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Water Conservation Policy Alternatives for the Ogallala Aquifer in Texas

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Abstract

Texas groundwater law is based on the rule of capture; however, recent legislation provides groundwater conservation districts with the authority to implement groundwater use rules to manage aquifers. The objective of this study was to develop optimization models to analyze effects of groundwater policies on the Ogallala Aquifer and evaluate economic impacts on the Southern High Plains of Texas. The results of this study indicate that a policy that restricts the quantity of groundwater pumped conserved more water over the 50-year time horizon than implementation of a water use fee, but at a higher cost to local economies.

Keywords: groundwater conservation, input-output model, nonlinear dynamic optimization, Ogallala Aquifer.

1. Introduction

Water scarcity, intergenerational transfers, and regional economic downturns are issues facing water policy decision makers in the Great Plains of the United States, especially those regions that are dependent on production agriculture and groundwater irrigation from the Ogallala Aquifer. In the southern portion of the aquifer, these conditions are magnified by low initial saturated thickness, low recharge rates, high water withdrawals, and water rights ownership. Texas policy makers at the state and regional groundwater district levels are working to develop policies that will conserve water in the aquifer while maintaining a healthy regional economy that is currently heavily dependent on irrigated agriculture. This study evaluated two types of conservation policies, a quota and a water pumpage fee, and the impact of each on conservation of water in the aquifer and the economic impact on irrigators and on the region. This study evaluated both the results of optimization models that maximized net income to the producer and the results of an input/output model that calculated the effects on the regional economy. By combining the results of the two models, policy makers can more readily identify the competing interests that are involved in the region.

Within the Southern High Plains region of Texas (SHPT) and Eastern New Mexico, over 95% of the water extracted from the Ogallala Aquifer is used for irrigation, so any effort to conserve water in the aquifer must focus on water withdrawals for agriculture (HDR Engineering, Inc., 2001). A combination of low-cost energy, fertile soils, favorable climate and a seemingly boundless supply of water resulted in expansion of irrigation beginning in the 1940s and 1950s for the production of cotton, feed grains, and wheat (High Plains Associates, 1982). As the level of irrigation increased over time, the aquifer was characterized as exhaustible due to high levels of withdrawals and low levels of recharge with recharge estimates varying from 0.2 to 1.8 centimeters per year across the region (Nativ, 1988 and Stovall, 2001). Diverse interests within the SHPT region are concerned that, at current withdrawal rates, the Ogallala Aquifer will reach economic depletion in many areas resulting in decreased crop yields and declining economic activity throughout the region (High Plains Underground Water Conservation Distinct No. 1, 2004).

In Texas, surface landowners own the right to pump and use groundwater under their property for beneficial use. While Texas courts have upheld the rule of capture over the past 100 years, the courts have left the regulation of groundwater to the Legislature (Kaiser, 1998 and Kaiser & Skillern, 2001). Groundwater management districts were established in 1949 (House Research Organization, 2000 and Templer, 1989), and the Texas Legislature confirmed in 1997 and 2002 that groundwater management districts are the preferred institutions for management of groundwater, providing authority for districts to manage groundwater withdrawals through alternative regulatory policies such as water pumpage fees and water pumping quotas (House Research Organization, 2000 and Texas Joint Committee On Water Resources, 2002).

This study uses a dynamic optimization technique to evaluate the impacts of these proposed changes in water district rules. By using dynamic optimization, a key assumption is that water in the aquifer acts as a private property good rather than a common property good, thereby assuming that the tragedy of the commons does not apply in this aquifer and that long-term benefits of water conservation accrue to the water user. Although not a true private good, it can be argued that given the storability and transmissivity characteristics of the aquifer, this aquifer tends toward a private good more than a common good. Alley, Reilly, and Franke (1999) discussed the difference in characteristics of aquifers, which, at the extremes, are described as a bathtub or egg carton as a means to provide a visualization of the common and private property aspects of the aquifer. They proposed that the Ogallala Aquifer tended to act as an egg carton more than a bathtub, therefore it could be considered more of a private good than a common good.

Gisser and Sanchez (1980) presented results that suggest that for a large aquifer with linear water demand functions differences between the results of competitive decisions and optimal control were so small that they could be ignored. Other studies (Nieswiadomy 1985, Rubio and Casino 2001, Koundour 2004) have reevaluated the Gisser Sanchez effect (GSE) and found that it holds under given assumptions.

The optimal control approach was used for this study for three reasons. The first is by claiming the Gisser Sanchez effect in which no difference is found between the competitive and optimal control approaches on the basis of the large aquifer assumption. Although the GSE is used to argue that optimal control with its costs of implementation is not preferred to competitive decision making, recent legislation is moving toward more centralized control of groundwater. The second reason, therefore, was that since recent legislation paved the way for movement away from exclusive owner control, the time was right to provide some analysis of the impacts of these proposed policies to illustrate that GSE is still in effect and that control policies come at a cost to water rights owners and society. The third reason for the optimal control approach is to provide results that can be compared to the many competitive, myopic rule studies that have been performed for the Ogallala Aquifer.

Bredehoeft and Young (1970) noted that three policy tools can be used in aquifer management: centralized decision-making, assigned quotas or pumping rights, and extraction fees or taxes on withdrawals. Centralized decision making is unlikely to be adopted and, in Texas, centralized decision-making is inconsistent with the intent of recent legislation of "protecting the groundwater resource while respecting landowners' property right historically acknowledged to be associated with ownership of real property" (Texas Joint Committee On Water Resources, 2002, p. 44). The instruments of pumping quotas and water pumpage fees are possible and within the authority given to groundwater conservation districts by the Texas Legislature.

In this study, policies that conserve water in the aquifer are defined as those approaches that reduce the amount of water withdrawn from the aquifer at a given level of water application efficiency. This reduction in the amount of water pumped represents a reduction in water applied to crops and, consequently, results in either a reduction in the consumptive use by the crops being irrigated or a reduction in the area irrigated. In other words, the reduction in pumpage results in a reduction in the total amount of water used thus conserving the water by maintaining it in the aquifer. The water conservation policy alternatives selected for evaluation in this study were: (1) a water pumpage fee of US $\$0.08\text{x}10^{-2}$ meter^{-3} pumped ($1 per acre foot) and (2) a restriction on the drawdown of the aquifer over a 50-year planning horizon to 50% of the initial (current) saturated thickness (50/50 policy). The water pumpage fee was authorized by state legislation in 2002 but has yet to be implemented by any groundwater management district. The 50/50 policy was also authorized by state legislation and has been implemented by one groundwater conservation district in the northern counties of Texas and is being considered for implementation by other districts (Panhandle Groundwater District, 2004).

Several studies (Feng, 1992; Harman, 1966; Lansford, Gollehon, Mapel, Creel, & Ben-David, 1983; Stovall, 2001; and Terrell, 1998) have shown that with continued use, the level of the aquifer will continue to decline toward economic depletion. Economic depletion is defined as the exhaustion of a resource to the point at which the cost of extraction is greater than the value of the extracted resource. In this case, economic depletion is encountered at the aquifer level at which the marginal value product of applied irrigation water equals the marginal input cost of applying the water to the crop. As pump lift increases, the marginal cost of pumping groundwater increases. It is likely that with the decline of the aquifer, agricultural practices will transition from irrigated to non-irrigated. Terrell (1998) showed that with the transition from irrigated to dryland production systems, the SHPT regional economy would suffer significantly due to the decline in total crop production and the associated decline in economic activity.

Groundwater conservation districts in the SHPT region are faced with evaluating and implementing new groundwater management policies to address declining aquifer levels. They must consider the effectiveness of possible policy alternatives in conserving water in the aquifer and the potential impacts on the agricultural and regional economy. The objective of this study was to analyze the impacts of the water pumpage fee and 50/50 water conservation policy alternatives on the aquifer and the economy of the Southern High Plains region of Texas.

2. Methods and Procedures

The geographical study region included 19 counties of the SHPT as shown in Figure 1. Dynamic optimization models were developed for each of the 19 counties to estimate the economic life of the aquifer across the region under alternative water conservation policies. The direct policy impacts to production agriculture provided by the dynamic optimization models were used in an input-output model to estimate the regional economic impact of each water conservation policy.

2.1 Specification of the dynamic non-linear optimization model

Rowse (1995) describes the value of using non-linear dynamic programming models for computing the optimal allocation of natural resources and illustrates the effectiveness of using a single computing environment rather than multiple path modeling procedures such as the current-period decision rule. Non-linear dynamic programming models were developed using the General Algebraic Modeling System (GAMS) to facilitate multiple runs of the model under different water conservation policies (Brooke, Kendrick, Meeraus, & Raman, 2003).

The objective function of the optimization model for this study maximized the present value of annual net returns to land, management, groundwater stock, risk, and investment over a specified planning horizon. Annual net income per hectare may be expressed as:

(1) $$NI_t = \sum_c \sum_i \Theta_{cit} \{ (P_c Y_{cit}(WP_{cit})) - C_{cit}(WP_{cit}, L_t, ST_t) \},$$

where NI_t represents net income per hectare, c represents the crop grown, i represents irrigated or non-irrigated systems where i=1 represents irrigated systems and i=0 represents non-irrigated systems, t represents the time period, Θ_{cit} represents the percentage of crop c produced with irrigation system i in period t, P_c represents the price of crop c, Y_{cit} represents the yield per hectare of crop c produced with irrigation system i in period t, WP_{cit} represents the amount of water pumped in cubic meters to irrigate crop c through irrigation system i in period t, C_{cit} represents the cost of production per hectare of crop c produced with irrigation system i in period t, L_t represents the pump lift in meters in time t, ST_t represents the saturated thickness of the aquifer in time t, and NI_t represents the net income in time t. Yield (Y_{cit}) was calculated using the crop production functions as previously discussed. The objective function was maximized for a 50-year planning horizon and may be expressed as:

(2) $$Maximize\ \ PVNI = \sum_{t=1}^{50} NI_t (1+r)^{-t} \ ,$$

where PVNI is the present value of net income and r represents the social discount rate of 3%.

The dynamic optimization model can be represented as:

(3) $$Maximize\ \ PVNI = \sum_t \sum_i \sum_c \ \Theta_{cit} \{ (P_c Y_{cit}(WP_{cit})) - C_{cit}(WP_{cit}, L_t, ST_t) \} (1+r)^{-t};$$

Subject to:

(4) $$ST_{t+1} = ST_t - \left[\left(\sum_c \sum_i \Theta_{cit} WP_{cit} \right) - R_t \right] A/s;$$

(5) $$L_{t+1} = L_t + \left[\left(\sum_c \sum_i \Theta_{cit} WP_{cit} \right) - R_t \right] A/s;$$

(6) $GPC_t = (ST_t / IST)^2 * (120 * WY / AW)$;

(7) $WT_t = \sum_c \sum_i \Theta_{cit} * WP_{cit}$;

(8) $WT_t \leq GPC_t$;

(9) $PC_{cit} = \{[EF(L_t + 0.1 * PRS)EP] / EFF\} * WP_{cit}$;

(10) $C_{cit} = VC_{ci} + PC_{cit} + HC_{cit} + MC_i + DP_i + LC_i$;

(11) $\sum_c \Theta_{it} \leq Initial\ Irrigated\ Area$;

(12) $\Theta_{cit} \geq 0.9\ \Theta_{cit-1}$;

(13) $\sum_c \sum_i \Theta_{ci} \leq 1$ for all t; and

(14) $\Theta_{cit} \geq 0$.

The objective function expressed in Equation 3 was obtained by substituting Equation 1 into Equation 2. Equations 4 and 5 are equations of motion for the two state variables of saturated thickness (ST_t) and pumping lift (L_t), where R_t is the annual recharge rate in meters, A is the percentage of irrigated area expressed as the initial irrigated area in the county divided by the area of the county overlying the aquifer, s represents the specific yield of the aquifer. The base year for initial saturated thickness and irrigated area was 2001.

Equations 6, 7, and 8 express the relationship between the amount of water pumped and the amount of water available. Equation 6 calculates the maximum amount of water that can be pumped in each time period. Gross pumping capacity in period t (GPC_t), is a function of initial saturated thickness *(IST)*, average initial well yield for a county *(WY)*, and average number of wells per irrigated hectare for a county *(AW)* (Harman, 1966; Terrell, 1998; and Texas Water Development Board, 2001). The factor of 120 cubic meters per liter per minute is developed from the assumption of 2000 pumping hours in a growing season.[1] Equation 7 expresses the total amount of water pumped per hectare (WT_t) as the sum of water pumped on each crop. Equation 8 is a constraint requiring the amount of water pumped (WT_t) to be less than or equal to the amount of water available for pumping (GPC_t).

Equation 9 calculates the cost of pumping (PC_{cit}) for crop c produced by irrigation system i in period t, where EF represents the energy use factor for electricity, PRS represents the irrigation system operating pressure, EP represents energy price per unit of electricity, EFF represents pump engine efficiency, and the factor 0.1 meter is the height of a column of water that will exert a pressure of 1 kilopascal (Terrell, 1998). Equation 10 expresses the cost of production (C_{cit}) for crop c produced by irrigation system i in period t, where VC_{ci} is the variable cost of production per hectare, HC_{cit} is the harvest costs per hectare, MC_i is the annual maintenance cost per hectare for the irrigation system, DP_i is the annual depreciation cost per hectare for the irrigation system, and LC_i is the irrigation labor cost per hectare for the irrigation system.

Equation 11 ensures that the irrigated area does not increase from the amount being irrigated at the beginning of the planning horizon. Equation 12 limits the annual change in the area of any crop to no more than 10% of the previous year's area. This limit on the rate of transition between crop enterprises controls the rate at which the model switches from one enterprise to another in order to replicate an orderly transition between crop enterprises. Both equations 11 and 12 are used to capture unobserved constraints that impact irrigators decisions but which are not replicated in the model. These equations are an attempt to ensure the model results mimic actual observations.

Equation 13 limits the sum of the percentage of area for all crops *c* produced by all irrigation systems *i* for each period *t* to be less than or equal to 1. Equation 14 ensures that the values of the decision variables are non-negative.

WP_{cit}, representing the amount of water pumped in cubic meters in equations 3, 4, 5, 7, and 9, is a critical factor in determining costs of production. When the returns above specified costs for irrigated crops are less than the returns above specified costs for non-irrigated crops due to increasing pump lift, water is no longer pumped. When this happens, WP_{cit} equals zero, thus reducing pumping costs and other irrigation-related costs to zero.

2.2 *Parameters for dynamic non-linear optimization model*

Dynamic optimization models were developed for each of the 19 counties to estimate the optimal level of water extraction for irrigation and the resulting present value of net income from crop production over a planning horizon of 50 years. The models were used to establish a baseline scenario using current water policy and two conservation policy alternatives: (1) a water pumpage fee of US $\$0.08\text{x}10^{-2}$ meter^{-3} pumped ($1 per acre foot), and (2) a restriction on the drawdown of the aquifer over a 50-year planning horizon to 50% of the saturated thickness at the beginning of the study (50/50 policy).

The functional relationship between crop yield and applied irrigation water was estimated for the primary crops grown in the region. The Crop Production and Management Model (CROPMAN) was used to estimate the response of crop yields to applied irrigation water (Gerik, et al., 2003). CROPMAN requires the designation of the crop, type of irrigation system, soil type, and weather data location. Production techniques and timing of cultural practices were held constant with only the amount of applied irrigation water varying. The irrigation timing was also held constant with the amount of irrigation water applied divided between the various dates of irrigation.

Production functions for irrigated crops were estimated for corn, cotton, grain sorghum, peanuts, and wheat using the results from CROPMAN. Yield response functions were estimated using a quadratic functional form with yield per hectare as the dependent variable and applied irrigation water as the independent variable. The quadratic functional form was used to ensure that a global maximum would be achieved in the optimization model. The production functions were estimated using ordinary least squares regression techniques with the intercept set at the 3-year average yield for dryland production of each crop.

The two modeling assumptions of irrigation efficiency and recharge require additional discussion due to their importance as components of the model especially as projections are made for a relatively long horizon of fifty years. First, an irrigation efficiency of 90% was used for the model development. This is consistent with efficiencies found in improved center pivot irrigation systems and serves as a proxy for future irrigation technologies that may be adopted during the fifty year planning horizon. Currently across the region, center pivot systems comprise 70% of the irrigation systems while furrow irrigation systems with efficiencies of approximately 75% comprise 30% of the irrigation systems. As improved irrigation technologies, such as subsurface drip irrigation with efficiency estimates of 98%, become more widely adopted, the average efficiencies across the region will approach the 90% level used in the model development (Texas Water Development Board, 2001).

Recharge values include both natural recharge and return flows (Stovall, 2001). As explained by Kendy, Molden, Steenhuis, Liu, & Wang (2003), if improved efficiencies result in lower water withdrawals, the return flows to the aquifer will be reduced, thereby speeding the depletion of the aquifer. Two factors, however, influence the relative impact of reduced return flows in this region and support the assumption of constant total recharge values. Water levels of the Ogallala Aquifer in this region are relatively deep and infiltration rates are relatively slow resulting in a long lagged response of the aquifer level to changes in the level of return flows. The other factor reported by Peterson and Ding (2005), is that "water spreading" is common in the Ogallala region which is a result of improved technical efficiency of irrigation systems. This improvement in efficiency leads to more area being irrigated with the same amount of water thus resulting in no net water savings.

The county-level dynamic optimization models were solved using GAMS. County specific data for each model include total land area, land area overlying the Ogallala Aquifer, amount of annual recharge, specific yield for the aquifer, initial saturated thickness, initial pump lift, initial well yield, initial area per well, initial area per crop, and initial irrigated area. Crop specific data include commodity prices, variable costs of dryland crop production excluding harvest costs, added variable costs for irrigated crop production, and harvest costs per unit of production. Commodity prices used in the analysis were averages of monthly prices for fifteen years from 1987 through 2001 as reported by the Texas Agricultural Statistics Service (various years). The variable costs for dryland crop production and the additional costs for irrigated production were taken from enterprise budgets developed by the Texas Cooperative Extension Service for Texas Extension District 2 (Texas Agricultural Extension Service, 2003).

Pumping costs were based on an energy use factor for electricity of 5.24×10^{-3} KWH per meter of lift per cubic meter, irrigation system operating pressure of 110 kPa, energy price of $0.0633 per KWH, and pump engine efficiency of 50%. Other costs include the initial cost of the irrigation system of $692 per hectare, annual depreciation percentage of 5%, irrigation labor of 5 hours per hectare, and labor cost of $8 per hour. Annual maintenance cost was set at 8% of initial irrigation system cost, and a real discount rate of 3% was assumed (Terrell, 1998). Cost calculations included harvest costs, pumping costs, and total costs of production for irrigated and dryland crops. The units for the resulting values were expressed in $/hectare.

2.3 Input-Output Model

The results of the dynamic nonlinear optimization models were imported into the input-output model, IMPLAN, to estimate the regional economic impact of the two water policy alternatives relative to the baseline scenario. The production levels for corn, cotton, grain sorghum, peanuts, and winter wheat under the two water alternative policies analyzed in 10-year increments resulted in five agricultural production "snapshots" for simulation years 10, 20, 30, 40, and 50 (Terrell, Johnson, and Segarra, 2002). The impact of each water policy on regional economic activity relative to the baseline condition was estimated using IMPLAN. For each "snapshot" year the difference in agricultural gross revenue was calculated between the simulated water policy value and the simulated baseline level provided by the dynamic programming model.

The 1998 IMPLAN data set which included economic data for all counties in Texas was used to generate an input-output model for the 19 county region. A descriptive IMPLAN model was first developed for the baseline scenario, then a predictive model was developed using the Type SAM multipliers that consider direct, indirect, and induced effects from changes in output within specific sectors of the economy (Minnesota IMPLAN Group, Inc., 2000). The change in the predictive model was the calculated change in gross revenue between the baseline production levels for each commodity and their respective values under each water policy alternative.

3. Results

3.1 Regional Results of the Non-linear Optimization Models

The simulated transition from irrigated to dryland cropland over the 50-year planning horizon for the region is presented in Table 1 for the baseline and two alternative water policies: water pumpage fee and 50/50 policies. The initial percentage of irrigated area for each county was reported by the Texas Agricultural Statistics Service for the year 2001 (Texas Agricultural Statistics Service, 2002). Irrigated area for subsequent years for each county was estimated using the dynamic programming model. Under the baseline scenario, the average percentage of irrigated area in the region decreased from approximately 52% to 23% over the planning horizon. The water pumpage fee policy showed little deviation from the baseline scenario, which was predictable due to the low water pumpage fee of $0.0008 per cubic meter allowed under current legislation compared to the average pumping costs for the region of approximately $0.04 per cubic meter. The 50/50 water conservation policy simulated a decrease in the average irrigated area from 52% to 17% of total cropland over the 50-year planning horizon. The 50/50 policy was more restrictive of groundwater withdrawals; therefore, a faster transition from irrigated to dryland production occurred under this policy.

Average aquifer saturated thickness across the region (weighted mean) under the baseline situation decreased approximately 38% from an initial level of approximately 21.4 meters to 13.1 meters by year 50 of the planning horizon as shown in Table 2. The decline in saturated thickness projected under the water pumpage fee policy is only slightly less than the decline in baseline scenario and average saturated thickness is 13.3 meters by year 50, only 0.2 meters of saturated thickness greater than the baseline scenario. The average saturated thickness projected under the 50/50 policy declined by 30% from 21.4 meters to 14.9 meters by year 50 of the planning horizon.

Under the baseline conditions, the drawdown over 50 years did not exceed 50% of initial saturated thickness in 12 of the 19 counties, resulting in a smaller than expected drawdown of 30% across the region. Several factors contributed to these counties not reaching the 50% drawdown level. Of the 12 counties, seven maintained a constant level of irrigated area while five began an immediate decrease in irrigated area. The five counties that began the immediate decrease all had relatively high percentage of irrigated area initially (> 60%). Two of these counties had the greatest irrigated area in corn while two others had the greatest irrigated area in cotton. Three of these counties had pumping costs in the highest quartile (>$0.05 / cubic meter) with medium to high well yields (2500-3500 lpm). All five of these counties had only medium level initial saturated thickness (20-24 meters). The seven counties that maintained a steady level of irrigated area all had low to mid range pumping costs (<$0.04/ cubic meter) and initial water withdrawals (< 0.09 cubic meters). These seven counties had the smallest irrigated area (<50%) of the 19 counties.

Present values of net income from crop production for the 19-county region were calculated for the baseline and the two alternative water conservation policies over the 50-year period using a 3% discount rate. The total present value of the net income for the region under baseline scenario is $5,060 million, or $1191 per hectare. The water pumpage fee policy resulted in a 5.5% decrease in total present value of net income from the baseline to a value of $4,780 million, or $1124 per hectare. The 50/50 policy resulted in a decline from the baseline of 3.7% to a total present value of net income of $4,870 million, or $1147 per hectare. This may seem counter-intuitive that the policy that results in the least change in water use will cause the greater negative impact on net income. The water use fee is imposed on all water used while the 50/50 quota only affects the last unit of water used and only in those counties that used more that 50% of the water. The average net income across the region therefore was not impacted as severely by the 50/50 policy as by the water use fee.

The efficiency in reducing the decline of saturated thickness over the planning horizon can be measured for each policy as the ratio of the decrease in the present value of net income per hectare from the baseline scenario for the agricultural producer and the associated change in the level of saturated thickness under the alternative policy. The ratio estimates the average cost in foregone net income to maintain an additional meter of saturated thickness in the aquifer compared to the baseline scenario. The water pumpage fee conserved 0.24 meter of the saturated thickness relative to the baseline at a present value cost of $66.72 per hectare, resulting in an efficiency ratio value of $278 per meter of saturated thickness saved. The 50/50 policy, on the other hand, conserved 1.8 meter of the saturated thickness relative to the baseline at a present value cost of $44.50 per hectare, resulting in an efficiency ratio value of $25 per meter of saturated thickness saved. The ratio illustrates the interaction between water conserved in the aquifer and net income lost to the agricultural producer and the advantage of the increased flexibility available with the 50/50 policy. Under the water pumpage fee policy the increased cost of production due to the imposition of the fee contributes to a greater cost in net income to agricultural producers, while the water savings are substantially less.

The analysis indicated that for the water pumpage fee to be effective in reducing the decline in saturated thickness, a higher fee would be required. Currently, the maximum allowed water use fee for agricultural uses is $0.0008 per cubic meter ($1 per acre foot). Table 3 shows the water pumpage fees per cubic meter of water pumped necessary to maintain the same level of conservation as the 50/50 policy for the seven counties that exceeded the 50% drawdown in 50 years under the baseline scenario. Examining the results from two counties shows the wide difference in the requirements for water pumpage fees. Specifically, Swisher County requires a fee of $0.032 per cubic meter of water pumped while Terry County requires a fee of $0.004 per cubic meter of water pumped. The difference in these levels is the result of differences in initial saturated thickness, level of water withdrawals, and value of crops irrigated.

3.2 Input-Output Model

The regional economic impact of the alternative water conservation policies was developed using the IMPLAN input-output model. The values used in the IMPLAN model were the changes in regional gross revenue for the commodities of cotton, corn, grain sorghum, wheat, and peanuts from the baseline scenario for each of the two alternative policies. The changes in gross revenue from the baseline scenario were evaluated in 10-year increments for years 10, 20, 30, 40, and 50 of the planning horizon. The water pumpage fee policy exhibited the least change in gross revenues (direct economic output shown in Table 4) from the baseline scenario, ranging from

$48 million below the baseline scenario in year 40 to $13 million above the baseline scenario in year 50. The 50/50 policy exhibited a decline in gross revenue through year 40 to a level $410 million below the baseline scenario then increased to $324 million below the baseline scenario in year 50. It is important to note that total gross revenue is the direct effect measure in the regional analysis while net income was the measure for the farm-level analysis. One of the key differences in the two measures is the water pumpage fee. In the farm-level analysis, the fee is included in the analysis while the fee is not considered in the regional analysis. The fee enters the local economy through the water districts' purchase of management, labor, and equipment.

The total regional economic impacts from the direct, indirect and induced effects are shown in Table 4. Direct impacts are derived directly from the change in gross revenue. Indirect impacts are defined as those effects that are related to producer purchases of goods and services from other industries, such as fertilizer, chemicals, equipment, and fuel and were found to be 53% of direct impacts. Induced effects are defined as those effects that are related to changes in household spending caused by changes in gross revenue and were found to be 16% of direct impacts.

The baseline scenario is considered to be the index with a value of zero and the differences between the results of the baseline and the two policies are the impacts on the regional economy. The water pumpage fee policy followed the path of the baseline with little change in regional impact as shown by the relatively small differences and exhibited a decrease in annual regional economic activity of $81 million from the baseline in year 40. The 50/50 policy exhibited a much greater economic impact as shown by the relatively larger values. The 50/50 policy did not follow the same path as the baseline with an early divergence due to a greater rate of decreasing irrigated area in the early years of the study and exhibited a decline in annual regional economic activity to a level \$547 million below the baseline scenario in year 50. The smaller difference in year 50 is a result of the baseline scenario beginning to show a greater rate of loss of irrigated area in the later years of the study.

The present value of gross revenue from each crop produced for each year of the planning horizon multiplied by the appropriate SAM multiplier from the IMPLAN model provided the present value of the total regional economic activity generated by the specified agricultural production for each policy. The water pumpage fee and 50/50 policies generated \$624 million or \$147 per cropland hectare and \$9,368 million or \$2206 per cropland hectare less regional economic activity compared to the baseline scenario, respectively.

When considering the efficiency measure of regional economic activity per meter of saturated thickness saved, the total economic cost of maintaining a meter of saturated thickness under the water pumpage fee policy was \$244 per meter of saturated thickness (\$0.45 per cubic meter of water) and \$496 per meter of saturated thickness (\$0.81 per cubic meter of water) under the 50/50 policy. The evaluation found an opposite relationship compared to the ratio applied to the change in net income to agricultural producers. One of the key factors for this reversal is the use of the water pumpage fee as an input into the economy rather than a direct effect. This illustrates the importance of defining the desired effects of proposed policies. In this case, the water use fee is the most efficient when considering regional economic impacts but the least efficient in terms of producer net income. Similarly, the 50/50 policy is most efficient when considering producer net income but least efficient when considering the regional economic impacts.

4. Conclusions

Groundwater conservation districts in Texas have been identified by the Texas Legislature through Texas Senate Bills 1 (1997) and 2 (2002) as the primary regulatory authorities to implement groundwater management policies to address the state's expanding water demand and declining aquifer levels. As groundwater conservation districts in the SHPT evaluate the implementation of new groundwater management policies, they should consider the effectiveness of various policy alternatives in conserving water in the Ogallala Aquifer and the potential impacts on the agricultural and regional economy.

This study evaluated the impacts of two alternative water management policies, a water pumpage fee and a 50/50 quota, on the saturated thickness of the Ogallala Aquifer, net income to agricultural producers, and the regional SHPT economy. The alternative policies were evaluated relative to a baseline scenario of the present water management policy in the region over a 50-year planning horizon. The alternative water management policies were chosen for evaluation because of their inclusion in recent legislation addressing water policy in Texas (water pumpage fee) or adoption by groundwater conservation districts as district policy (50/50 quota).

Under the baseline scenario only 7 of the 19 counties showed declines in saturated thickness greater than 50% over the 50-year planning horizon. Across the SHPT, the average saturated thickness declined 38.8% and irrigated area declined from 52.1% to 22.9% of total cropland. The baseline scenario assumed that no new water management policies would be implemented over a 50-year planning horizon.

The comparison of the alternative water management policies to the baseline scenario indicated that a water pumpage fee of $\$0.08 \times 10^{-2}$ per cubic meter was not effective in reducing the decline in the saturated thickness to any significant extent. Under the water fee policy the reduction in the present value of net income to the agricultural producer was greatest due to the additional cost of the fee to irrigation users. Although water pumpage fees can be used in a management policy to enhance conservation, the low fee is essentially a revenue generating mechanism for the groundwater district with very little impact on water conservation. The analysis indicated that for the water pumpage fee to be effective in reducing the decline in saturated thickness, a higher fee would be required. The region should be divided into sub-regions with similar hydrology and water withdrawal patterns in order to maintain water pumpage fees that will be effective conservation tools. In addition, the water pumpage fee has a direct effect on net farm incomes because the fee is an added cost associated with irrigation.

The 50/50 quota policy showed the greatest effect on the decline in the regional average saturated thickness compared to the baseline scenario, reducing the regional drawdown in saturated thickness over the 50-year time horizon from 38.8% under the baseline scenario to

30.4% for the 50/50 policy. Net income was lower compared to the baseline, however, under the 50/50 policy the reduction in net income per meter of reduced drawdown in saturated thickness was much lower compared to the water pumpage fee policy. From a water management standpoint, the 50/50 quota policy appears to be the more effective and efficient of the two alternative water conservation policies evaluated.

The goal of reducing the drawdown in saturated thickness over time can only be reached by reducing total water withdrawals rather than improving irrigation efficiency. Within the models developed for this study, water conservation was accomplished by shifting toward crop enterprises that require less applied water or toward dryland production. The end result under each alternative policy was a reduced level of overall crop production, a lower level of net income to the agricultural sector, and a lower level of gross revenues contributed by the agricultural sector to the regional economy.

By combining the optimization analysis and regional economy analysis in this study, we are able to illustrate the opposing impacts on the two members of the community. The water fee policy has virtually no impact on the regional economy but has a large negative impact on producers' net income. The 50/50 policy, on the other hand, did not reduce producers' net income as much as the water fee policy but the impact on the regional economy was dramatic due to the effect of the reduced irrigated area and the reduction in economic activity for input purchases. Although using both the optimization and input/output models adds complexity to the analysis, the results allow policy makers to understand the competing interest involved in the region.

Of the two alternative policies evaluated, the 50/50 quota policy was found to be the more effective in terms of the amount of water conserved and thus, maintaining a greater level of saturated thickness over the planning horizon. However, the 50/50 policy was only effective in those counties with high water withdrawals or low initial saturated thickness. In those counties with low water withdrawals and high initial saturated thickness, the policy had no effect on reducing water withdrawals, leading to distributional inequities across the region. Under the 50/50 quota policy, it was also found that the SHPT regional economy would be negatively impacted due to the reduced level of gross revenues contributed by the agricultural sector. For these reasons, groundwater conservation district policy makers should consider distributional inequities across the region due to the heterogeneity of the aquifer and of water withdrawal patterns, as well as the relative trade-offs between water conservation and economic impact when considering changes in current policies.

5. Policy Implementation

Currently, these policies have not been implemented in any of the water districts of the study area, although the Panhandle Groundwater Conservation Distinct in an area north of the study area has implemented the 50/50 policy in a relatively small study zones. Two methods have been discussed to implement the 50/50 policy. The first of which makes use of monitoring wells on the property to ensure that the saturated thickness does not decline past the 50% level at any time during the 50 year period. An irrigator could possibly use the allotted 50% in less time than 50 years then stop pumping and stay within the stated guidelines.

Another potential method being discussed for the 50/50 policy is an annual quota to be monitored sing monitoring wells on the property that will result I no more than 50% reduction in saturated thickness over the 50 year period. The most straightforward approach is 1% per year using the initial saturated thickness to calculate the annual allowed drawdown throughout the 50 years period. Another approach is to set the annual allowed drawdown at 1.25% of saturated thickness and recalculate every 5 years with the saturated thickness level at that time. The latter method allows more water use in the early years and rewards conservation efforts. For instance, if the water table is maintained ate 80% of initial level, the irrigator will be able to use the same amount of water as that allowed in the 1% alternative. The irrigator under the 1% alternative has not incentive to conserve because the allotted water remains the same even if he is able to reduce drawdown over the years. Although the advantage of the 125% per year alternative seems counter-intuitive because it allows more water to be used in the early years, the alternative provides the irrigator with flexibility and incentive to reduce drawdown over the years.

The water use fee as currently defined will be assessed by the underground water district and will be used locally in the district rather that at the state level. As shown, the $1 per acre foot of water use does very little to change the level of water pumped. Therefore, this fee becomes another method of collecting revenue for the water conservation district rather than a conservation tool.

[1] From the assumption of 2,000 pumping hours, the following relationship was developed: [(2000 hours) * (60 minutes/hour)] / (1000 liters / cubic meter)] = 120 cubic meters / liter per minute.

[2] Saturated thickness of the aquifer was converted to cubic meters of water using a storage coefficient of 15% per meter of saturated thickness.

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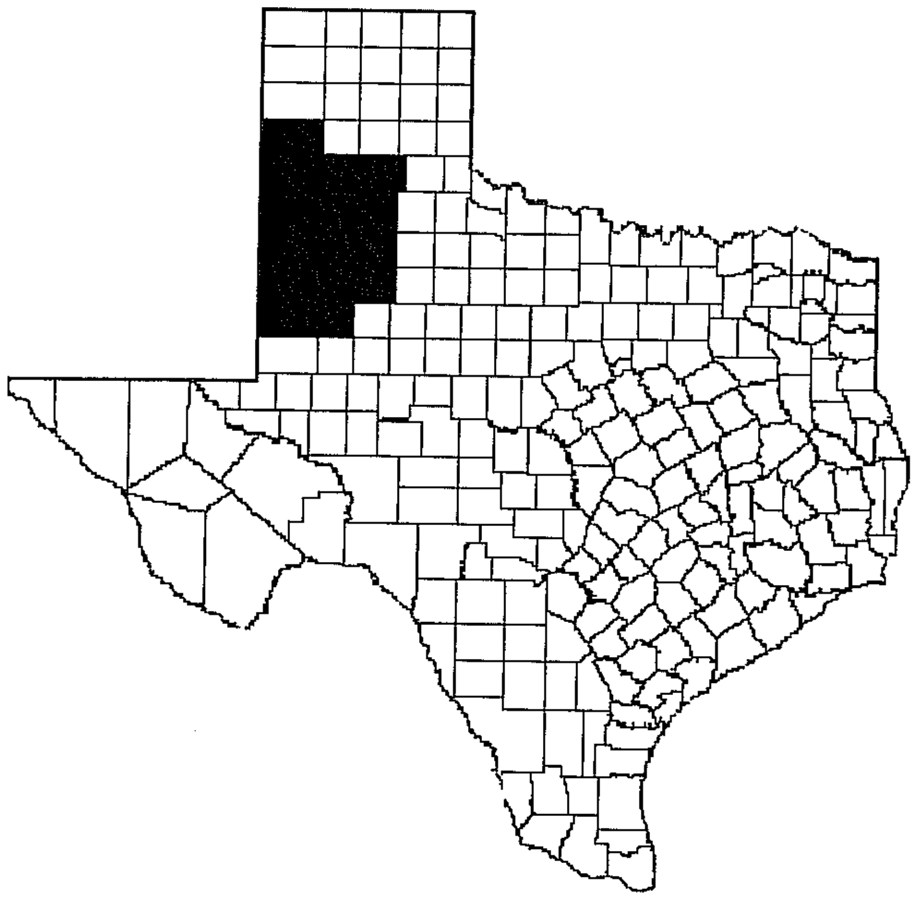

Figure 1. Southern High Plains Region of Texas

Table 1. Percent Irrigated Area within the Region over the 50-Year Time Horizon by Policy Policy

Period	Baseline (%)	Water pumpage fee Policy (%)	50/50 Policy (%)
1	52.1	52.1	52.1
5	49.4	48.8	48.5
10	44.8	43.9	41.7
15	39.4	38.9	34.7
20	35.2	34.9	29.6
25	31.5	31.4	26.8
30	29.2	29.1	24.1
35	27.6	28.0	19.8
40	28.4	27.2	20.3
45	25.4	25.7	18.0
50	22.9	23.2	16.5

Table 2. Average Saturated Thickness in Meters Over the 50-Year Time Horizon by Policy

Period	Baseline (meters)	Water pumpage fee Policy (meters)	50/50 Policy (meters)
1	21.4	21.4	21.4
5	20.0	20.0	20.0
10	18.4	18.5	18.5
15	17.1	17.2	17.4
20	16.1	16.2	16.6
25	15.3	15.5	16.0
30	14.7	14.9	15.6
35	14.3	14.5	15.4
40	13.8	14.0	15.2
45	13.4	13.6	15.0
50	13.1	13.3	14.9

Table 3. Water Pumpage Fee Necessary to Conserve Water to the Level of 50% Drawdown in 50 Years for those Counties that Withdrew More Than 50% in 50 years under the Baseline Scenario.

County	Water Pumpage Fee Required to Conserve Water at 50% Drawdown in 50 years ($/cubic meter x 10^{-2})
Deaf Smith	0.73
Floyd	1.22
Hale	2.11
Hockley	0.65
Lubbock	2.03
Swisher	3.16
Terry	0.41

Table 4. Change in Regional Economic Output in Dollars from Baseline over the 50-Year Time Horizon

Period	Direct ($ million)	Indirect ($ million)	Induced ($ million)	Total ($ million)
Water pumpage fee policy				
10	-34.6	-18.2	-5.5	-58.3
20	-11.9	-6.3	-1.9	-20.1
30	-4.7	-2.5	-0.7	-7.9
40	-48.4	-25.5	-7.8	-81.8
50	+13.1	+6.9	+2.1	+22.1
50/50 policy				
10	-169.1	-89.2	-26.8	-285.1
20	-248.9	-131.3	-39.8	-420.1
30	-224.5	-118.4	-36.0	-378.9
40	-410.2	-216.5	-65.6	-692.3
50	-324.2	-171.1	-51.8	-547.2