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WATER CONSERVATION POLICY ALTERNATIVES FOR THE TEXAS SOUTHERN HIGH PLAINS

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Abstract

This study examined the regional impact of alternative groundwater conservation policies on the Ogallala Aquifer of the Southern High Plains of Texas. Nonlinear optimization models were developed to analyze three scenarios involving imposing production fees, restricting annual pumpage, and restricting the decline in saturated thickness of the aquifer for the purpose of conserving regional water resources. The three alternatives were analyzed for their effectiveness in restricting the aquifer drawdown and the associated agricultural costs of each alternative.

Introduction

The Southern High Plains of Texas is facing a future water shortage caused by the declining water levels of the Ogallala Aquifer. Municipal water availability is not considered to be in a crisis situation at the present time, but water available for agricultural irrigation is declining in some areas to the point of economic or physical depletion. As water available for irrigation declines, yields of agricultural products will decrease. The economic impact of decreased agricultural production and sales may impact rural communities negatively sooner than a municipal water availability crisis.

The source of irrigation water for this region is the southern portion of the Ogallala Aquifer. The Ogallala Aquifer is considered an exhaustible aquifer in this region due to a low recharge rate. Pumpage from the aquifer far exceeds recharge. Agriculture uses 95% of the water pumped from the aquifer in the Southern Texas High Plains (HDR, 2001).

Several studies have shown that with continued use, the level of water in the aquifer will continue to decline toward economic depletion. With the decline of the aquifer, agricultural cropping systems will transition from irrigated systems to non-irrigated systems. The transition will have a gradual effect on the region, as well as on individual farmers. As saturated thickness decreases, the amount of water available at each well and the rate of pumpage will decrease, resulting in fewer acres irrigated per well. Rather than an immediate transition from irrigated to dryland cropping practices, each irrigating farmer will irrigate fewer acres over time, contributing to the decrease in irrigated acres in the region

Landowners in Texas control the extraction of groundwater with some limits imposed by underground water conservation districts. Texas water law was structurally impacted by the passage of Senate Bill 2 (SB2) in 2002, which provided a regulatory basis enabling local and state government agencies to impose stronger controls on the extraction of groundwater. Article 2 of SB2 authorized groundwater districts to assess production fees based on the amount of water authorized to be withdrawn or actually withdrawn. Article 2 states that the fees shall not exceed $1 per acre-foot per year for agricultural production or $10 per acre-foot per year for other purposes (Senate Bill 2, and TJCWR, 2002).

Adoption and implementation of effective water conservation policies can extend the life of the Ogallala Aquifer in the Southern High Plains of Texas. With the passage of Senate Bill 2, Texas underground water conservation districts have the authority to restrict a landowner's use of water and impose production fees. If underground water conservation districts begin to implement policies that reduce pumpage, this could result in the extension of the life of the Ogallala Aquifer. By restricting the amount of water to be used for irrigation, individual farmers would plant fewer irrigated acres and more non-irrigated acres than with unrestricted water use, but they would be able to irrigate longer into the future on the reduced number of irrigated acres.

Regional water conservation policy decision-makers must consider the economic benefit of extending the life of the aquifer and the impact of various policy instruments that can be used. The primary objective of this study was to analyze the impact of water conservation policy alternatives on the regional economy of the Southern High Plains of Texas.

Methods and Procedures

In order to analyze the impact of water conservation policy alternatives for the regional economy of the Southern High Plains of Texas, a dynamic optimization model was used to estimate the economic life of the aquifer across the region under different water conservation scenarios. The overall study region included 19 counties within the Groundwater Management Area 2 (GMA2), which includes 19 of the 21 counties within the Region O planning area and 12 of the 15 counties within the High Plains Underground Water Conservation District #1.

The model used in this study is a modification of the models used by Feng (1992) and Terrell (1998) with adjustments made to develop a nonlinear dynamic model that considered nonlinear crop enterprise production functions. The models developed for this study estimated the optimal level of water extraction for irrigation and the resulting net present value of net returns over a planning horizon of 50 years. The models were run for a baseline scenario with no change in water conservation policy and for three conservation policy alternatives: (1) a production fee of $1 per acre-foot pumped, (2) an annual restriction of water use to 75% of a 10 year average water use, and (3) a restriction on the drawdown of the aquifer over the 50-year planning horizon to 50% of the initial saturated thickness at the beginning of the period. The results of this study considered the changes in water use per acre, saturated thickness, pumping lift, gross revenue per acre, and net income per acre as the differences of the values of the alternative policy scenarios from the values found in the baseline scenario.

Non-linear dynamic programming with GAMS (Brooke, et al, 1998) was used in this study to facilitate multiple runs of the model considering different water conservation scenarios. In order to develop the non-linear programming model, the functional relationship between yield and applied irrigation water needed to be developed for key crops in the region. In this study, the Crop Production and Management Model (CROPMAN) (Gerik and Harman, 2003) was used to develop the production functions describing the yield response to applied water. The model requires the user to designate the crop, type of irrigation system, soil type, and weather station location. The gross soil type was selected using the USDA soil map for each county and selecting the predominant soil type shown for the major crop-producing region of the county. The production functions for dryland and irrigated crops were estimated for corn, cotton, grain sorghum, peanuts, and wheat. The production techniques and timing of cultural practices were held constant for irrigated crops with only the irrigation amounts varying. The irrigation timing was also held constant with the amount of irrigation water applied divided between the various dates of irrigation. The yields were recorded for each irrigation amount for each crop. Yield response functions were estimated using a quadratic functional form with yield per acre as the dependent variable and irrigated water applied as the independent variable. The models were estimated using the ordinary least squared regression technique.

The optimization model incorporated the production functions from the CROPMAN models to develop a non-linear form of the model. County specific data for each model include land area of the county, land area of the county overlying the Ogallala Aquifer, amount of annual recharge, specific yield for the aquifer, initial saturated thickness, initial pump lift, initial well yield, initial acres per well, initial acres per crop, and initial number of irrigated acres in the county. Crop specific data include the 15-year average of commodity prices, variable costs of dryland crop production excluding harvest costs, the added variable costs for irrigated crop production, and harvest costs per unit of production. Commodity prices used in the analysis are averages of monthly prices for fifteen years as reported by the Texas Agricultural Statistics Service. The variable costs for dryland crop production and the additional costs for irrigation were taken from enterprise budgets developed by the Texas Agricultural Extension Service for Texas Extension District 2. Energy data included an energy use factor for electricity of 0.164 KWH / feet of lift / acre-inch, system operating pressure of 16.5 pounds per square inch, energy price of $0.0633 per KWH, and pump engine efficiency of 50%. Other costs include the initial cost of the irrigation system of $280 per acre, annual depreciation percentage of 5%, irrigation labor of 2 hours per acre, labor cost of $8 per hour, annual maintenance cost of 8% of initial cost, and a discount rate of 3%. Cost calculations included harvest costs, pumping costs, and total costs of production for irrigated and dryland crops. The units for the resulting values are dollars per acre ($/acre).

Results

Irrigated Acres

The results of the baseline analysis as shown in Figure 1 indicate that the average number of irrigated acres in the region initially increases from approximately 52% to approximately 68% in the first 10 years of the planning horizon. This increase in irrigated acres is the result of treating each county as a homogeneous unit with one soil type and consistent hydrogeologic characteristics averaged across the county, and the deviation of current crop selection and resource allocation to the optimal solution. The assumption that all irrigated acres are under sprinkler LEPA irrigation systems also contributes to this increase due to the higher efficiency of the LEPA systems over furrow irrigated systems which account for a significant portion of the irrigated acres currently. To mitigate the effect of the increase in irrigated acres with the optimization model, comparative analysis was conducted in relation to the baseline solution rather than absolute conditions.

The production fee scenario that included a fee of $1 per acre-foot of water used predictably showed little deviation from the baseline scenario, although always at the same level or below the baseline number of irrigated acres. At the end of the 50-year period, irrigated acres were approximately 33% of total crop acres for the production fee scenario and approximately 36% for the baseline scenario. The baseline and production fee scenarios exhibit a rapid decline in the number of irrigated acres from approximately 68% in year 12 to approximately 35% in year 40. Both scenarios tend to stabilize at that point through the completion of the 50-year period.

The scenario that restricted annual water use to a level of 75% of the average water used in the initial 10-year period showed a steady decrease in irrigated acres from the initial 52% to approximately 32% by year 28. The ending level of irrigated acres was very close to the average irrigated acres in the baseline and between the ending level of irrigated acres for the baseline and production fee scenarios.

The third conservation scenario restricted water users to depleting the aquifer to no more than 50% of the initial level of saturated thickness. The initial number of irrigated acres followed the baseline through year 7 then began a steep decline in the number of irrigated acres to a level of approximately 12% by year 50.

Average Annual Water Use

Average annual water use per acre is the amount of water used on irrigated crops averaged across all cropland acres and expressed as the number of inches of water used per consolidated acre. The water use is calculated by multiplying the amount of water used for each acre of irrigated crop by the percentage of cropland that particular crop covers.

Average annual water use for the baseline and production fee scenarios as shown in Figure 2 increased over the first 10 years in a similar pattern as the average irrigated acres from approximately 8 inches per acre to approximately 14 inches per acre. The cause of this increase in water use included the increase in irrigated acres as well as a shift in some counties to more water intensive crops. The decline in average annual water use began in year 11 and continued through year 42 at which time both scenarios stabilized at approximately 8 inches per acre for the baseline scenario and approximately 6.5 inches per acre for the production fee scenario.

The conservation scenario that restricted annual water use began the decline in average annual water use early in the period and continued through year 27 at which time it stabilized and remained relatively constant at approximately 6.5 inches per acre. The ending water use in year 50 was very similar to the annual water use exhibited in the production fee scenario.

The conservation scenario that restricted the decline in the saturated thickness of the aquifer showed a rapid decline in water use from a high of approximately 12 inches per acre in year 7 to approximately 2.5 inches per acre in year 45.

Saturated Thickness

The average saturated thickness of the baseline and production fee scenarios as shown in Figure 3 decreased rapidly from an initial level of approximately 70 feet to approximately 40 feet by year 30. The rate of decline then slowed resulting in an average saturated thickness of 32 feet for the baseline scenario and 33 feet for the production fee scenario by year 50. The saturated thickness projected by the production fee scenario is greater than the baseline throughout the 50-year period although only slightly greater. The average saturated thickness projected by the scenario restricting annual water use exhibits a much slower decline from the initial level of 70 feet to a level of 45 feet at the end of the 50-year period. The average saturated thickness projected by the scenario that restricts the decline in saturated thickness of the aquifer initially exhibits a decline with the baseline scenario until year 20 at which time the level of the saturated thickness stabilized at approximately 45 feet. From the results of the model, the scenarios that result in the least decline in saturated thickness are the scenarios that restrict water use either on an annual basis or by restricting the decline of the aquifer.

Annual Net Income

Annual net income per acre for the baseline and production fee scenarios as shown in Figure 4 increased through year 17 to a level of approximately $29 per acre then began to decrease slowly to a level of approximately $21 per acre by year 50. The annual value for both scenarios differed very little through the 50-year period.

The annual net income per acre for the scenario that restricted annual water use increased rapidly through year 43 to a level of approximately $25 per acre then remained stable through the end of the 50-year period. The annual net income per acre for the scenario that restricted the decline in saturated thickness increased rapidly following the path of the baseline scenario until approximately year 30 when it began to decrease at a more rapid rate to a level of $20 per acre by year 40.

Net Present Value

Net present value of total net income for the 19-county region was calculated over the 50-year period using a discount rate of 3% and is shown in Figure 5. The net present value of the net income for the region for the baseline scenario was $6.77 billion, or $645 per acre. The production fee scenario resulted in a decrease in net present value of net income of 4% from the baseline with a value of $6.52 billion, or $621 per acre. The scenario that restricted annual water use resulted in the greatest decrease from the baseline of 16% with a value of $5.72 billion, or $545 per acre. The scenario that restricted the decline of saturated thickness resulted in a decline from baseline of 6% with a value of $6.22 billion, or $593 per acre.

Conclusions and Discussion

Recent legislation has provided regulatory alternatives for use by the underground water conservation districts to manage groundwater use. This study has investigated three alternatives and the impact of their use on the groundwater level and on the economy of the 19-county region of the Southern High Plains of Texas.

The alternative scenario that imposed production fees of $1 per acre-foot exhibited little change from the baseline scenario with irrigated acres showing less than 1% change from baseline throughout the period, water use decreasing to 17% less water used annually in year 50 than in the baseline scenario, saturated thickness at 6.5% greater than the baseline scenario in year 50, and the annual net income per acre in year 50 at 1.5% less than the baseline scenario.

The alternative water policy scenario that restricted annual water use resulted in an immediate decrease in water used and crop revenue. The level of annual water use stabilized in year 28 with the end result of a level of saturated thickness 30% greater that the baseline by the end of the 50-year period. The net present value of net income per acre, however, was dramatically lower than baseline and the lowest of the three alternatives considered, at approximately 15% below baseline.

The alternative water policy scenario that restricted the amount of drawdown of the aquifer to 50% of the initial level of saturated thickness resulted in a level of saturated thickness similar to the annual water use restriction alternative at the end of the 50-year period and a net present value of annual net income only 6% below baseline levels. This method allowed more producer flexibility than the annual water use restriction resulting in water use and cropping patterns similar to the baseline early in the period but progressing at a slower rate to a level of crop production that allowed more water being saved.

The difference in net present value of annual net income between these two methods of water pumpage restriction is a result of the discount rate and the time value of money. The annual water use restriction method caused an immediate decrease in water use and crop production in the early years of the period when the present value of annual net income was highest. Restricting the aquifer drawdown allowed continued production and water use early in the period with restricting conditions beginning during the latter half of the 50-year period when present value was lower than earlier years.

The effectiveness of the three methods can be measured with a ratio comparing the change in net present value of annual net income per acre from baseline and the associated change in level of saturated thickness. The values for the ratios are $11.58 per foot of saturated thickness change for the production fee scenario, $8.20 per foot of saturated thickness change for the annual restriction scenario, and $3.86 per foot of saturated thickness change for the drawdown restriction scenario. Restricting aquifer drawdown is much more effective than the other alternatives considered. These values represent the cost in reduced net income per acre per foot of saturated thickness remaining above the baseline at the end of the 50-year planning horizon. The purpose of the ratio is to establish a cost of maintaining the water in the aquifer rather than pumping it. The negative change in the net present value of the annual net income, or loss, is considered the cost of maintaining the water for each scenario. The benefit for each scenario is the positive change in the level of saturated thickness of the aquifer. The ratio demonstrates the effectiveness of each scenario by showing the cost associated with maintaining one acre-foot of water in the aquifer rather than pumping.

Of the three alternatives evaluated, the alternative that restricts drawdown to 50% of the initial saturated thickness is the most effective, saving the most water in the aquifer at the least cost to the regional economy. This policy has several advantages compared to the other policies evaluated. Agricultural producers would have more flexibility in managing their irrigation practices under this scenario compared to the restriction on annual water use. An annual pumpage restriction could create a situation where producers would be unable to supply the optimal levels of irrigation water in drought years, whereas, the drawdown restriction provides the flexibility for producers to make those decisions in extreme situations such as drought.

The production fee scenario did not cause as much reduction in the loss of saturated thickness as did the annual water use restriction scenario or the restriction on drawdown of saturated thickness. The production fee authorized in Senate Bill 2 of $1 per acre-foot is not sufficient to impact an irrigator's decision with respect to the levels of water applied. A much higher production fee will be required for this type of policy to be effective in reducing irrigation levels.

Other considerations that are beyond the scope of this study are the cost of administering the different alternatives and the popular and political reception of the different alternatives. It seems that the drawdown restriction policy is the least intrusive to the water user and the most easily monitored, therefore, the most popular and least costly in addition to being the most effective.

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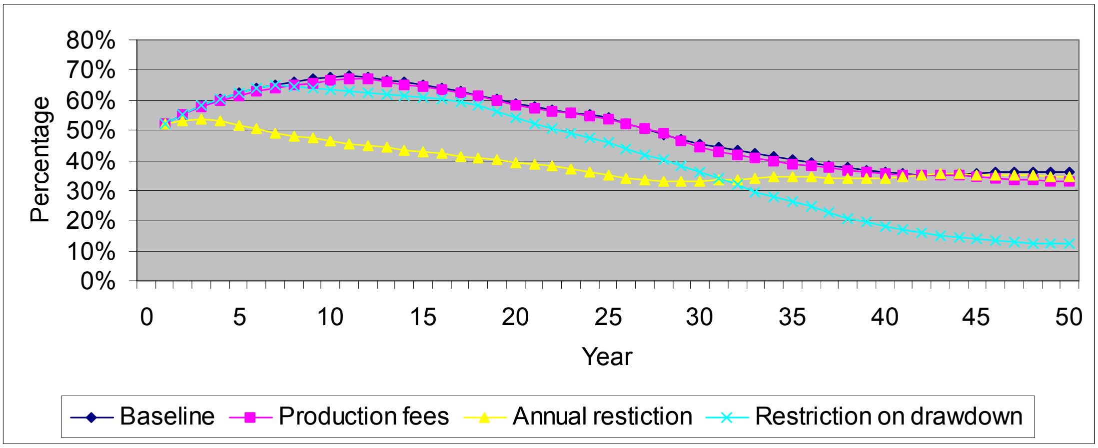

Figure 1. Average irrigated acres.

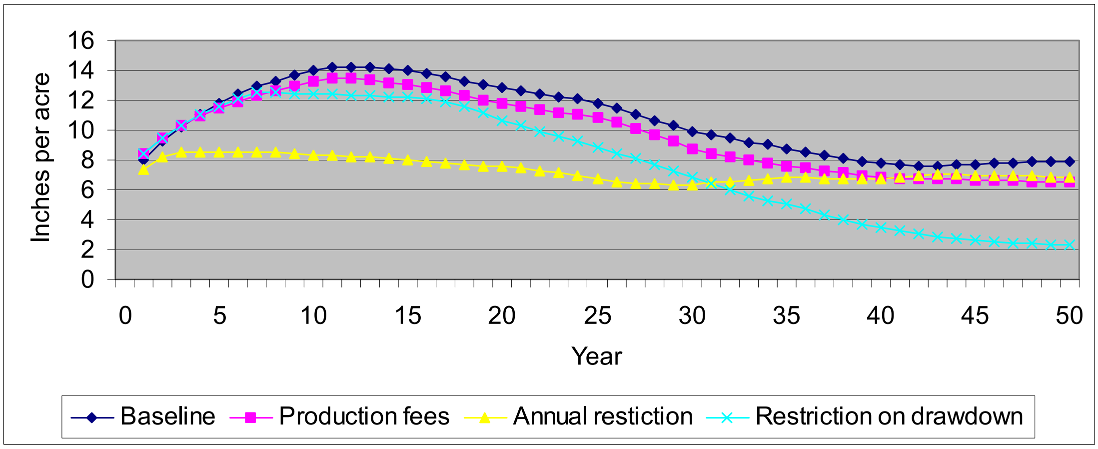

Figure 2. Average water use.

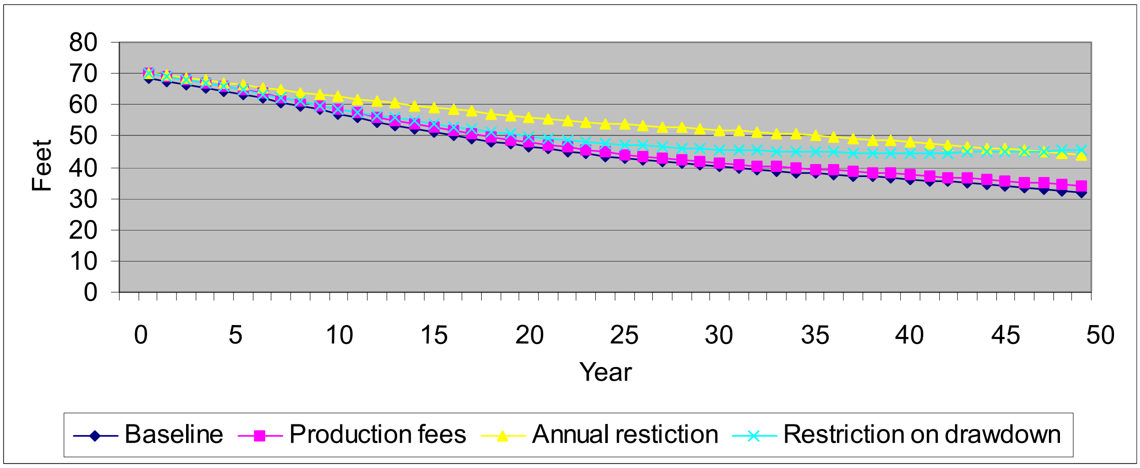

Figure 3. Saturated thickness.

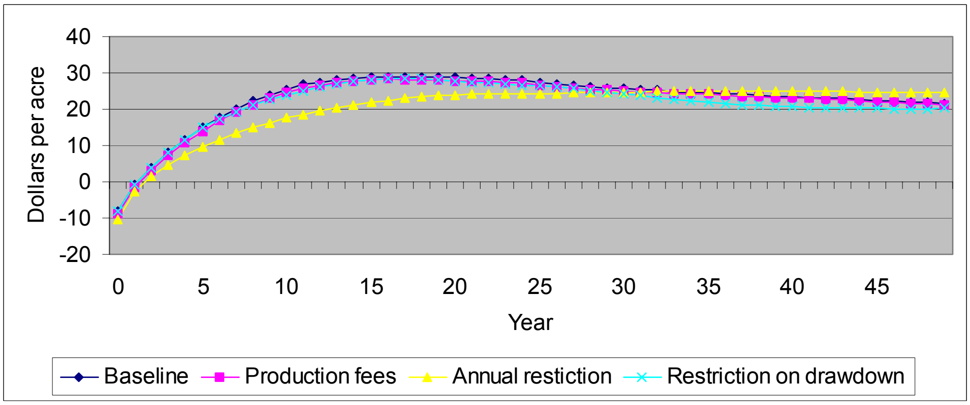

Figure 4. Net income per acre.

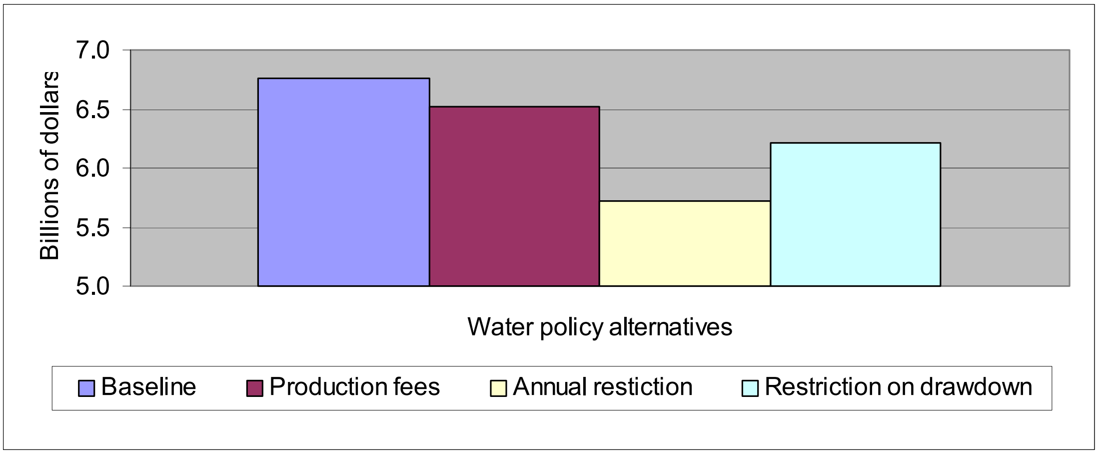

Figure 5. Net present value.