Economic Optimization of Groundwater Resources in the Texas Panhandle

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Abstract: An economic optimization model for a sixty years planning horizon is developed using available groundwater resources in the Texas 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 decline of the Ogallala Aquifer, which is the primary source of irrigation water for the Texas Panhandle, due to excessive extraction rates poses questions about the economic, social and political future of the area.

Economic optimization models for each of the 23 counties in the Texas Panhandle are developed with a goal of maximizing the net income from crop production. Nine major crops are selected. Results from the 60-year analysis for the 23 counties indicate a significant transition from irrigated agriculture to dryland farming. Total irrigated crop acres in the study area decrease by approximately 83 percent from 1.79 million acres to 0.30 million acres while total dryland crop acres increase by about 125 percent from 1.20 million acres to 2.69 million acres. Total groundwater use in the study area significantly declines for the planning horizon by 71 percent from 2.16 million ac-ft to 0.63 million ac-ft. The average saturated thickness of the Ogallala Aquifer in the 23 counties shows a 21 percent decline over the planning period.

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 also be used to assess the socio-economic impacts of depleting groundwater availability from the Ogallala Aquifer in the region.

Key Words: Economic Optimization, Groundwater Resources, Input Efficiency, Irrigated Agriculture, Southern Ogallala Aquifer, Texas 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 primary reason why underground water resources in the Great Plains are being used at a rate higher than the natural rate of recharge, is because of the revenues 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. Furthermore, many of the current and expected technological advances in agricultural production could have significant impacts on how the future sustainability of underground water resources in the Great Plains is approached.

The economic focus on irrigation from the Ogallala aquifer and the impact on the region have shifted from development and expansion in the 1950s and 1960s to the implications of the depletion of the aquifer in the 1990s and 2000s (Grubb 1966; Osborn and McCrary 1972; Musick et al 1990; Amosson et al 2001; Colette, Robinson, and Almas 2001). The decline in the water level in the Ogallala aquifer is an on-going concern. Wells that produced 1000 to 1200 gallons per minute in the 1960's often produced less than 200 gallons per minute in the 1990's. Since there is only limited recharge of the Ogallala aquifer in this area, irrigation water is a fixed supply and excessive pumping results in shortening the economic life of the farming operation and in reducing the returns to the resources held by the farmer. This situation has serious implications not only for the many rural communities on the Texas Panhandle, 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.

Stewart (2003) said that the irrigated area has already decreased from more than 5.9 million acres to about 4.5 million acres. The reduction of total irrigated land will continue for the next several decades as producers switch from irrigation to dryland farming. Therefore, the sustainability of agricultural activities should be central to addressing the declining water table of the Aquifer with regard to current political, social and economic factors. It is important not only to measure the potential impact of declining groundwater on agricultural activities by developing regional economic optimization models, but also to develop sustainable irrigation practices to conserve a limited natural resource.

The application of economic principles to the solution of management problems and the development of decision aids that incorporate current scientific knowledge and economic theory is essential to the future success of agriculture and the discipline of agricultural economics. This study addresses both areas. It is timely and the application of the information and procedures is critical to the survival of agricultural producers faced by the declining water supply associated with the decline in the Ogallala Aquifer. The objectives of this study are:

1) To develop an economic optimization model for the Texas Panhandle (Southern Ogallala Aquifer Region) with a goal of maximizing the beneficial use of ground water, and
2) To use the model to evaluate the long-term economic impacts of depleting ground water on the regional economy.

Study Area, Data Collection, and Research Methodology: The Southern Ogallala Central Region includes the 26 counties in the Texas Panhandle, three counties from the

Oklahoma Panhandle and one county from Eastern New Mexico. This study focuses on the 23 counties in the Texas Panhandle that represent the most irrigated agriculture in the area. The counties are Armstrong, Briscoe, Carson, Castro, Dallam, Deaf Smith, Donley, Gray, Hansford, Hartley, Hemphill, Hutchison, Moore, Lipscomb, Ochiltree, Oldham, Parmer, Potter, Randall, Roberts, Sherman, Swisher, and Wheeler. Figures 1 and 2 illustrate the overall Southern Ogallala Aquifer region and the 26 counties of Texas Panhandle area, respectively.

In order to determine harvested acres for the model, planted irrigated acres for nine major crops are obtained from the Farm Service Agency (FSA, 2000) and planted dryland acres are obtained from NASS (USDA, 2005). The crops are selected due to their high contribution to the use of groundwater and include pasture, corn, cotton, sorghum, soybean, wheat, peanut, alfalfa, and sorghum forage. Direct and indirect costs include all variable costs except those included as variable in the model such as fertilizers, seed, labor, and energy. These costs are adjusted from projected budget values for specific county crop yield and water coefficient. Crop yields are obtained from the NASS and the Texas Crop and Livestock Budgets (Amosson et al, 2003). Crop prices are calculated using five-year average prices between 1999 and 2003. Input prices such as fertilizer, seed, and labor are also taken from the Texas Crop and Livestock Budgets. Energy prices such as gasoline, diesel, and natural gas are five-year average prices of the years 1999 to 2003 from the Energy Information Administration (EIA, 2005).

Hydrologic data are obtained from two sources: calculated data such as saturated thickness and groundwater volume from Dutton et al. (2001) and the real well data from Driller’s Report (Texas Water Development Board, 2005). Total groundwater volume, saturated thickness, and the depth from surface to groundwater bed are used for determining water availability and increases in natural gas requirements from the declining groundwater table estimated by the dynamic programming procedure. Methodology for calculating saturated thickness and the level of water availability is described in Figure 3.

The first step in modeling is to identify the problem and define a system of mathematical expression to address the problem. In this study, the problem is to optimize the return from the use of groundwater from the declining Ogallala Aquifer. In the model, there are decision variables that belong to the decision-making process. For example, a farmer can make a decision on the amount of water applied to his field or on his crop mix (Bernardo et al., 1987). Constraints are functions of the decision variables indicating the interaction of the decision with the availability of resource that affect the obtainment of the good. The objective of the model is to maximize net income from crop production for each county. Net income is defined as the returns to land, risk, management, and the underground water stock. It is calculated as gross returns minus total cost of production, where the latter consists of variable and fixed costs. The variable costs of production include the cost of pumping underground water, investment and maintenance costs associated with the establishment and up-keep of irrigation systems/practices, and non-water production costs.

The next step is to build a static-state optimization model for each of the twenty-three counties for the baseline year, which is the year 2000 in this case. Results from a static model such as ground water use provide a basis for calculating the water availability level and additional requirements of natural gas during the dynamic programming procedure of the planning horizon. The last step is to calculate the net present value of a series of net income for each county. A three percent discount rate is used to calculate the net prevent value.

The model is based on assumptions that limited ground water is optimally allocated among competing agricultural activities, and farmers make rational decisions to maximize their net income when facing scarce resource constraints including land, water, and production inputs. The model maximizes the farmer's net income from land, management, and the underground water availability for a certain year. A standard linear-programming (LP) model is constructed for each county and each year in the planning period. The county LP model for a given year (t) is described mathematically in the following form:

$$\text{Maximize } NI_{c,t} = \sum c_j X_j$$
$$\text{Subject to } \sum a_{ij} X_j <= b_i \text{ and } X_j >= 0$$

where $i = 1,..., m,\ j = 1,..., n$; and c_j is the objective row coefficient for the jth column, X_j is the jth activity, a_{ij} is the technical coefficient in the ith constraint row and jth activity column, b_i is value of right hand side in the ith row. The subscripts c indicates county and t indicates a given year of the planning horizon.

Net present value (NPV) calculation for a certain county, c is indicated by the following formula:

$$NPV_c = \sum_{0}^{60} \frac{NI_{c,t}}{(1+r)^t}$$

where $NI_{c,t}$ is farmers' net income of county c at year t. The discount rate is indicated by r.

In addition to the production and cost functions, the model requires several other economic and hydrologic parameters. These include: expected crop prices, variable production costs, irrigation labor requirements, water delivery costs, initial pumping depths, initial aquifer saturated thickness, and initial pumping capacity.

All the county models have the same number of activities. Forty-five activities in each model consist of three categories of activities, such as crop activities, marketing activities, and input purchasing activities. Values in the objective function row represent production costs and commodity prices.

There are 73 constraints for each of the county models. These constraints are divided into 5 categories: the water availability, production, cropland use upper and lower bounds, total cropland, input, and marketing transfer. Crop water coefficients are used as values in the water availability constraint row. Each of the 23 county models has the same dimensions of the coefficient matrix but coefficients in the matrix are specific for each county since values are representative of county crop yields and crop water use coefficients. The model constraints also consist of equations of motion based on county-specific hydrologic parameters. These equations control the dynamic behavior of both saturated thickness and pumping lift. Coefficients in the matrix of the base year model remain constant during the dynamic programming period, except natural gas coefficients. New natural gas requirement are calculated for each irrigated crop each year in order to account for additional pumping lifts as the water table declines.

Results of the base model for each county establish the starting point for the dynamic analysis over the 60-year planning horizon. The amount of groundwater used in the base model forms the basis for calculating the groundwater availability of subsequent years and the additional amount of natural gas required for the additional lift resulting from the declining groundwater table.

This study analyzes changes in cropland use in response to declining water availability and increasing natural gas requirements associated with the declining groundwater. Results of crop land use from the base model determine the level of upper and lower bounds for each crop production activity in the subsequent model year. This procedure continues until the end of the planning period. Individual crop acreages are allowed to vary within a range of plus-or-minus ten percent each year.

Groundwater use of the model for one year is used to calculate a new level of water available and additional natural gas requirement in the model in the following year. The calculation of the additional natural gas required is based on the following quadratic equation:

$$NG = 0.0038 \times L + 0.088 \times PSI - ((7.623E-6) \times PSI) \times (L) - (3.3E-6) \times L^2$$

where NG is the mcf of natural gas for pumping one ac-in of groundwater, L is the system lift in feet, and PSI is the system pressure per square-inch. Since the model assumes all irrigated land is under sprinkler irrigation, 15 is used for a PSI value. Pumping lift is obtained by subtracting saturated thickness from initial depth from the surface to the bottom of the aquifer. There is a different pumping lift at each year because of declining water table so that additional natural gas is the difference between natural gas required at a certain year and natural gas use at the base year. The pumping cost is calculated from well-known engineering formulas that relate pumping costs to pumping lift, operating system pressure, and the price of energy (Amosson et al., 2001).

Results and Discussion: The expected aggregate changes in cropping pattern in the entire region for irrigated crops mainly corn, and wheat show acreage reductions of about 81 and 99 percent. The proportion of corn in the total harvested crop acres drops from 22 percent to four percent. Irrigated wheat almost disappeared by the end of the period despite its initial large portion in total crop acres. On the other hand, acres for major dryland crops such as dryland cotton, and dryland wheat increase significantly by approximately 214 and 212 percent, respectively. The proportion of dryland wheat significantly increases from about 26 percent to 82 percent for the same period. With respect to minor crops, all crops except alfalfa exhibit a reduction in their production acreage. Crop acres for alfalfa increase from 2,271 to 159,283.

Alfalfa accounts for only 0.04 percent of cropland in 2000 but represent about five percent of total crop acres in 2060.

Only Dallam County results are presented in detail in this paper instead of presenting results for all 23 counties due to space limitation. The initial irrigated acres for the year 2000 in Dallam County are 219,061. This accounts for 79 percent of total cropland within the county. Irrigated corn uses about 57 percent of the total cropland and irrigated wheat and dryland wheat follows with 19 and 16 percent, respectively. During the 60-year analysis, county net revenue decreases by approximately five percent from $6.52 million to $5.89 million. The present value of net income for Dallam County for the 60-year period is $177.54 million.

The sharp drop in the first six years is due to the decline in the acreage for corn and irrigated wheat. Revenue increases for the next five years as more water efficient soybean production is substituted for corn. However, net revenue begins to decline again around 2010 when even growing soybean with irrigation is not economically profitable. The downward trend of net revenue continues until expansion of production of a high value crop such as alfalfa makes an impact on the net revenue. Results of the analysis show that by 2060 eighty three percent of total cropland is under dryland farming in Dallam County.

Figure 4 shows the change of saturated thickness throughout the time horizon (60 years). It began at 126 feet and will be 67.82 feet by year 60. Change in pumping lift is shown in Figure 5. It started from 365 feet and increased to 423 feet at the end of time horizon. Figure 6 shows the nominal net revenue per crop acre over 60 years, which was $23.47 in year 1 and increased to $23.84 in year 5 because of the adjustment of crop acreage, and was minimum at $20.92 by year 50 because of the declining saturated thickness and then it started increasing from year 52 to year

60 due to increase in irrigated alfalfa acres and in year 60 net revenue per acre has been estimated at $21.22.

The change of crop patterns is presented in Table 1. The irrigated corn decreased from 56.76% of cropland (year 1) to 12.82% by year 60 due to the declining saturated thickness. The acreage of other irrigated crops also decreased over years except alfalfa. The acreage of dryland wheat increased from 15.63% to 82.54% of cropland by year 60. While, the acreage of dryland sorghum decreased from 5.48% to 0.01% of cropland. Details about present value of net revenue, water use, and harvested acres for major crops for the 60 years are presented in Table 2. Table 3 contains information about yearly hydrological data such as saturated thickness, estimated water use and remaining groundwater volume.

Production levels for crops are greatly affected by changes in crop distribution over the planning period. With respect to changes in inputs, seeds for all the crops except wheat and alfalfa decrease for the period. Consumption levels of both nitrogen and phosphorous fertilizers are reduced because of the transfer of cropland from fertilizer intensive crops such as corn to less intensive crops like dryland wheat. For the energy consumption, there is no big change in consumption of either diesel or gasoline but natural gas use declines due to the reduction in irrigation. The economic optimization model can be used to analyze alternative policy scenarios such as change in natural gas prices, water pumping restriction and incentives to producers for management practices to be used for water conservation.

Summary and Implications: Total irrigated crop acres in the study area decrease by approximately 83 percent while total dryland crop acres increase by about 125 percent. Total groundwater use in the area significantly declines over the planning horizon by 71 percent from 2.16 million ac-ft to 0.63 million ac-ft. The trends and relative changes indicated by this study seem appropriate. The model shows the reduction of total irrigated land for the planning period as producers switch from irrigation to dryland farming. Comparing net present value of an LP model under different policy scenarios can be used to calculate opportunity costs for conserving natural resources. For example, the difference in NPV, for two alternatives might represent the amount of payment required by farmers as compensation for adopting a policy that restricts the use of their resources.

However, care should be taken in interpreting the magnitude of the individual values as true cardinal relationships. The usefulness of the model can be improved by expanding the definition of crop land to include crop rotations that include fallow such as wheat-fallow or wheat-sorghum-fallow rotations, and adjusting the yields to reflect the production practices.

The optimization models applied to agriculture often yield “unrealistic” results. The optimal solutions of the model often diverge from farmers’ observed behavior. A common example is that when model produces a corner solution where all land is planted to a single crop (implying this crop is the most profitable alternative given the model parameters), while farmers were observed to diversify their acreage portfolio across several crops.

References:

Amosson, S.H., L. New, L. Almas, F. Bretz, and T Marek. *Economics of Irrigation Systems.”* Texas Agricultural Extension Bulletin B-6113, Texas Cooperative Extension, The Texas A&M University System, 2001.

Amosson, S. H., J. G. Smith, Lal K. Almas, and F. E. Bretz. “Texas Crop and Livestock Enterprise Budgets, Texas High Plains, Projected for 2004.” B-1241 (C1 and C2) and B-1241 (L1 and L2), Texas Cooperative Extension, College Station, Texas, 2003

Bernardo, D.J., N.K. Whittlesey, K.E. Saxton, and D.L. Basset. “An Irrigation model for management of limited water supplies.” *Western Journal of Agricultural Economics.* 12: 164-173, 1987.

Colette, W. Arden, C. Robinson, and L. Almas. "A statistical model using PET and weather data to predict the economic optimal irrigation level for corn production in the Texas Panhandle." Proceedings of KSU Conference on Applied Statistics in Agriculture, Manhattan, Kansas, 2001.

Dutton, A.R., R.C. Reedy, and R.E. Mace. "Saturated Thickness in the Ogallala Aquifer in the Planning Area Simulation for 2000 through 2050 withdrawal Projection." Paper prepared for Panhandle Water Planning Group Panhandle Regional Planning Commission, Contract No. UTA01-462, December 2001.

Energy Information Administration (EIA). http://www.eia.doe.gov/ (accessed February 2005)

Farm Service Agency. *Irrigated crop acres for the 26 counties in the Texas Panhandle,* 2000.

Grubb, Herbert W. *Importance of Irrigation Water to the Economy of the Texas High Plains*. Report 11. Texas Technological College for the Texas Water Development Board, Austin, Texas, 1966.

Mourits, M.C.M., R.B.M. Huirne, A.A. Dijkhuizen, A.R. Kristensen, and D.T. Galligan. "Economic optimization of dairy heifer management decisions." *Agricultural Systems* 61: 17-31, 1999.

Musick, J. T., F. B. Pringle, W. L. Harman, and B. A. Stewart. "*Long-Term Irrigation Trends – Texas High Plains*." Applied Engineering in Agriculture, 6 (6): 717-724, 1990.

Osborn, James E., and William C. McCray. *An Interindustry Analysis of the Texas High Plains Part I*. Department of Agricultural Economics. Texas Tech University, Lubbock, Texas, 1972.

Stewart, B. "Aquifer Ogallala." In *Encyclopedia of Water Science*. Marcel Dekker, Inc. pp.43-44, 2003.

Texas Water Development Board. *Driller's Report.* http://134.125.70.235/drillers-new/index.asp, February 2005.

The Kerr Center. *The Ogallala Aquifer*. http://www.kerrcenter.com/publications/ogallala_aquifer.pdf, January 2005.

U. S. Department of Agriculture, National Agricultural Statistics Service (USDA-NASS). http://www.nass.usda.gov:81/ipedbcnty/sso-mapl.htm (accessed March 2005)

U.S. Department of the Interior, USGS. *Water in Storage and Approaches to Ground-Water Management, High Plains Aquifer, 2000.* Circular 1243. Washington DC., 2003.

Table 1. Dallam County Crop Change Pattern for Selected years

Crop\Year	2000	2015	2030	2045	2060
			Crop %		
Pasture Irrigated	1.27	0.26	0.05	0.01	0.00
Corn Irrigated	56.76	44.78	33.57	24.24	12.82
Sorghum Irrigated	1.63	0.33	0.07	0.01	0.00
Sorghum Dry	5.48	1.13	0.23	0.05	0.01
Soybean Irrigated	0.26	0.40	0.08	0.02	0.00
Wheat Irrigated	18.88	3.89	0.80	0.16	0.03
Wheat Dry	15.63	49.12	64.93	74.41	82.54
Alfalfa	0.01	0.05	0.20	0.82	3.44
Alfalfa Establishment	0.00	0.02	0.07	0.27	1.15

Table 2. Estimated Present Value of Revenue, Water Use, and Crop Acres, Dallam County

Year	PV ($)	Water Use (ac-in)	Pasture	Corn	Sorghum I	Sorghum NI	Soybean	Wheat I	Wheat NI	Alfalfa
2000	6,515,894	3,440,247	3,515	157,571	4,515	15,202	732	52,417	43,380	31
2001	6,254,828	3,343,574	3,164	155,856	4,064	13,681	805	47,175	47,718	35
2002	6,015,467	3,250,938	2,847	153,981	3,657	12,313	885	42,458	52,490	38
2003	5,797,032	3,162,116	2,562	151,972	3,292	11,082	974	38,212	57,739	42
2004	5,598,819	3,076,901	2,306	149,852	2,963	9,974	1,071	34,391	63,513	46
2005	5,420,190	2,995,100	2,076	147,639	2,666	8,976	1,178	30,952	69,864	51
2006	5,260,578	2,916,533	1,868	145,351	2,400	8,079	1,296	27,857	76,851	56
2007	5,119,482	2,841,029	1,681	143,004	2,160	7,271	1,426	25,071	84,536	61
2008	4,996,470	2,768,433	1,513	140,609	1,944	6,544	1,569	22,564	92,989	67
2009	4,891,176	2,698,595	1,362	138,179	1,749	5,889	1,725	20,307	102,288	74
2010	4,803,300	2,631,378	1,226	135,722	1,574	5,300	1,898	18,277	112,517	81
2011	4,662,147	2,566,651	1,103	133,452	1,417	4,770	1,708	16,449	118,539	90
2012	4,512,416	2,504,293	993	131,170	1,275	4,293	1,537	14,804	123,363	99
2013	4,366,748	2,444,189	893	128,885	1,148	3,864	1,384	13,324	127,932	108
2014	4,225,197	2,386,232	804	126,603	1,033	3,478	1,245	11,991	132,268	119
2015	4,087,786	2,330,320	724	124,330	930	3,130	1,121	10,792	136,386	131
2016	3,954,512	2,276,357	651	122,071	837	2,817	1,009	9,713	140,303	144
2017	3,825,350	2,224,255	586	119,830	753	2,535	908	8,742	144,032	159
2018	3,700,254	2,173,928	528	117,611	678	2,282	817	7,868	147,587	175
2019	3,579,166	2,125,296	475	115,415	610	2,054	735	7,081	150,980	192
2020	3,462,017	2,078,283	427	113,246	549	1,848	662	6,373	154,223	211
2021	3,348,725	2,032,819	385	111,106	494	1,663	596	5,735	157,325	232
2022	3,239,204	1,988,837	346	108,994	445	1,497	536	5,162	160,295	256
2023	3,133,361	1,946,271	312	106,913	400	1,347	482	4,646	163,143	281
2024	3,031,100	1,905,062	280	104,864	360	1,213	434	4,181	165,877	309
2025	2,932,323	1,865,152	252	102,845	324	1,091	391	3,763	168,503	340
2026	2,836,929	1,826,488	227	100,858	292	982	352	3,387	171,029	374
2027	2,744,817	1,789,018	204	98,901	263	884	317	3,048	173,462	412
2028	2,655,886	1,752,693	184	96,975	236	796	285	2,743	175,806	453
2029	2,570,036	1,717,467	166	95,078	213	716	256	2,469	178,068	498
2030	2,487,169	1,683,296	149	93,210	191	644	231	2,222	180,253	548

Table 2. Estimated Present Value of Revenue, Water Use, and Crop Acres, Dallam County (Continued)

Year	PV ($)	Water Use (ac-in)	Pasture	Corn	Sorghum I	Sorghum NI	Soybean	Wheat I	Wheat NI	Alfalfa
2031	2,407,187	1,650,138	134	91,369	172	580	208	2,000	182,366	603
2032	2,329,995	1,617,953	121	89,554	155	522	187	1,800	184,411	663
2033	2,255,500	1,586,704	109	87,763	140	470	168	1,620	186,393	729
2034	2,183,613	1,556,354	98	85,994	126	423	151	1,458	188,316	802
2035	2,114,244	1,526,869	88	84,246	113	381	136	1,312	190,183	882
2036	2,047,311	1,498,217	79	82,516	102	342	123	1,181	192,000	971
2037	1,982,729	1,470,367	71	80,802	92	308	110	1,063	193,768	1,068
2038	1,920,420	1,443,288	64	79,101	82	277	99	957	195,491	1,174
2039	1,860,308	1,416,953	58	77,410	74	250	89	861	197,174	1,292
2040	1,802,318	1,391,334	52	75,726	67	225	80	775	198,819	1,421
2041	1,746,382	1,366,405	47	74,047	60	202	72	697	200,430	1,563
2042	1,692,430	1,342,143	42	72,367	54	182	65	628	202,009	1,719
2043	1,640,398	1,318,523	38	70,684	49	164	59	565	203,560	1,891
2044	1,590,225	1,295,523	34	68,993	44	147	53	508	205,087	2,080
2045	1,541,850	1,273,121	31	67,290	39	133	48	457	206,591	2,288
2046	1,495,218	1,251,297	28	65,569	35	119	43	412	208,078	2,517
2047	1,450,275	1,230,031	25	63,826	32	107	38	371	209,550	2,769
2048	1,406,969	1,209,304	22	62,054	29	97	35	334	211,010	3,046
2049	1,365,253	1,189,098	20	60,247	26	87	31	300	212,462	3,350
2050	1,325,080	1,169,396	18	58,398	23	78	28	270	213,911	3,685
2051	1,286,406	1,150,180	16	56,501	21	71	25	243	215,359	4,054
2052	1,249,191	1,131,436	15	54,546	19	63	23	219	216,811	4,459
2053	1,213,397	1,113,147	13	52,524	17	57	20	197	218,272	4,905
2054	1,178,987	1,095,299	12	50,427	15	51	18	177	219,746	5,396
2055	1,145,927	1,077,879	11	48,244	14	46	17	160	221,237	5,936
2056	1,114,186	1,060,871	10	45,962	12	42	15	144	222,752	6,529
2057	1,083,734	1,044,264	9	43,570	11	37	13	129	224,296	7,182
2058	1,054,546	1,028,045	8	41,053	10	34	12	116	225,875	7,900
2059	1,026,597	1,012,202	7	38,397	9	30	11	105	227,496	8,690
2060	999,863	996,724	6	35,585	8	27	10	94	229,166	9,559

Table 3. Yearly Hydrological Data such as Saturated Thickness, Groundwater Use and Remaining Groundwater Volume in Dallam County

Year	Str Tht (ft)	Water used (ac-in)	R. Water Volume (ac-in)	Year	Str Tht (ft)	Water used (ac-in)	R. Water Volume (ac-in)
2000	126.00	3,440,247	239,679,753	2031	87.26	1,650,138	166,728,108
2001	124.22	3,343,574	236,336,178	2032	86.41	1,617,953	165,110,155
2002	122.48	3,250,938	233,085,240	2033	85.57	1,586,704	163,523,451
2003	120.80	3,162,116	229,923,124	2034	84.75	1,556,354	161,967,098
2004	119.16	3,076,901	226,846,222	2035	83.94	1,526,869	160,440,228
2005	117.57	2,995,100	223,851,122	2036	83.15	1,498,217	158,942,011
2006	116.01	2,916,533	220,934,589	2037	82.37	1,470,367	157,471,644
2007	114.50	2,841,029	218,093,560	2038	81.61	1,443,288	156,028,356
2008	113.03	2,768,433	215,325,127	2039	80.86	1,416,953	154,611,403
2009	111.59	2,698,595	212,626,532	2040	80.13	1,391,334	153,220,069
2010	110.20	2,631,378	209,995,155	2041	79.41	1,366,405	151,853,664
2011	108.83	2,566,651	207,428,504	2042	78.70	1,342,143	150,511,521
2012	107.50	2,504,293	204,924,210	2043	78.00	1,318,523	149,192,998
2013	106.20	2,444,189	202,480,021	2044	77.32	1,295,523	147,897,474
2014	104.94	2,386,232	200,093,789	2045	76.65	1,273,121	146,624,353
2015	103.70	2,330,320	197,763,470	2046	75.99	1,251,297	145,373,056
2016	102.49	2,276,357	195,487,112	2047	75.34	1,230,031	144,143,025
2017	101.31	2,224,255	193,262,857	2048	74.70	1,209,304	142,933,720
2018	100.16	2,173,928	191,088,930	2049	74.08	1,189,098	141,744,622
2019	99.03	2,125,296	188,963,634	2050	73.46	1,169,396	140,575,227
2020	97.93	2,078,283	186,885,351	2051	72.85	1,150,180	139,425,047
2021	96.86	2,032,819	184,852,531	2052	72.26	1,131,436	138,293,611
2022	95.80	1,988,837	182,863,695	2053	71.67	1,113,147	137,180,464
2023	94.77	1,946,271	180,917,424	2054	71.10	1,095,299	136,085,165
2024	93.76	1,905,062	179,012,362	2055	70.53	1,077,879	135,007,286
2025	92.78	1,865,152	177,147,210	2056	69.97	1,060,871	133,946,415
2026	91.81	1,826,488	175,320,721	2057	69.42	1,044,264	132,902,150
2027	90.86	1,789,018	173,531,703	2058	68.88	1,028,045	131,874,105
2028	89.93	1,752,693	171,779,010	2059	68.35	1,012,202	130,861,902
2029	89.03	1,717,467	170,061,542	2060	67.82	996,724	129,865,179
2030	88.14	1,683,296	168,378,246				

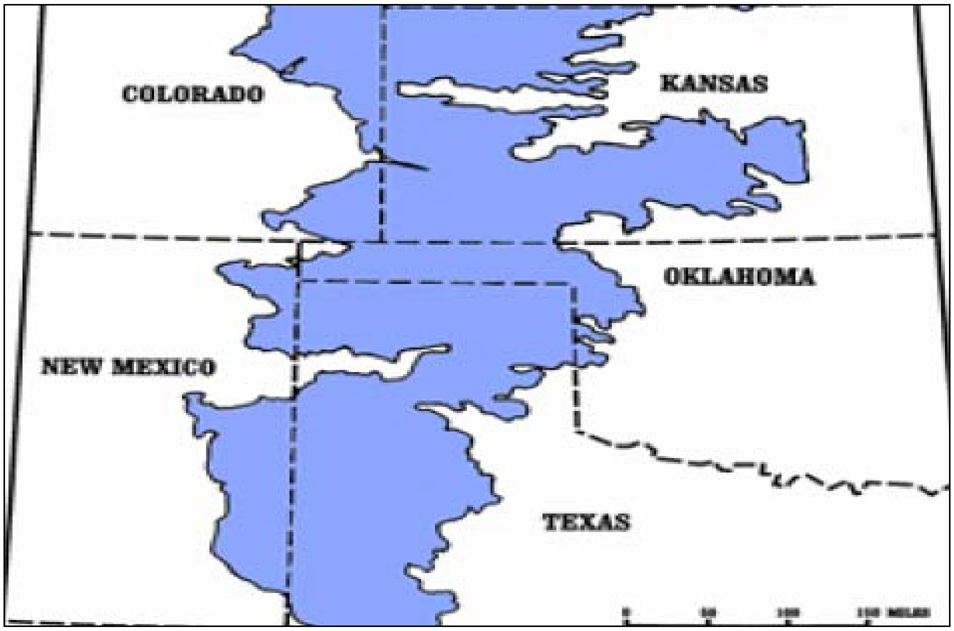

Figure 1. Southern Ogallala Aquifer Region (The Kerr Center, 2005)

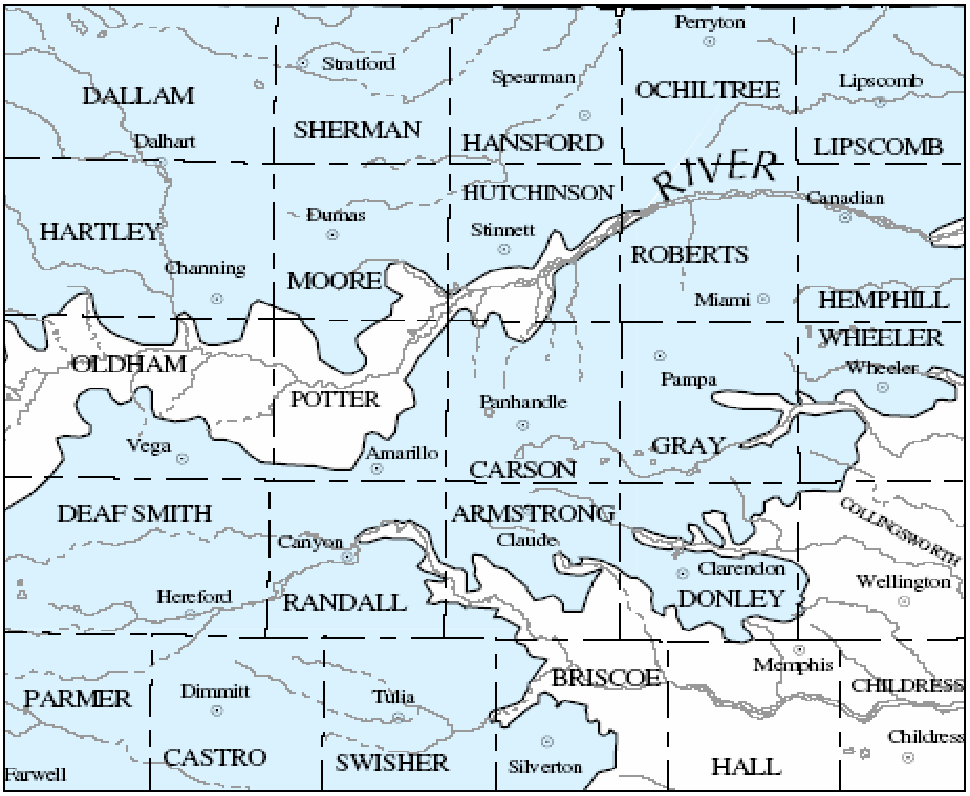

Figure 2. Twenty-six Counties in the Texas Panhandle (USDI-USGS, 2003)

Saturated Thickness	126	ft	ST
Groundwater Volume in Storage	243,120,000	ac-in	
Harvested Acres	219,061	acres	HA
Water volume per harvested acres	1,110	ac-in/acre	
Saturated Thickness per ac-in per harvested acres	0.11353094	t/ac-in/acr	STAHA

For Dallam county, withdrawing 1 ac-in groundwater will lower water level
by 0.11353094 ft.

Water use at year 0	3,440,247	ac-in	WUY0
Reduction in Saturate Thickness = (WUY0/HA)*STAH	1.78295146	ft	RST
New saturated thickness at year 1= (ST-RST)	124.217049	ft	STY1

Calculation of groundwater availability
Inverse square relationship between saturated thickness and water capacity
Therefore, a well with 50 percent reduction in saturated thickness can only pump
25 percent of water compared with its initial capacity.

ST	STY1	STY1/ST	Square of (STY1/ST)	SQS1/ST
126	124.217	0.98585	0.97189942	

New Groundwater availibitliy at year 1=WUY0*SQS1/ST	3,343,574	ac-in	WAY1

Figure 3. Example of methodology for calculating saturated thickness and water availability for using data for Dallam County

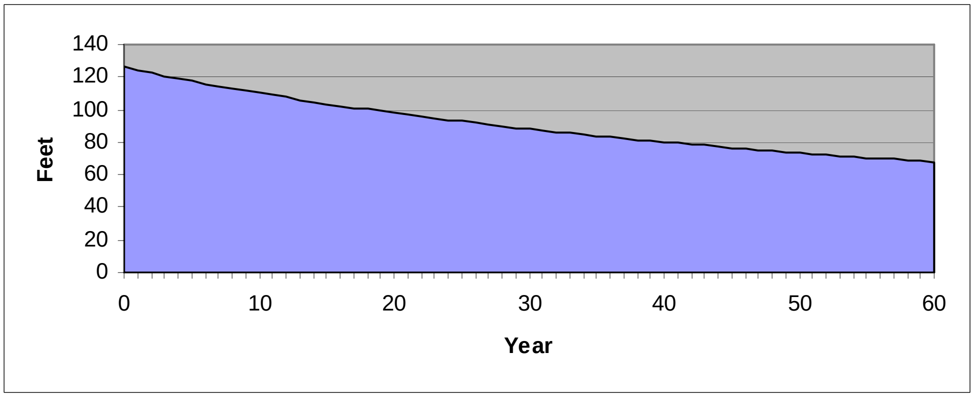

Figure 4. Changes in Saturated Thickness, Dallam County

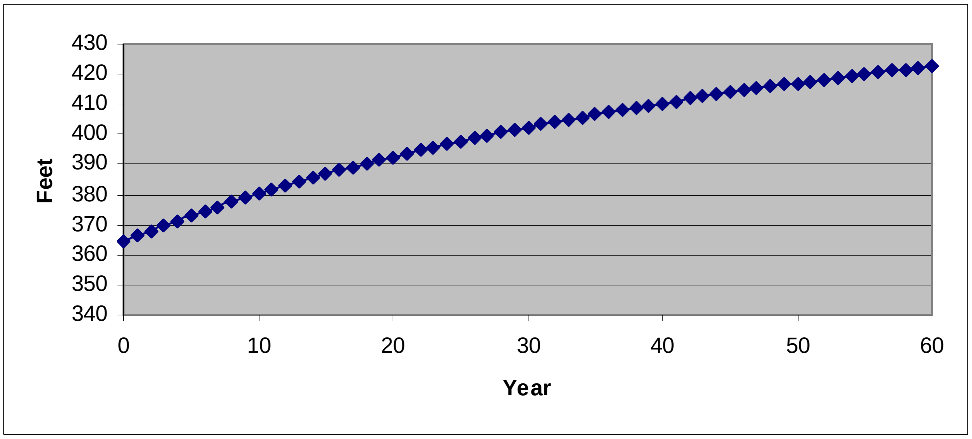

Figure 5. Changes in Pumping Lift, Dallam County

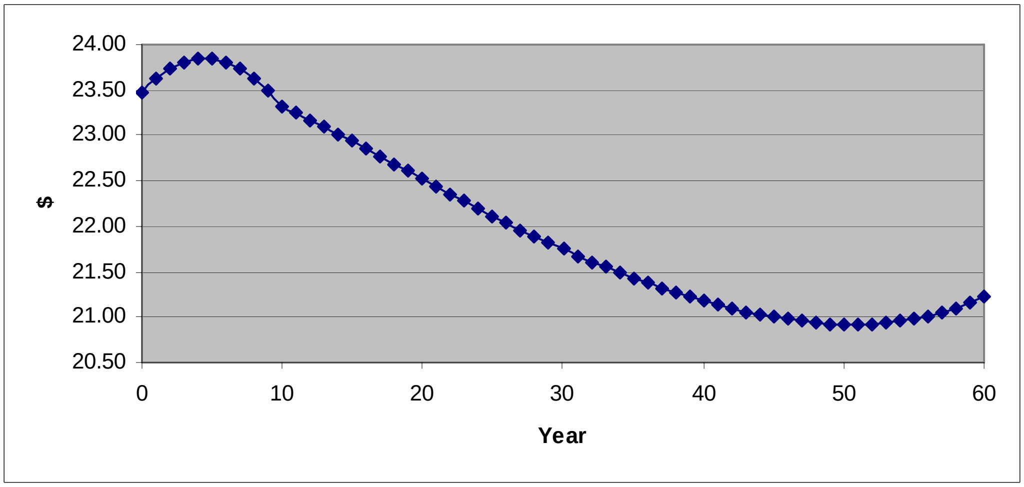

Figure 6. Nominal Revenue per Cropland Acre, Dallam County