Aquifer Depletion and the Cost of Water Conservation: The Southern High Plains of Texas Case

by

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Abstract

Irrigated agriculture has played a vital role in the development and growth of the Great Plains Region of the United States. The primary source of water for irrigation in this region is the Ogallala Aquifer. The Southern portion of the Ogallala Aquifer is considered exhaustible due to the low level of recharge relative to the quantities of water pumped. Analysis and evaluation of water conservation policies which could extend the economic life of the Ogallala Aquifer in the Southern High Plains of Texas and Eastern New Mexico, and which could contribute to maintaining the viability of the regional economy is important. This study evaluates the impacts of water conservation policies which limit drawdown of the Ogallala Aquifer.

County level dynamic optimization models maximizing net present value of net returns to land, management, groundwater, and irrigation systems over a sixty year planning horizon were formulated to evaluate three aquifer drawdown restrictions. The results of this study indicate that because of the differences in hydrologic characteristics and current irrigation levels across counties in the study area, blanket water conservation policies for the region as a whole are likely to be inefficient. This study concludes that for this region, water conservation policies that focus on counties that would deplete the aquifer to less than 30 ft. of saturated thickness possess the lowest implicit cost of conserving saturated thickness.

Key words: water conservation, water policy evaluation, aquifer management, dynamic optimization.

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Introduction

Since the late 1800's, irrigated agriculture has played a vital role in the development and growth of the Great Plains Region of the United States. The primary source of water for irrigation in this region is the Ogallala Aquifer, which encompasses 174,000 square miles and underlies parts of eight states (Alley, Riley, and Franke, 1999). In the Great Plains Region, the water pumped from the Ogallala Aquifer accounts for approximately 65% of the total water used for irrigation in the U.S. annually (High Plains Water District No. 1, 2004).

The Southern portion of the Ogallala Aquifer is considered exhaustible due to the relatively low level of recharge when compared to the quantities of water pumped annually for agricultural production (Birkenfeld, 2003). The Great Plains region produces approximately 45% of the national production of wheat, 25% of the national production of corn, over 88% of the national production of grain sorghum, and 32% of the national production of cotton (National Agricultural Statistics Service, 1999).

Water conservation policies may effectively extend the economic life of the Ogallala Aquifer in the Southern High Plains of Texas and Eastern New Mexico, and may contribute to maintaining the viability of a regional economy which is highly dependent on agricultural production. This study evaluates water conservation policies which limit drawdown of the Ogallala Aquifer over a sixty year planning horizon.

The policy alternatives considered in this study include: 1) compensating producers for decreasing water usage to 0% drawdown relative to the amount that would have otherwise been used over sixty years through a water conservation reserve program, 2) limiting water usage to limit drawdown to 50% of the water that would be used in the absence of a policy over sixty years, and 3) limiting water usage to limit drawdown to 75% of what would be remaining in the aquifer without a policy over sixty years.

The first alternative considered is similar to the Federal Conservation Reserve Program (CRP) enacted for soil conservation, but with a goal of water conservation. The second and third alternatives are directly linked to Senate Bills 1 and 2 passed by the Texas Legislature in 1997 and 2001, respectively.

Study Area

This study focuses on the Southern Sub-Region (Figure 1) of the Great Plains which includes the Southern portion of the Texas Panhandle and Eastern Plains of New Mexico. Specifically, the counties considered were: Andrews, Bailey, Borden, Cochran, Crosby, Dawson, Dickens, Floyd, Gaines, Garza, Glasscock, Hale, Hockley, Howard, Lamb, Lubbock, Lynn, Martin, Midland, Motley, Terry, and Yoakum in Texas, and Lea and Roosevelt in New Mexico.

Objectives

The primary objective of this study was to analyze and evaluate the impacts of selected water conservation policy alternatives on the Ogallala Aquifer underlying the

Southern High Plains of Texas and Eastern New Mexico for the purposes of identifying effective ways of achieving conservation of the aquifer and keeping the heavily agriculturally dependent economy viable. The specific objectives were to: (1) evaluate the likelihood that water conservation policy alternatives could extend the economic life of the aquifer and (2) evaluate the economic life of the aquifer across the region under different water conservation alternatives for a sixty year planning horizon.

Optimization Model Specification

The framework of the optimization model used in this study was originally developed by Feng (1992), and has been expanded and modified by Terrell (1998), Johnson (2003), and Das (2004). The objective of the this study's county level optimization models was to maximize net present value of net returns to land, management, groundwater, and irrigation systems over a sixty year planning horizon for a given county as a whole. The objective function is:

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

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

$$NR_t = \sum_i \sum_k \Theta_{ikt} \{ P_i Y_{ikt} [WA_{ikt}, (WP_{ikt})] - C_{ik} (WP_{ikt}, X_t, ST_t)\}. \qquad (2)$$

Where: i represents crops grown; k represents irrigation technologies used; Θ_{ikt} is the percentage of crop i produced using irrigation technology k in time t, P_i is the output price of crop i, WA_{ikt} and WP_{ikt} are per acre irrigation water applied and water pumped per acre respectively. $Y_{ikt}[\cdot]$ is the per acre yield production function, C_{ikt} represents the costs per acre, X_t is pump lift at time t, ST_t represents the saturated thickness of the aquifer at time t. The constraints of the model are:

$$ST_{t+1} = ST_t - [(\sum_i \sum_k \Theta_{ikt} * WP_{ikt}) - R]A/s, \quad (3)$$

$$X_{t+1} = X_t + [(\sum_i \sum_k \Theta_{ikt} * WP_{ikt}) - R]A/s, \quad (4)$$

$$GPC_t = (ST_t/IST)^2 * (4.42*WY/AW), \quad (5)$$

$$WT_t = \sum_i \sum_k \Theta_{ikt} * WP_{ikt}, \quad (6)$$

$$WT_t \le GPC_t \quad (7)$$

$$PC_{ikt} = \{[EF(X_t + 2.31*PSI)EP]/EFF\}*WP_{ikt}, \quad (8)$$

$$C_{ikt} = VC_{ik} + PC_{ikt} + HC_{ikt} + MC_k + DP_k + LC_k \quad (9)$$

$$\sum_i \sum_k \Theta_{ikt} \le 1 \text{ for all t}, \quad (10)$$

$$\Theta_{ikt} \ge (2/3)\ \Theta_{ikt-1}, \quad (11)$$

$$\Theta_{ikt} \ge 0. \quad (12)$$

Equations (3) and (4) represent the two equations of motion included in the model which update the two state variables, saturated thickness and pumping lift, ST_t and X_t, respectively. R represents the annual recharge rate in feet, 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.

Constraints (5), (6) and (7) are the water application and water pumping capacity constraints, respectively. In equation (5), GPC represents gross pumping capacity, IST represents the initial saturated thickness of the aquifer and WY represents the average initial well yield for the county. Equation (6) represents the total amount of water pumped per acre, WT_t, as the sum of water pumped on each crop. Constraint (7) requires WT_t to be less than or equal to GPC.

Equations (8) and (9) represent the cost functions in the model. In Equation (8), PC_{cit} represents the cost of pumping, EF represents the energy use factor for electricity, EP is the price of energy, EFF represents pump efficiency, and 2.31 feet is the height of a column of water that will exert a pressure of 1 pound per square inch. Equation (9) expresses the cost of production, C_{ikt} in terms of VC_{ik}, the variable cost of production per acre, HC_{ikt}, the harvest cost per acre, MC_k, the irrigation system maintenance cost per acre, DP_k, the per acre depreciation of the irrigation system per year, and LC_k, the cost of labor per acre for the irrigation system.

Equation (10) 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 1. Equation (11) is a constraint placed in the model to limit the annual shift to a 33% change from the previous year's acreage. Equation (12) is a non-negativity constraint to assure all decision variables in the model take on positive values.

Data Used

The county specific data compiled for each county within the study region for both Texas and New Mexico included a five year average of planted acreage of cotton, corn, grain sorghum, wheat and peanuts; total acreage under conventional furrow, low application spray application (LEPA) and dryland. Operating costs were also collected for specific crops, including fertilizer, herbicide, seed, insecticide, fuel, irrigation technology maintenance, irrigation, labor, and harvesting costs. Finally, hydrologic data were collected, including the area of each county overlying the aquifer, average recharge, total crop acres per irrigation well, average saturated thickness of the aquifer, initial well yield, and average pump lift.

Results

Optimal levels of saturated thickness depletion, annual net revenue per acre, pumping lift, water applied per cropland acre, cost of pumping, and net present value of net returns per acre (NPV) by county were derived using the non-linear dynamic optimization model for a baseline scenario (no restrictions on water use) and the three water conservation policy alternatives considered. Five counties in the study area, Borden, Dickens, Howard, Martin, and Motley showed increases in saturated thickness over the sixty year planning horizon, likely due to minimal irrigation in these counties. For this reason, policy results reported for these counties are for the 0% drawdown policy only. The remaining policy alternatives' results for these counties are not reported because the policy restrictions were non-binding and showed no deviation from the baseline. These five counties in the region also showed relatively low net revenue per acre and water applied per cropland acre. These counties lie relatively close to the eastern edge of the Ogallala Aquifer and have low saturated thickness levels and low concentration irrigation compared to other counties in the study area.

Apart from the five low saturated thickness counties mentioned above, results of the baseline scenario and policy alternatives showed generally consistent trends across the region in irrigation practices and cropping patterns. Though the overall regional trends are similar in irrigation practices and cropping patterns, the results of the policies also show that the impacts of the policies differ greatly across the region. One major factor examined that demonstrates the major differences across the region is the implicit cost of each policy. Table 1 depicts the implicit cost of water conservation per acre foot of saturated thickness on a cropland acre basis for the 0% drawdown policy, the 50% total drawdown policy, and the 75% drawdown policy. That is, given a baseline of per acre net present value of returns that would result from the optimal use of ground water in a given county. If the optimal amount of water that would be used in a specific county was to be reduced by 25% (allowing a 75% drawdown from the base), the third column in Table 1 depicts the associated loss in revenue per foot of saturated thickness basis. In the case that ground water use is desired to be completely curtailed (0% drawdown), the first column in Table 1 depicts per foot of saturated thickness associated cost (reduction of revenue) of conserving all ground water by county.

The cost of conserving an additional foot of saturated thickness under these policies is a direct effect of saturated thickness depletion and NPV for each scenario. Andrews, Howard, and Roosevelt Counties, for example, showed either no or a minute amount of aquifer depletion in the unconstrained baseline; therefore, the implicit cost of conserving a foot of saturated thickness is relatively high in those counties. The cost of an additional foot of saturated thickness conservation in Howard County is $2,281.00 for the reason that in the baseline scenario, the saturated thickness increases approximately the same level it does in the 0% policy: the year sixty saturated thickness is only 0.9 ft. higher than the unconstrained baseline scenario in turn causing the significantly high cost. Alternatively, Hale and Lubbock Counties are high water use counties and showed significant levels of depletion in the baseline scenario. Therefore, the implicit cost of an additional foot of saturated thickness in these counties is much lower.

Another interesting finding shown in Table 1 is the increased marginal cost of water conservation as conservation goals are increased. The cost of the 0% drawdown policy is notably higher than both, the 50% total and the 75% policies for all counties in the study area. Conversely, the gap in the costs of an additional foot of saturated thickness between the 50% and the 75% drawdown policies are in close proximity to one another. Gaines County for example shows that the cost of an additional foot of saturated thickness is only $3.77 more in the 50% policy than in the 75% policy. Overall, the results indicate that policy impacts vary greatly across the region. How a policy alternative impacts a particular county depends on the hydrologic characteristics of the county, the level of current irrigation, and the profitability of the crops produced.

Policy Implications

As expected, the 0% Drawdown policy conserved massive amounts of water in the Ogallala Aquifer; but it also significantly decreased NPV and agricultural economic activity across the region. This restrictive policy is not necessary for most counties in the region to conserve water, and would likely have detrimental effects to the regional economy. The decrease in economic activity would be similar to the effects expected in the case of total aquifer exhaustion, which is what water conservation policies are attempting to circumvent. As stated previously, five counties showed an increase in saturated thickness throughout the planning horizon in the unconstrained baseline scenario. Many other counties did exhibit aquifer drawdown in the unconstrained baseline scenario, but not to the extent that a policy this restrictive on water use would be required across the region. This policy would be best used in only those counties, or areas of counties, with extensive annual aquifer drawdown, and be implemented on a portion of total cropland acres within a county.

The 50% Drawdown and 75% Drawdown policies exhibited similar trends. Comparable to the 0% water conservation policy discussed above, neither of these two policies is likely be necessary across the study region. In many counties the 75% drawdown and often the 50% drawdown restrictions were not binding constraints because the levels of saturated thickness underlying those counties in the unconstrained baseline scenario did not decline to the 50% or 75% drawdown levels. As expected, both the 50% drawdown policy and the 75% drawdown policy caused a decrease from the unconstrained baseline NPV, and both conserved water in the aquifer relative to the unconstrained baseline. The 75% policy had a slightly higher NPV than the 50% policy whereas the 50% drawdown policy conserved 25% more water than did the 75% policy.

These two policies were the most restricting on high water use counties. Hale County, for example, which is the highest water use county in the study area, showed a NPV 16% lower than in the baseline for the 50% policy while the 75% policy NPV was 7% lower than the unconstrained baseline. However, the 50% policy conserved an additional 16 ft. more saturated thickness than did the 75% policy.

Alternatively, for Midland County, a low water use county, the NPV for the 50% total policy was 7% lower than in the baseline whereas the 75% policy NPV was only 2% below the baseline. However, in this case, the 50% policy conserved 4 ft. of saturated thickness relative to the unconstrained baseline and the 75% policy conserved 3 ft. of saturated thickness relative to the baseline.

Conclusions

This study indicates that because of the significant differences in hydrologic characteristics and current irrigation levels across the study area, blanket water conservation policies for the region as a whole are likely to be inefficient. Under the baseline scenario, there are many counties in the study area that do not deplete saturated thickness to a level that would warrant implementation of a conservation policy. The cost of conserving an additional foot of saturated thickness in low water use counties is high. Legislative time and resources obtained through taxation would be more efficiently spent enacting policies to conserve water in those counties that more heavily utilize the aquifer underlying the county. For this region, water conservation policies that focus on counties that deplete the aquifer to less than 30 ft. of saturated thickness, where the implicit cost of conserving a foot of saturated thickness is relatively low, can achieve water conservation goals at a lower cost. These are the most heavily irrigated counties in the study region, and society as a whole would most likely benefit from the focus of water conservation in these high water use counties.

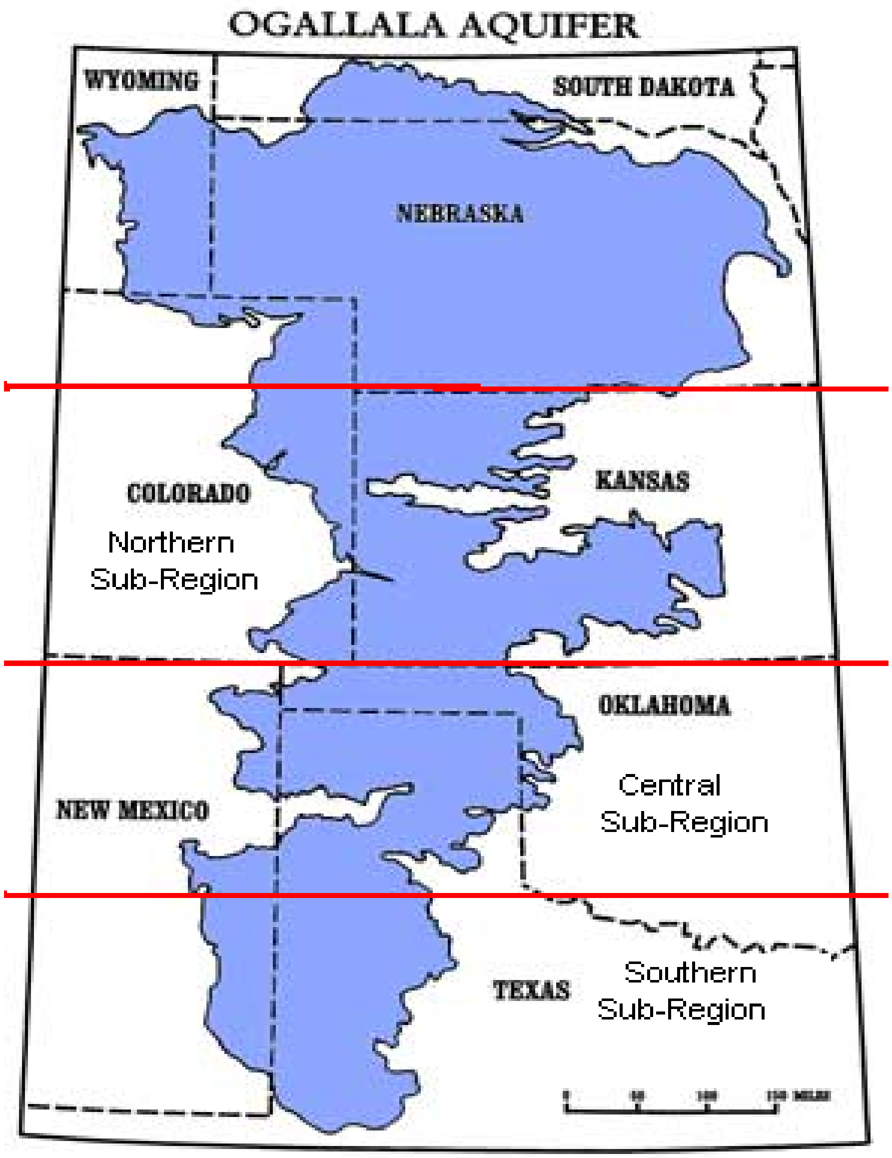

Figure 1: Map of the Ogallala Aquifer and the Great Plains Region.

Table 1. Implicit Cost (Discounted Dollars) of Water Conservation Per Foot of Saturated Thickness, by Policy on a Cropland Acre Basis

County	0% Drawdown	50% Drawdown	75% Drawdown
Andrews	800.98	435.07	340.28
Bailey	21.38	10.12	7.11
Borden	341.89	N/A	N/A
Cochran	54.82	27.75	20.99
Crosby	25.43	11.90	8.24
Dawson	79.88	20.60	10.56
Dickens	70.03	N/A	N/A
Floyd	49.96	34.68	28.62
Gaines	29.56	20.81	17.04
Garza	119.78	55.00	37.11
Glasscock	43.41	8.91	4.29
Hale	38.60	33.81	29.56
Hockley	58.70	41.27	35.30
Howard	2281.00	N/A	N/A
Lamb	20.11	14.34	11.92
Lea	427.32	226.68	164.24
Lubbock	21.04	16.36	14.31
Lynn	82.68	29.43	14.30
Martin	473.23	N/A	N/A
Midland	112.42	47.32	27.87
Motley	80.17	N/A	N/A
Roosevelt	343.90	110.89	63.37
Terry	83.98	59.58	48.78
Yoakum	58.35	34.70	27.65

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