Economic Value of Groundwater Resources and Irrigated Agriculture in the Oklahoma Panhandle

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An economic optimization model was developed using available groundwater resources in the Oklahoma Panhandle to estimate value of water for irrigated agriculture in the area. The model will serve as policy tool to analyze alternative water management strategies and conservation programs to assess the economic impact of depleting Ogallala Aquifer.

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Abstract:
An economic optimization model for a sixty years planning horizon is developed using available groundwater resources in the Oklahoma Panhandle. Net present value and total water use over 60 years is used to estimate the value of water for irrigated agriculture in the area. The model will serve as a policy tool to analyze alternative water management strategies and water conservation programs that can possibly be implemented in the area. The results from the model will be used to assess the economic impact of depleting groundwater availability from the Ogallala Aquifer.

Key Words: Ogallala Aquifer, Irrigated Agriculture, Groundwater Conservation, Water Management Policy, Oklahoma Panhandle.

Introduction:
The current state of underground water utilization and availability in the Great Plains is a reflection of the combined result of current economic, social, and political factors. The underground water resources in the Great Plains are being used at a rate higher than the natural rate of recharge because the revenue stemming from their current use is higher than the associated cost of extraction. However, underground water use in the Great Plains, given the critical dependence of the regional economy on this resource, is an inter-generational issue that must be evaluated in terms of the sustainability of agricultural activities in the long run. For this reason, given the current state of economic, social, and political factors, the sustainability of this resource and its associated economic consequences need to be better understood.

Due to the fact that in portions of the Ogallala Aquifer upto 40 percent of the pre-development storage has already been depleted and that overdraft continues to take place on the majority of the irrigated cropland overlying the Ogallala Aquifer, the transition from irrigated to dryland agriculture is likely to continue to take place and the need to implement irrigation practices that would be sustainable over time are imperative. This situation has serious implications not only for the many rural communities on the Great Plains, whose economic base depends on water resources from Ogallala Aquifer, but for the future and continued assurance of the overall competitiveness of the American agricultural sector in the global economy.

The agricultural economy dominates the High Plains region. Manjula (2000) in her study on the Ogallala aquifer mentioned that approximately 27 percent of the irrigated land in United States is in the High Plains and about 30 percent of the groundwater used for irrigation in the country is pumped from that aquifer. Livestock production is also an important commodity in the central high plains region with more than 5.3 million cattle and calves in inventory in 2002. Texas County in Oklahoma ranked third in swine production in the nation in 2002 with about 1.1 million hogs in inventory (USDA, Census 2002).

The pumping of the groundwater to support the agricultural sector in the High Plains started extensively during the 1950s. It showed an upward trend until the 1970s with approximately 8 million acre feet but decreased to half the amount in the 1980s. It then slightly increased during the 1990s. With the development of advanced and efficient irrigation methods, producers shifted from dryland farming to irrigated farming. An increase in number of irrigated acres demanded more crop water for irrigation. With 96 percent of the total withdrawals for irrigation (USGS, 2004) water levels have declined more than 100 feet in parts of Texas, Oklahoma and New Mexico overlying the aquifer. Some regions have already exhausted their underground water supply as a source of irrigation. Other parts have more favorable saturated thicknesses and recharge rates and are less vulnerable. Groundwater was extensively pumped to support the highly productive and profitable agricultural economy. This turned the once dry plains into a fertile and productive region, but the region faces depleting ground water resources and increasing pumping costs for the producers today.

The study area for this research includes Cimarron, Texas, and Beaver Counties of the Oklahoma Panhandle (Figure 1). These counties mostly use water from the underlying Ogallala aquifer to irrigate crops. Withdrawal from the aquifer in this region has greatly surpassed the rate of natural recharge. Birkenfeld (2003) stated that the rate of recharge compared to the depletion of the aquifer is quite insignificant. Water-level declines and reduced recharge rate have resulted in increased costs for ground-water withdrawals because of increased pumping lift, increased energy prices, and decreased well yields.

In most of the agricultural areas above the aquifer, each farmer attempts to maximize returns from crop production. The choice of maximizing net returns plays a role in decision-making regarding the amount of groundwater to be used, which could result in excessive pumping from the aquifer as a whole. The choice that producers make on groundwater usage can adversely affect the future availability of water. This can have a detrimental impact on the groundwater resources as well as on the regional economy. Therefore, it is not only important to measure the effect of declining water availability from Ogallala aquifer on agricultural activities by developing integrated resource management models but also to develop alternative water management or conservation policies that will lessen the burden on this finite resource.

Evaluation of groundwater resources will help identify the causes of excessive pumping and it can also be used to deal with the water allocation problems in the study area and their effect on the net revenues from crop production. This study aims to provide both policy analysts and farmers with a valuable tool for water planning and management. The specific objectives of the study are

1) Develop dynamic optimization models for Cimarron, Texas, Beaver and Curry Counties with a goal of maximizing the beneficial use of groundwater as indicated by the net returns per acre
2) To use the models to evaluate long term impacts of depleting groundwater and to compare the present values of the net returns from crop production over a 60-year period.

Data Collection and Model Development:

The Oklahoma Panhandle, composed of Cimarron, Texas and Beaver counties, is a 5,680 square mile semi-arid area in western Oklahoma. Annual precipitation ranges from 16 to 28 inches including an average of 18 inches of snowfall. The Ogallala aquifer, the single largest source of groundwater in the state, underlies the panhandle and portions of extreme western counties in Oklahoma. Though lacking in surface supplies, the region has tremendous groundwater resources with an estimated storage of 112 million acre-feet, based on USGS studies. In 1998, a study by USGS showed that the saturated thickness in the northwestern Oklahoma ranged from nearly zero to 430 feet with the greatest thickness occurring in eastern Texas and northwestern Beaver counties. The estimated overall average saturated thickness in the panhandle region is around 129 feet (USGS 2000). Wells in the region ranged from 100 to 500 feet in depth with yields usually between 100 and 1,000 gallons per minute (gpm).

Agriculture is one of the most important segments of Oklahoma's economy. The Ogallala aquifer supports the most extensive agricultural activities in the region. Crops and feeding operations flourish on lands irrigated from the aquifer. The aquifer provides nearly all of the Panhandle's irrigation needs. The three Panhandle counties are the largest irrigation water users, and Texas County is the largest water user among Oklahoma's counties (USGS 2002).

Most of the water pumped from the Oklahoma High Plains is used to irrigate crops. The remainder is used for livestock, municipal, and domestic needs. Prior to 1950, crop production in the area was almost exclusively dry-land wheat and grain sorghum. However, with the introduction of irrigation practices, principal crops in the area now include alfalfa, corn, and grain sorghum which are produced to supply feed for the livestock industry in the area, and wheat which is produced primarily for the export market. Estimates show that 205,873 acres are irrigated from the Ogallala, more than 90 percent of that total lying in the three Panhandle counties **(**USGS 2000**)**. Even with the aquifer's large storage volume, localized water levels have declined in recent years. Continued overdraft of the Ogallala formation and water level declines of two to three feet per year in many areas make physical exhaustion of the aquifer a major concern.

Research Procedure:

The first step in any optimization analysis is choosing a quantity to be maximized or minimized. Park (2005) developed economic optimization models of the Ogallala aquifer for the Texas Panhandle. This study follows the previous groundwater studies 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 (2005) 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 consideres crop production functions. Non-linear dynamic programming with General Algebraic Modeling System (GAMS) (Brooke et al. 1998) 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 details on county production functions can be found in Adusumilli, 2007. 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.

Saturated thickness and pumping lift data by county are compiled from the United States Geological Survey (USGS) and the Oklahoma Water Resources Board (OWRB) fact sheets for the most recent year's data. 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 county area and the number of acres for each county are obtained from the 2002 U.S. Census of Agriculture. Irrigated and dryland harvested acres of the major crops grown in the area are obtained from Farm Service Agency (FSA) for the years 2001 to 2005. Four crops corn, cotton, sorghum and wheat are selected due to their high contribution to the use of groundwater in the study area. The remainder of the acreage in the Oklahoma panhandle counties is either under Crop Reserve Program (CRP), left fallow or different grasses. It is assumed that only Low Energy Precision Application (LEPA) systems are utilized to pump the groundwater for irrigation purposes. The detailed data on acreages included in the study are shown in Table 1.

Prices for corn, cotton, sorghum and wheat are obtained from the National Agricultural Statistics Service (NASS) website. Average prices for the years 2001-2005 are used in the model. Enterprise budgets (2005) produced by Oklahoma State University are the primary sources for costs of production for the three counties in the Oklahoma panhandle. Natural gas is the primary source of power for irrigation purposes in the study area. The five-year average data on the price of natural gas is obtained from Energy Information Administration. The average annual industrial price for the years 2001-2005 is used for the study.

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:

$$STt+1 = STt – [(\Sigma i\ \Sigma k\ \Theta ikt * WPikt)]A/s, \quad \text{(iii)}$$

$$Xt+1 = Xt + [(\Sigma i\ \Sigma k\ \Theta ikt * WPikt)]\ A/s, \quad \text{(iv)}$$

$$GPCt = (STt/IST)^2 * (4.42*WY/AW), \quad \text{(v)}$$

$$WTt = \Sigma i\ \Sigma k\ \Theta ikt * WPikt\ , \quad \text{(vi)}$$

$$WTt \leq GPCt \quad \text{(vii)}$$

$$PCikt = \{[EF(Xt + 2.31*PSI)EP]/EFF\}*WPikt, \quad \text{(viii)}$$

$$Cikt = VCik + PCikt + HCikt + MCk + DPk + LCk \quad \text{(ix)}$$

$$\Sigma i\ \Sigma k\ \Theta ikt \leq 1 \text{ for all t}, \quad \text{(x)}$$

$$\Theta ikt \geq (0.9)\ \Theta ikt\text{-}1 \quad \text{(xi)}$$

$$\Theta ikt \geq 0. \quad \text{(xii)}$$

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, WTt, is the average water use on all acreage. Constraint (vii) requires WTt to be less than or equal to GPC.

Equations (viii) and (ix) represent the cost functions in the model. In Equation (viii), PCikt 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, Cikt in terms of VCik, is the variable cost of production per acre, HCikt, the harvest cost per acre, MCk, the irrigation system maintenance cost per acre, DPk, the per acre depreciation of the irrigation system per year, and LCk, 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:

The primary objective of the study is to analyze and evaluate the effects of the alternative water conservation policies on the area overlying the Ogallala aquifer in Cimarron, Texas, and Beaver counties of Oklahoma Panhandle. The specific objectives of the study are to develop dynamic optimization models for each county with a goal of maximizing the beneficial use of groundwater as indicated by the net returns per acre and to use the models to evaluate long term impacts of depleting groundwater over a 60-year period. The goal of this study is to establish an unconstrained baseline scenario, which satisfies the stated objectives of the research. This baseline model will be used for future policy analysis. Under this scenario the acreages in the counties under different crops are allowed to move out of a given crop and system and into another between years i.e. the model does not include the crop swap constraint. Saturated thickness, annual net revenue per acre, pump lift, water applied per cropland acre, cost of pumping, and net present value of net returns per acre (NPV) by county are derived using the non-linear dynamic optimization model for the baseline scenario for the three counties included in the study area.

Cimarron County:

Cimarron County has 101,575 irrigated and 183,202 dryland crop acres. It constitutes a total of 706,304 acres of land under crops, CRP and various grasses. The Ogallala aquifer underlies an area of 939,520 acres of the total 1,174,400 county acres. Wheat is the predominant crop grown in the county with 42,000 irrigated acres followed by corn and sorghum with 19,000 and 4,000 acres respectively. Irrigated cotton has negligible acreage in the county. Dryland wheat is grown on 87,000 acres followed by dryland sorghum with 55,000 acres. Dryland corn and dryland cotton are grown on very few acres. Dryland fallow constitutes of 43,663 acres in the county. Due to the limitation on the data available on the percentage of crops under various irrigation systems, it is assumed that all the irrigated acres in the county are under LEPA system. Saturated thickness declined from 129 feet to 127 feet during the 60-year period (Figure 2). The net revenue per acre was initially negative with -$16.55, steadily increases to $15.33 by year sixty (Figure 3). The Net Present Value (NPV) per acre of cultivated land for the county is $184.78. With respect to the cropping patterns, irrigated corn acreage decreases from 7.5% in year one to 3% by year ten and to 0.02% by year sixty. Irrigated sorghum also shows the same trend. The acreage decreases from 1.5% in year one to less than 1% by year ten and to 0% by year sixty. Similarly, irrigated wheat decreases from 16.9% in year one to 6.5% by year ten and to 0.03% by year sixty. Dryland sorghum increases from 22% in year one to 29% by year thirty and remains almost constant through year sixty. Dryland wheat decreases from 35% in year one to 46% by year thirty and remains at that level for the rest of the period. Dryalnd fallow acreage increases from 17% in year one to 23% by year thirty and remained at that level through year sixty. Details on the crop percentages of various crops throughout the planning horizon in the county are shown in Table 2.

Texas County:

Texas County is the largest county of the Oklahoma Panhandle. The county has 210,826 acres under irrigated and 221,596 acres under dryland conditions. It constitutes a total of 756,066 acres of land under crops, CRP and various grasses. The Ogallala aquifer underlies the complete area of the county that contains 1,311,360 acres. Wheat is the predominant crop grown in the county with 70,000 acres on irrigated acreage followed by corn and sorghum with 65,000 and 13,000 acres respectively. Irrigated cotton is grown on very few acres in the county. Dryland wheat is grown on 136,000 acres followed by dryland sorghum with 48,000 acres. Dryland corn and dryland cotton are grown on very few acres. Dryland fallow constitutes 68,893 acres in the county. Due to the limitation on the data available on the percentage of crops under various irrigation systems, it is assumed that all the irrigated acres in the county are under LEPA systems.

Saturated thickness declines from 275 feet to 270 feet during the 60-year period (Figure 5). The net revenue per acre for the county, initially negative with -$29.31, steadily increases to $16.00 by the end of year sixty (Figure 6). The Net Present Value (NPV) per acre of cultivated land for the county is $95.29. With respect to the cropping patterns, irrigated corn acreage decreases from 7.5% in year one to 3% by year ten and to 0.02% by year sixty. Irrigated sorghum acreage decreases from 1.5% in year one to 0% by year sixty. Irrigated wheat decreases from 17% in year one to 6.5% by year ten and to 0.03% by year sixty. Dryland sorghum increases from 22% in year one to 29% by year thirty and remains at that level throughout the planning period. Dryland wheat increases from 35% in year one to 46% by year thirty and to 47% by year sixty. Dryland fallow acreage increases from 17% in year one to 23% by year thirty and to 23.5% by the end of the planning period. Details on the crop percentages of various crops throughout the planning horizon in the county are shown in Table 2.

Beaver County:

Beaver County has 35,264 acres under irrigated and 196,204 acres under dryland conditions. It constitutes a total of 732,966 acres of land under crops, CRP and various grasses. The Ogallala aquifer totally underlies the county area that includes 1,132,160 acres. Wheat is the predominant crop grown in the county with 18,000 acres under irrigated acreage followed by corn and sorghum with 4,000 and 3,500 acres respectively. Irrigated cotton is grown on 1,500 acres in the county. Dryland wheat is grown on 146,390 acres followed by dryland sorghum with 19,000 acres. Dryland corn and dryland cotton are grown on very few acres. Dryland fallow constitutes 43,483 acres in the county. Due to the limitation on the data available on the percentage of crops under various irrigation systems, it was assumed that all the irrigated acres in the county are under LEPA systems.

Saturated thickness declines from 210 feet to 209 feet during the 60-year period. The net revenue per acre for the county, initially $14, steadily increases to $22.59 by year sixty (Figure 7). The Net Present Value (NPV) per acre for the county is $575.69. With respect to the cropping patterns, irrigated cotton acreage is less than 1% in year one and decreases to 0% by year sixty. Irrigated corn acreage decreases from 2% in year one to 0% by year sixty. Irrigated sorghum also shows the same trend. The acreage decreases from 1.5% in year one to less than 1% by year ten and to 0% by year sixty. Similarly, irrigated wheat decreases from 8% in year one to 3% by year ten and to 0.02% by year sixty. Dryland cotton decreases from less than 1% in year one to 0% by year sixty. Dryland sorghum increases from 8% in year one to 9% by year sixty. Dryland wheat increases from 61% in year one to 70% by year sixty. Dryland fallow acreage increases from

18% in year one to 21% by the end of year sixty. Details on the crop percentages of various crops throughout the planning horizon in the county are shown in Table 2.

Aggregate Changes in Crop Acres in the Study Area:

The cropping patterns in the study area change significantly from irrigated to dryland. Irrigated wheat and corn are the major irrigated crops in the region. These crops show a decrease in their acreages by the end of the planning period. The irrigated wheat crop percentage decreases from 15% in year one to almost 0% by the end of the planning horizon. Similarly, irrigated corn acreage decreases from 8% in year one to 0% by year sixty. On the other hand, dryland wheat, which is grown on a majority of the acreage in the area increases from 43% at the beginning of the study period to 57% by the end of year thirty and to 57.6% by the end of the planning period. The proportion of dryland sorghum significantly increases from 15% in year one to 21% by the end of the planning horizon. Dryland fallow acres increase from 16% in year one to 21% by the end of the planning period. Since a wheat-sorghum-fallow rotation is an accepted cultural practice in the area, the model included this rotation. The final dryland acreage ratio of 3:1:1 among dryland wheat, sorghum and fallow indicates the inclusion of the rotation in the final situation. The average saturated thickness of the Ogallala aquifer shows a 0.9% decline over the planning horizon. Figures 7 to 9 show the changes in crop percentages for the major crops for 2001, 2030, and 2060.

Summary and Conclusion:

Non-linear dynamic optimization models were developed for this study. The models used five year county average yields, crop production functions developed from CROPMAN, and county average hydrologic parameters to determine the levels of saturated thickness, annual net revenue per acre, pumping lift, water applied per cropland acre, and cost of pumping associated with the cropping pattern that maximizes the net present value of net returns per acre (NPV) over a sixty-year planning horizon.

The analysis exhibits a significant transition from irrigated to dryland farming in all the counties. As the groundwater declines, all irrigated crops show a continuous reduction in their acreage, while dryland crop acres increase in all the four counties during the planning horizon. Transition to dryland cropping is completed in all the counties by the end of the planning period. This research supports the suggestion by Almas et al. (2004) that alternate water management strategies and reallocation of water to higher value products would not only reduce the rate of decline of available resources but also maintain the economic stability of the area.

Hydrologic characters like saturated thickness, pump lift are assumed to be an average level for the entire county, even though it is different at different parts of the county. This may lead to the assumption that the county as a whole have adequate water for irrigation, when a portion of the country actually does not have sufficient water for irrigation. However, it was unfeasible for the purposes of this study to attain more precise hydrologic characteristics.

Estimated production functions are based on only one weather station and the dominant soil type in a county. It was also assumed in the model that all the irrigated acres in the counties included in the study area are under LEPA systems. This was due to the non-availability of the data with regard to the number of crop acres under different irrigation systems.

Dryland crop yields used in the study are assumed the same across the county, but in many counties, these numbers vary from one part to another. Furthermore, costs of production, commodity prices, and natural gas price are assumed to remain constant over the sixty-year planning horizon. Even though livestock forms a major component in the counties of Oklahoma panhandle, the model does not include this component, which is another major limitation for the study. The model can be improved by addition of livestock production activity. This addition would greatly improve the model results and would give more accurate picture of the future conditions of the region.

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Table 1. County acreages under different categories

	Cimarron	Texas	Beaver
Total Area (Acres)	1,174,400	1,311,360	1,132,16
Irrigated Acres	101,575	210,826	35,264
Dryland Acres	183,202	221,596	196,204
Fallow Land (acres)	43,663	68,893	43,483
Area under CRP (acres)	152,674	182,694	131,323
Range Land (acres)	268,853	140,950	370,175
Cattle Population (Jan 2007)	120,000	270,000	104,000
Acres Overlying the Aquifer	939,520	1,311,360	1,132,16

(Source: Farm Service Agency, 2005)

Table 2. Crop Percentages for Cimarron, Texas, and Beaver County over 60-year Period

County/Crop	2001	2010	2030	2050	2060
Cimarron					
I-Corn	7.51%	2.91%	0.35%	0.04%	0.02%
I-Sorghum	1.50%	0.58%	0.07%	0.01%	0.00%
I-Wheat	16.88%	6.54%	0.79%	0.10%	0.03%
D-Sorghum	21.90%	26.59%	29.22%	29.53%	29.56%
D-Wheat	34.75%	42.22%	46.36%	46.86%	46.91%
D-Fallow	17.40%	21.13%	23.20%	23.46%	23.48%
Texas					
I-Corn	16.21%	6.28%	0.76%	0.09%	0.03%
I-Sorghum	3.18%	1.23%	0.15%	0.02%	0.01%
I-Wheat	17.21%	6.67%	0.81%	0.10%	0.03%
D-Sorghum	11.92%	16.26%	18.68%	18.98%	19.00%
D-Wheat	33.72%	46.02%	52.85%	53.68%	53.76%
D-Fallow	17.04%	23.26%	26.71%	27.13%	27.17%
Beaver					
I-Corn	1.76%	0.68%	0.08%	0.01%	0.00%
I-Sorghum	1.53%	0.59%	0.07%	0.01%	0.00%
I-Wheat	7.73%	3.00%	0.36%	0.04%	0.02%
D-Sorghum	8.04%	8.61%	9.06%	9.12%	9.12%
D-Wheat	61.70%	66.90%	69.68%	70.02%	70.05%
D-Fallow	18.33%	19.87%	20.70%	20.80%	20.81%

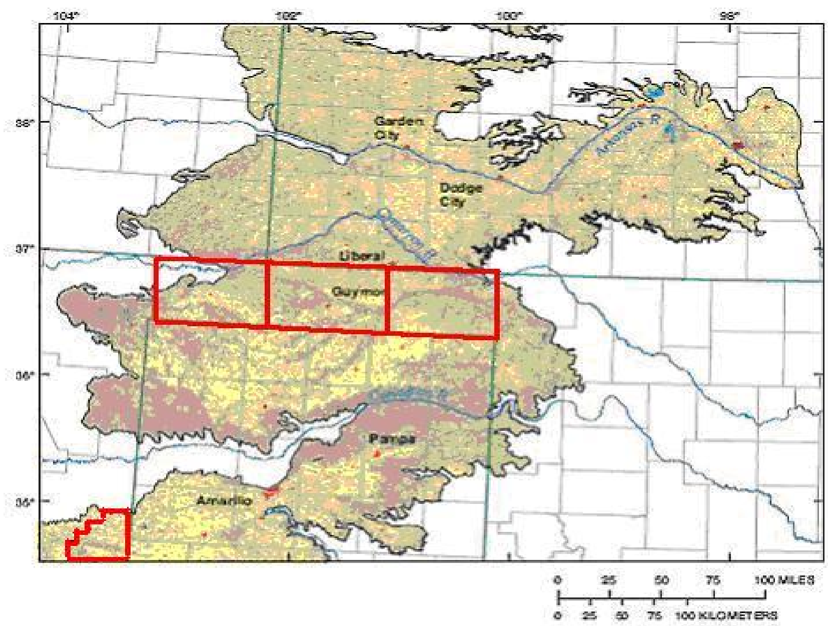

Figure 1: Water use by Northwestern Oklahoma counties.

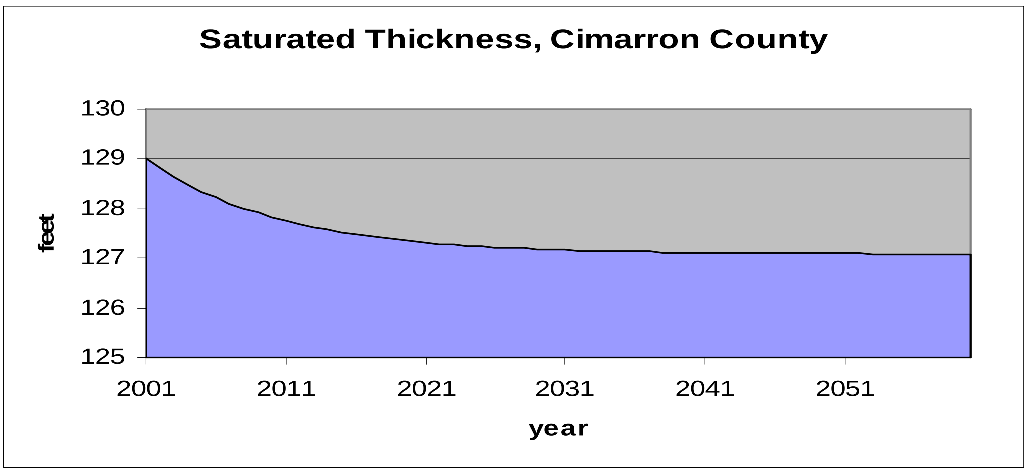

Figure 2. Change in Saturated Thickness during the 60-year period in Cimarron County

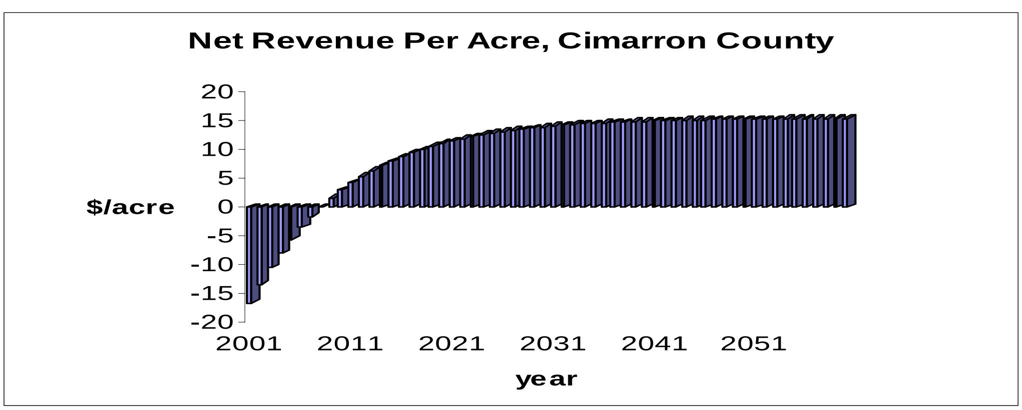

Figure 3. A 60-year Net Revenue per Acre curve for Cimarron County

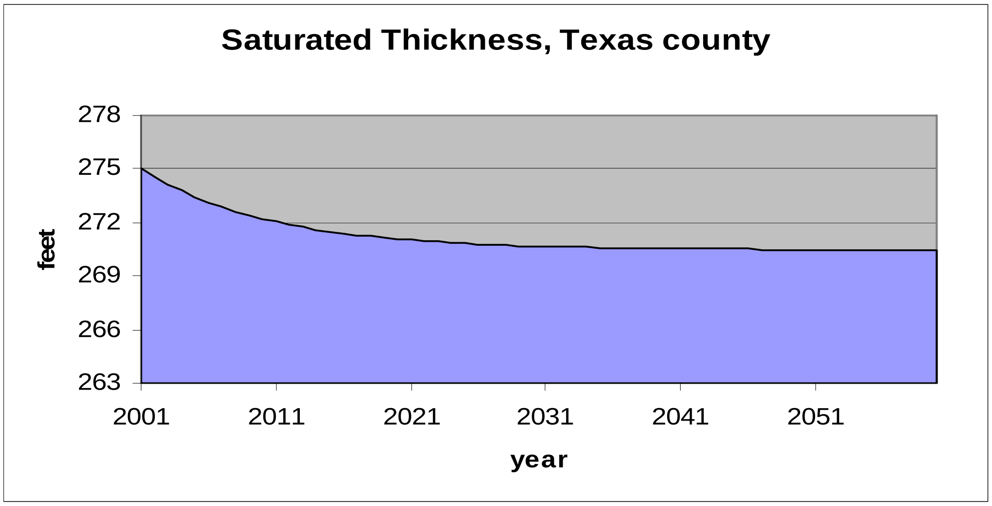

Figure 4. Change in Saturated Thickness during the 60-year period in Texas County

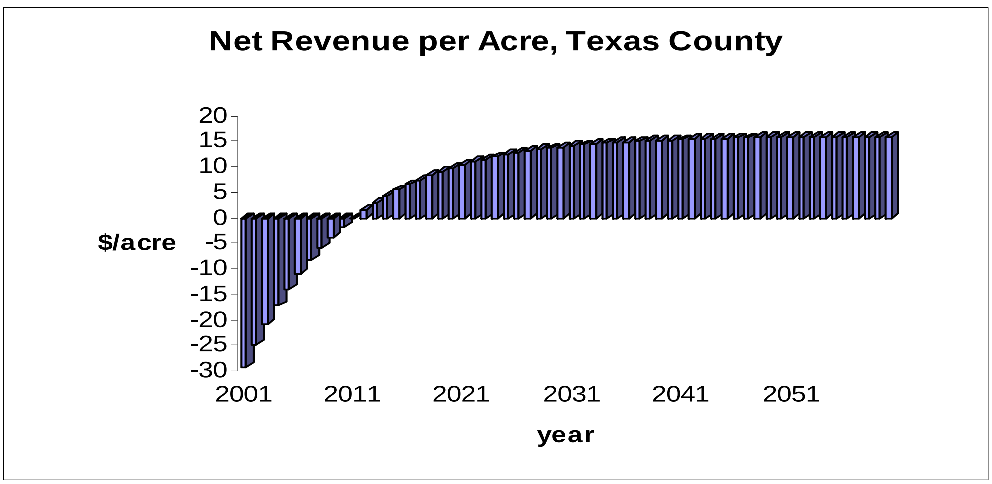

Figure 5. A 60-year Net Revenue per Acre curve for Texas County

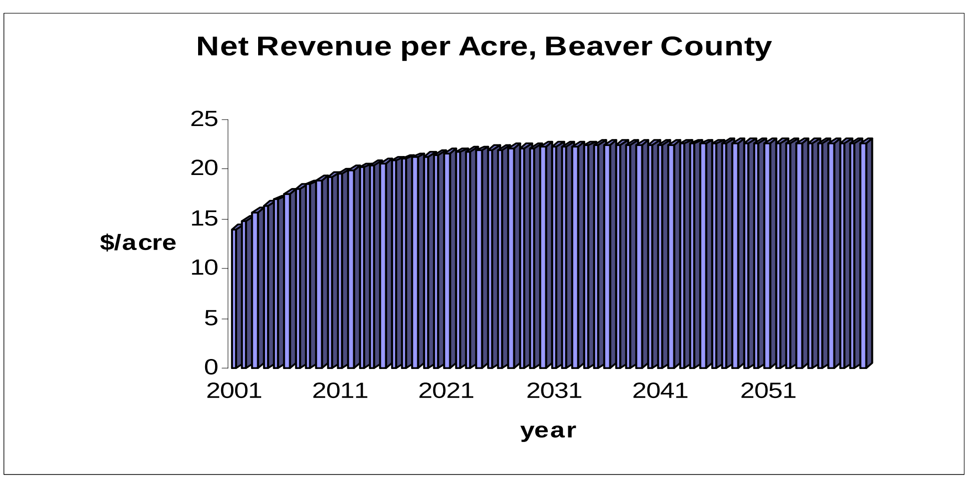

Figure 6. A 60-year Net Revenue per Acre curve for Beaver County

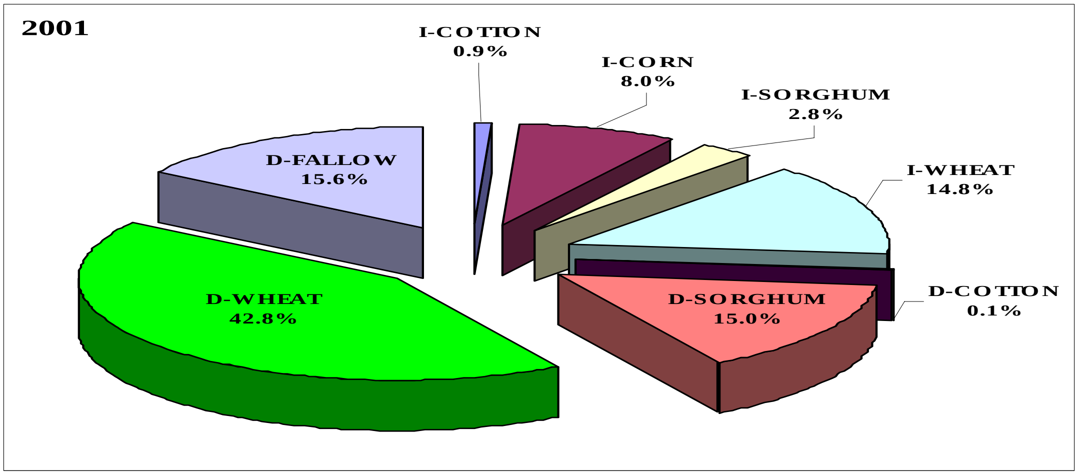

Figure 7. Crop acreage percentages in the study area during 2001

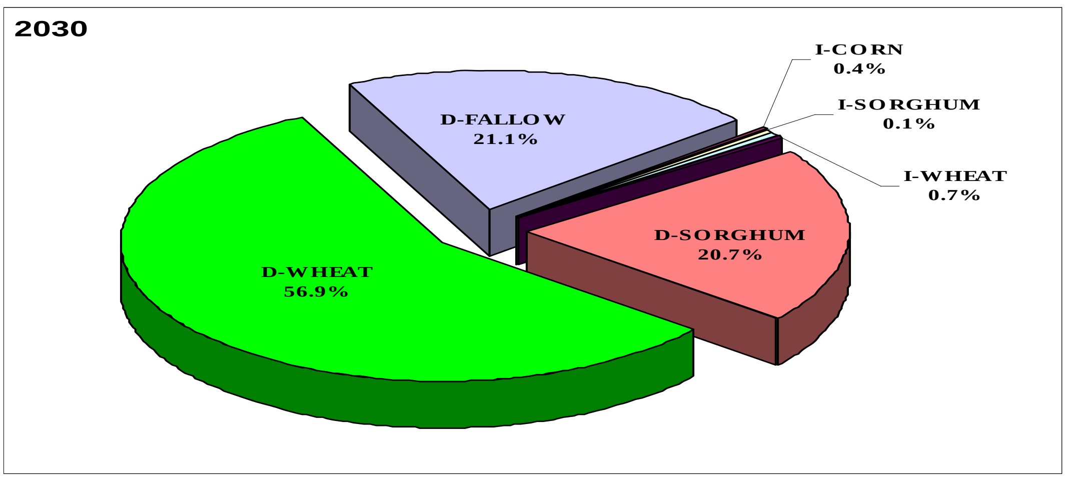

Figure 8. Crop acreage percentages in the study area during 2030

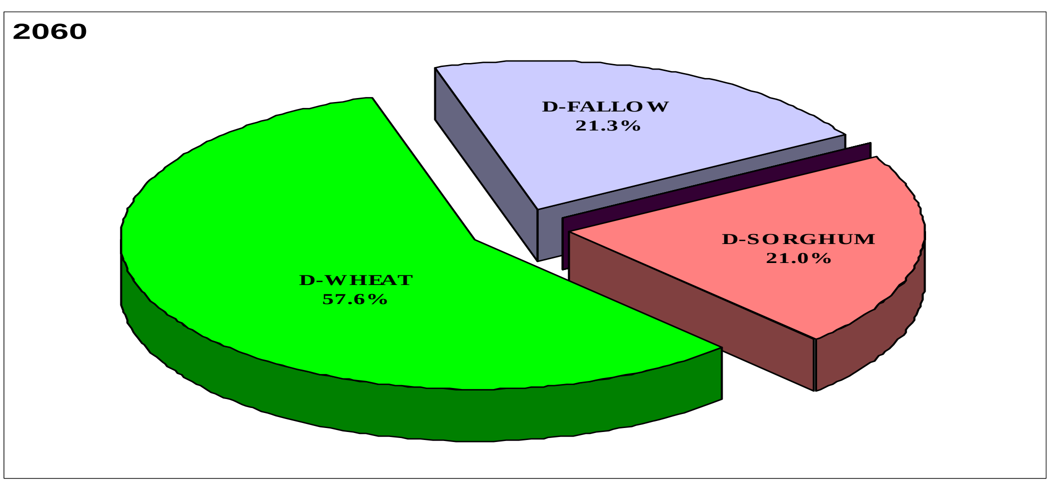

Figure 9. Crop acreage percentages in the study area during 2060