percent lower than the baseline scenario over 60 years (Table 5). Gross receipts of $47,013 million from crop production result in a total economic impact of $104,619 million in industry output, $48,052 million in value added and an average of 28,773 jobs.

Conclusion: The policies that showed the best results in terms of conserving the water available in the Ogallala Aquifer were the biotechnology adoption scenario and the water use restriction scenario. Both of these policies assume a 1% reduction in water use per year during the 60-year planning horizon. The irrigation adoption scenario resulted in very little savings of water, but it did allow for a greater number of irrigated acres in the later years of the scenario due to a slight decrease in water use per acre resulting from improved irrigation efficiency. Finally, the temporary and permanent conversion to dryland scenarios did not show any change in terms of water use compared to the baseline. This was due to the fact that conversion to dryland in the baseline occurs at about the same rate as that specified in the conversion policies.

In terms of economic costs, the biotechnology adoption policy by far provides the greatest net returns and net present values. However, as was previously mentioned, the yield increases provided in the models are based on seed varieties that are not yet available to producers. The next best policy in terms of net present value of returns was the irrigation adoption technology in that, while it decreased from the baseline, it only decreased by 0.31%. The conversion to dryland policies each had an increased net present value over the baseline, although this was because of the time of the net returns. Finally, the water-use restriction policy cost most of all the policies, resulted in a net present value per acre 5.48% less than the baseline as well as significantly fewer net returns throughout the 60-year simulation.

Several implications can be derived from the results of this study. First, some form of long term water use restriction (percentage per year or permanent conversion) is necessary in order to achieve any meaningful water savings. Second, accelerated adoption of improved biotechnology or irrigation technology without restrictions will not save water and, in fact, could increase water use lowering water availability in the future. However, using these strategies in combination with a water use restriction policy can negate the negative impacts to producer income and the regional economy. Finally, temporary conversion to dryland has little impact on long term water savings and should not be pursued.

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Table 1. Central Sub-Region Target Area Weighted Average Saturated Thickness (feet)*

Policy Scenario	Year 0	Year 10	Year 20	Year 30	Year 40	Year 50	Year 60
Baseline	111.3	95.5	78.1	65.0	55.7	49.0	43.7
Biotechnology	111.3	96.1	81.7	70.1	60.8	54.0	49.2
Change	*0.0%*	*0.7%*	*4.7%*	*7.9%*	*9.2%*	*10.2%*	*12.4%*
Irrigation Tech.	111.3	95.1	77.3	64.6	55.7	49.0	43.7
Change	*0.0%*	*-0.4%*	*-1.0%*	*-0.5%*	*-0.0%*	*-0.0%*	*-0.0%*
Water Use Rest.	111.3	95.1	79.5	68.8	60.3	53.9	49.2
Change	*0.0%*	*-0.4%*	*1.9%*	*6.0%*	*8.3%*	*10.0%*	*12.4%*
Temporary Conv.	111.3	95.5	78.3	65.4	56.3	49.5	44.1
Change	*0.0%*	*0.1%*	*0.3%*	*0.7%*	*1.1%*	*0.9%*	*0.8%*
Permanent Conv. (A)	111.3	95.5	78.3	65.6	56.5	49.7	44.2
Change	*0.0%*	*0.0%*	*0.3%*	*1.1%*	*1.4%*	*1.2%*	*1.1%*
Permanent Conv. (B)	111.3	95.5	78.3	65.6	56.5	49.7	44.2
Change	*0.0%*	*0.0%*	*0.3%*	*1.1%*	*1.4%*	*1.2%*	*1.1%*

*Averages are weighted by the area overlying the aquifer in each county.

Table 2. Central Sub-Region Target Area Total Water Use (1,000 acre-feet)

Policy Scenario	Year 0	Year 10	Year 20	Year 30	Year 40	Year 50	Year 60	Total
Baseline	2,303	2,489	2,182	1,659	1,121	899	755	98,446
Biotechnology	2,303	2,151	1,744	1,201	1,104	840	588	87,882
Change	*0.0%*	*-13.6%*	*-20.1%*	*-27.6%*	*-1.5%*	*-6.6%*	*-22.1%*	*-10.7%*
Irrigation Tech.	2,303	2,490	2,098	1,538	1,120	899	755	96,935
Change	*0.0%*	*0.1%*	*-3.8%*	*-7.3%*	*0.0%*	*0.0%*	*0.0%*	*-1.5%*
Water Use Rest.	2,303	2,318	1,671	1,391	1,046	815	597	87,881
Change	*0.0%*	*-6.9%*	*-23.4%*	*-16.2%*	*-6.6%*	*-9.4%*	*-21.0%*	*-10.7%*
Temporary Conv.	2,303	2,405	2,105	1,564	1,141	913	764	96,507
Change	*0.0%*	*-3.4%*	*-3.5%*	*-5.8%*	*1.8%*	*1.5%*	*1.3%*	*-2.0%*
Permanent Conv. (A)	2,303	2,412	2,040	1,550	1,150	919	768	96,340
Change	*0.0%*	*-3.1%*	*-6.5%*	*-6.6%*	*2.6%*	*2.2%*	*1.8%*	*-2.1%*
Permanent Conv. (B)	2,303	2,412	2,040	1,550	1,150	919	768	96,340
Change	*0.0%*	*-3.1%*	*-6.5%*	*-6.6%*	*2.6%*	*2.2%*	*1.8%*	*-2.1%*

Table 3. Central Sub-Region Target Area Irrigated Acres as a Percentage of Total Acres*

Policy Scenario	Year 0	Year 10	Year 20	Year 30	Year 40	Year 50	Year 60
Baseline	63.0%	56.8%	49.7%	38.1%	25.8%	20.7%	17.4%
Biotechnology	63.0%	50.7%	42.5%	36.5%	27.3%	20.9%	14.9%
Change	*0.0%*	*-10.6%*	*-14.5%*	*-4.2%*	*5.9%*	*1.1%*	*-14.4%*
Irrigation Tech.	63.0%	56.6%	47.6%	35.0%	25.7%	20.7%	17.3%
Change	*0.0%*	*-0.2%*	*-4.1%*	*-8.1%*	*-0.4%*	*-0.4%*	*-0.3%*
Water Use Rest.	63.0%	53.5%	39.6%	33.0%	24.6%	19.1%	14.0%
Change	*0.0%*	*-5.7%*	*-20.2%*	*-13.3%*	*-4.7%*	*-7.8%*	*-19.6%*
Temporary Conv.	63.0%	54.1%	47.3%	35.9%	26.3%	21.1%	17.6%
Change	*0.0%*	*-4.6%*	*-4.8%*	*-5.6%*	*2.0%*	*1.6%*	*1.4%*
Permanent Conv. (A)	63.0%	54.1%	45.2%	35.2%	26.5%	21.2%	17.7%
Change	*0.0%*	*-4.6%*	*-9.0%*	*-7.4%*	*2.8%*	*2.3%*	*1.9%*
Permanent Conv. (B)	63.0%	54.1%	45.2%	35.2%	26.5%	21.2%	17.7%
Change	*0.0%*	*-4.6%*	*-9.0%*	*-7.4%*	*2.8%*	*2.3%*	*1.9%*

*The percentage is based on the total irrigated acres in the target area (at time = t) divided by total irrigated and nonirrigated cropland acres in the target area.

Table 4. Central Sub-Region Target Area Average Net Income per Acre*

Policy Scenario	Year 10	Year 20	Year 30	Year 40	Year 50	Year 60	Net Present Value
Baseline	$180.48	$165.10	$142.80	$119.52	$111.78	$106.85	$4,307.36
Biotechnology	$191.13	$197.58	$207.30	$208.67	$217.25	$225.77	$5,505.16
Change	*5.9%*	*19.7%*	*45.2%*	*74.6%*	*94.4%*	*111.3%*	*27.8%*
Irrigation Tech.	$177.00	$158.91	$136.44	$117.73	$110.39	$105.73	$4,216.14
Change	*-1.9%*	*-3.8%*	*-4.5%*	*-1.5%*	*-1.2%*	*-1.1%*	*-2.1%*
Water Use Rest.	$172.13	$145.52	$132.87	$116.79	$107.69	$99.43	$4,074.99
Change	*-4.6%*	*-11.9%*	*-7.0%*	*-2.3%*	*-3.7%*	*-6.9%*	*-5.4%*
Temporary Conv.	$171.54	$161.43	$140.13	$120.32	$112.30	$107.21	$4,197.53
Change	*-5.0%*	*-2.2%*	*-1.9%*	*0.7%*	*0.5%*	*0.3%*	*-2.5%*
Permanent Conv. (A)	$171.62	$158.47	$139.38	$120.69	$112.52	$107.36	$4,187.06
Change	*-4.9%*	*-4.0%*	*-2.4%*	*1.0%*	*0.7%*	*0.5%*	*-2.8%*
Permanent Conv. (B)	$176.76	$159.50	$139.38	$120.69	$112.52	$107.36	$4,244.23
Change	*-2.1%*	*-3.4%*	*-2.4%*	*1.0%*	*0.7%*	*0.5%*	*-1.5%*

*The average is based on the total irrigated and nonirrigated net revenue (at time = t) divided by total irrigated and nonirrigated cropland acres.

Table 5. Texas Panhandle 60 Year Regional Economic Impacts

	Direct	Indirect	Induced	Total	Change from Baseline	% Change from Baseline
Baseline						
Output*	47,622	37,319	21,029	105,970		
Value Added*	15,478	20,274	12,882	48,634		
Employment	17,922	7,561	3,701	29,183		
Biotech						
Output*	50,243	39,437	22,313	111,993	6,023	6%
Value Added*	16,097	21,572	13,668	51,337	2,704	6%
Employment	18,327	8,180	3,927	30,434	1,251	4%
Technology Adoption						
Output*	47,410	37,144	20,955	105,509	-462	0%
Value Added*	15,398	20,195	12,837	48,430	-204	0%
Employment	17,792	7,547	3,688	29,026	-157	-1%
Water Use Restriction						
Output*	46,249	36,243	20,523	103,014	-2,956	-3%
Value Added*	14,909	19,793	12,572	47,273	-1,360	-3%
Employment	17,044	7,476	3,612	28,133	-1,050	-4%
Temporary Conversion						
Output*	46,764	36,641	20,664	104,069	-1,902	-2%
Value Added*	15,188	19,919	12,658	47,765	-869	-2%
Employment	17,560	7,440	3,636	28,637	-546	-2%
Permanent Conversion (A)						
Output*	46,650	36,541	20,623	103,813	-2,157	-2%
Value Added*	15,156	19,869	12,633	47,658	-976	-2%
Employment	17,508	7,427	3,629	28,564	-619	-2%
Permanent Conversion (B)						
Output*	47,013	36,799	20,806	104,619	-1,352	-1%
Value Added*	15,282	20,025	12,745	48,052	-582	-1%
Employment	17,611	7,500	3,662	28,773	-411	-1%

*Millions of dollars