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Impact of Irrigation Efficiency Improvements and Government Payment Programs on the Agricultural Cost of Groundwater Conservation in the Texas High Plains

David B. Willis
Associate Professor
Department of Applied Economics and Statistics
Clemson University

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INTRODUCTION

The Ground and Surface Water Conservation section of the proposed 2007 Food and Energy Security Act provides $300 million dollars to agricultural producers that adopt on-farm conservation practices that result in a "net water savings". Net water savings is interpreted as any practice that increases irrigation efficiency (Underwood 2007). However, as Huffaker and Whittlesey (1995) note, irrigation efficiency increases can create the "illusion of water conservation, when in reality the consumptive use of water may increase". If the congressional intent of the "net water savings" language is to reduce groundwater mining rates and/or augment stream flow levels, then treating irrigation efficiency increases as a conservation measure, without additional restrictions on water use, may result in outcomes inconsistent with the conservation objective. Despite the decoupling of the counter cyclical payment (CCP) and direct payment (DP), the loan deficiency payment (LDP) continues to affect producer decisions regarding crop choice and groundwater use in the THP. This is particularly true for two crops extensively grown in the THP, cotton and wheat. Between 2000 and 2004 the LDP averaged $0.135 per pound for cotton (35.0 percent of market price) and $0.122 per bushel for wheat (4.6 percent of average market price).

This research focuses on the impact of that loan deficiency payments and improved irrigation technology have had on groundwater use in the THP. A second research objective is to examine the average and marginal cost to irrigated agriculture of decreasing groundwater extraction rates under alternative irrigation technologies, with and without the loan deficiency payment.

EMPIRICAL SETTING

In the Texas High Plains (THP), the panhandle region of northwest Texas, agricultural groundwater withdrawals account for 96% of all Southern Ogallala aquifer withdrawals (TWDB 2007). The heavy agricultural reliance on groundwater to satisfy water crop demand is attributable to limited surface supplies and the high cost of developing surface water storage facilities within the region. The Southern Ogallala aquifer annual withdrawal level is estimated to be more than 10 times greater than the natural recharge rate (Guru and Horne 2000), and the aquifer is now being mined as an exhaustible resource. Due to heavy agricultural withdrawals over the last 50 years, Southern Ogallala groundwater reserves are approximately 50 percent of their 1940 storage level (Ogallala Commons 2004).

As illustrated in Figure 1, the 42,000 square mile Southern Ogallala Aquifer comprises the southern-most third of the Ogallala Aquifer system. The Canadian River valley and the Prairie Dog Fork of the Red River valley divide the Southern High Plains from the Central High Plains region of the Ogallala Aquifer (Stovall 2001). Eighty-five percent of the Southern Ogallala aquifer is located within Texas and the remaining 15% is in eastern New Mexico (HPUWCD undated). There is very little hydraulic connectivity between the Southern Ogallala aquifer and the Central Ogallala aquifer (Stovall 2001).

Agricultural settlements began to dot the THP landscape in the late 1870s and groundwater wells were first hand-dug near present-day Lubbock in 1878. However, irrigation technology did not begin to be significantly adopted within the region until Word War II demands and post war price supports for cotton and wheat, and intensive crop production in the region, made large scale irrigation production profitable in the 1940s and 1950s (Green 1973). By 1960, production agriculture in the THP had transitioned from small subsistence farms to large profitable farms with substantial investments in irrigation technology. Moreover, irrigation technology was being adopted to increase crop yield and profitability rather than as a form of self-insurance against drought. However, this economic development came with a cost. Heavy groundwater withdrawals over the prior decades had lowered the water table more than two-hundred feet from pre-development levels in some areas by the mid 1970s (TWDB 2007). Increased pump lifts associated with the dropping water table in combination with high energy prices led to a contraction in irrigated acreage. As illustrated in Figure 2, irrigated acreage decreased from an all-time high of nearly 6 million acres in 1974 to slightly less than 4 million acres by 1989.

Low energy precision application (LEPA) irrigation systems were developed in the late 1980s to counter the costs of increasing pump lift and higher energy cost. Water application efficiency under LEPA irrigation is higher than for the center pivot sprinkler and furrow irrigation systems that were previously used (Lewis 1990). Today about 69 percent of the irrigation systems in the THP are LEPA systems with a 90 percent irrigation efficiency the remaining 31 percent of the irrigation systems are furrow irrigation gravity systems with an irrigation efficiency of 70 percent. With the introduction of LEAP, between 1989 and 2002, irrigated acres increased from 3.9 million to 4.6 million (United States Census of Agriculture, various issues). Despite the introduction of the more water efficient LEPA systems, the water table continued to decline throughout the 1990s in many areas of the THP (Dutton et al. 2000).

Recent Texas legislation (Senate Bills 1 and 2) explicitly recognizes the growing scarcity of Texas' groundwater supplies, and requires the Texas Water Development Board (TWDB) to develop a statewide water use plan that incorporates locally developed regional water plans. The Groundwater conservation districts in the Texas High Plains are faced with evaluating and implementing new groundwater management policies to address declining aquifer levels. Knowledge of the impact that irrigation technology and government programs have on agricultural conservation cost is essential to accurately estimating to the cost imposed upon irrigated agriculture if withdrawal rates are reduced below expected baseline use.

METHODS AND PROCEEDURES

Model Overview

Detailed county-level economic models are constructed for the 19 THP counties that overlay the Southern Ogallala Aquifer. These nineteen THP counties account for 97 percent of all Texas agricultural groundwater withdrawals from the Southern Ogallala Aquifer (Das and Willis 2004). The economic model estimates the optimal agricultural groundwater extraction time path that maximizes the present value of agricultural net returns over a 50-year planning horizon. The Crop Production and Management Model (Gerik et. al. 2003) was used to develop nonlinear crop production functions to describe crop yield response to applied water for given soil types, irrigation systems, fixed input levels, and average weather conditions. County-specific irrigated crop production functions are estimated for the five dominant irrigated crops grown in the 19-county study area (95 production equations in all). These five crops are corn, cotton, grain sorghum, peanuts, and wheat and collectively account for 97 percent of agricultural crop water use within the study area. A quadratic functional form was used to estimate the crop yield response to applied water, the production functions were estimated using ordinary least squares regression with the intercept set at the 5-year dryland county yield average for each crop for the years 2000-2004. To provide a dryland alternative to irrigation, county-specific average dryland yields are determined for each of the crops assuming average weather conditions and representative management techniques.

Additional county-specific data input into the dynamic economic model include initial saturated thickness, initial average pump lift, initial average well yield, initial average acres served per well, and initial number of irrigated and dryland acres by crop. The variable costs for dryland crop production and the additional costs for irrigation are taken from enterprise budgets for Texas Extension District 2 (Texas Agricultural Extension Service 2003). 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 per acre cost of each irrigation system, irrigation system depreciation, annual per acre irrigation system labor, maintenance, and depreciation cost. Average crop price was calculated data for the years 2000-2004 using data reported by the Texas Agricultural Statistics Service. Crop LDP were calculated as specified in the Farm and Rural Investment Act of 2002 under the assumption that the 2000-2004 average crop market price was realized. Under the average assumed crop price no LDP were paid on Sorghum, Peanuts, or Corn. A 3 percent real discount rate is used to convert 50 years of annual returns to present values. Figure 3 identifies the location of the nineteen Texas counties that account for 97% of Texas' Southern Ogallala agricultural groundwater withdrawals.

Model Specification

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

$$(1) \qquad NI_t = \sum_c \sum_i \Theta_{cit} \{([P_c + LDP_c] * Y_{cit}(WP_{cit})) - TVC_{cit}(WP_{cit}, L_t, ST_t)\},$$

where *c* represents the crop grown, *i* represents the type of irrigation system (center pivot irrigated, furrow irrigated or non-irrigated), and *t* represents the time period, Θ_{cit} represents the percentage of crop *c* produced with irrigation system *i* in period *t*, P_c represents the price of crop *c*, LDP_c is the average loan deficiency payment per unit of crop c produced, Y_{cit} represents the yield per acre of crop *c* produced with irrigation system *i* in period *t*, $\mathrm{WP}_{\mathrm{cit}}$ represents the amount of water pumped in cubic meters to irrigate crop *c* through irrigation system *i* in period *t*, TVC_{cit} represents the total variable cost of production per acre of crop *c* produced with irrigation system *i* in period *t*, L_t represents the pump lift in meters in time *t*, ST_t represents the saturated thickness of the aquifer in time *t,* and NI_t represents the net income over variable cost in time *t*. Yield (Y_{cit}) was calculated using the previously discussed crop production functions. The objective function was maximized for a 50-year planning horizon and may be expressed as:

$$(2) \qquad Max\ PVNI = \sum_t^{50} NI_t * (1+r)^{-t}$$

(3)

$$Max\ PVNI = \sum_{c}\sum_{i}\sum_{t}\Theta_{cit} * \{([P_c + LDP_c] * Y_{cit}(WP_{cit})) - TVC_{cit}(WP_{cit}, L_t, ST_t)\} * (1+r)^{-t};$$

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

Subject to:

(4) $ST_{t+1} = ST_t - [(\sum \sum \Theta_{cit} * WP_{cit}) - R_t]/S;$

(5) $L_{t+1} = L_t + [(\sum \sum \Theta_{cit} * WP_{cit}) - R_t]/S;$

(6) $GPC_t = 4.42 * (IWY/AW) * (ST_t / IST_t)^2;$

(7) $PER\ ACRE\ WATER\ USE_t = \sum_{c}\sum_{i}\Theta_{cit} * WP_{cit};$

(8) $PER\ ACRE\ WATER\ USE_t \leq GPC_t;$

(9) $IRENGERYCOST_{cit} = \{[EF(L_t + 2.31 * PSI_i) * EP]/EFF\} * WP_{cit};$

(10) $TVC_{cit} = NIRVC_{ci} + IRRENERGYCOST_{cit} + HC_{cit} + MC_i + DP_i + LC_i;$

(11) $\sum_{c}\sum_{i}\Theta_{ci} \leq 1\ for\ all\ t;$

(12) $\sum_{c}\sum_{i}\Theta_{cit} \leq Initial\ Irrigated\ Percentage\ \ \forall\ i = center\ pivot\ or\ furrow;$

(13) $\Theta_{cit} \geq 0.666 * \Theta_{cit-1};$

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

(15) $TotalWaterUse_t = PerAcreWaterUse_t * TotalAcres;\ and$

(16) $\sum_{t} TotalWaterUse_t = Maximum\ Water\ Use.$

The objective function expressed in Equation 3 is obtained by substituting Equation 1 into Equation 2. Equations 4 and 5 are equations of motion for the two state variables of saturated thickness (ST_t) and pumping lift (L_t), where R_t is the annual recharge rate in acre inches per acre of aquifer, S represents the specific yield of the aquifer, and WP_{cit} is the acre inch volume of water withdrawn from the aquifer in period t and applied to crop *c* using irrigation technology *i* in period *t*. The base year for initial saturated thickness was taken from Stovall (2001).

Equations 6, 7, and 8 express the relationship between the amount of water pumped and the amount of water available. Equation 6 estimates the maximum volume of water that can be applied per irrigated acre in each time period. Per acre gross pumping capacity in period *t* (GPC_t), is a function of initial saturated thickness *(IST)*, average initial well yield for a county *(WY)*, and average number of wells per irrigated acre within the county *(AW)* (Harman, 1966; Terrell, 1998; and Texas Water Development Board, 2001). The unit of measure associated with the factor 4.42 is acre-inches per gallon per minute (ac-in/gpm) and the value was developed assuming a well pumps 2000 hours in the growing season.[1] Equation 7 calculates the volume of water pumped per irrigate acre ($PER\ ACRE\ WATER\ USE_t$) as the sum of water pumped on each crop under each technology weighted by the percent to total crop acreage produced under the crop and irrigation technology combination. Equation 8 is a constraint that assures the per acre volume of water pumped ($PER\ ACRE\ WATER\ USE_t$) is less than or equal to the per acre amount of water available for pumping (GPC_t). This specification inherently assumes that land-use practices and aquifer characteristics are homogenous within a county.

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[1] [(2000 hours) * (60 minutes/hour) * (43,560 cubic feet/acre-foot)] /[(7.48 gallons/cubic foot) * (12 inches/foot)] = 4.42 acre-inches/gallon per minute.

Equation 9 calculates the per acre irrigation energy cost of pumping and applying irrigation water to crop *c* produced using irrigation system *i* in period *t* ($IRENERGYCOST_{cit}$), where *EF* represents the energy use factor for electricity, L_t is well lift in period *t*, PSI_i is irrigation system operating pressure in pounds per square inch (zero for furrow irrigation), *EP* represents energy price per unit of electricity, *EFF* represents pump engine efficiency, and the factor 2.31 is the height in feet of a column of water that will exert a pressure of 1 pound per square inch (Terrell, 1998). Equation 10 calculates the total variable cost per acre (TVC_{cit}) for crop *c* produced by irrigation system *i* in period *t.* Per acre TVC_{cit} is calculated as the sum of $NIRVC_{ci}$ non irrigation related variable cost for crop *c* under irrigation technology *i,* plus HC_{cit} the per acre harvest cost for crop *c* under irrigation system *i*, plus MC_i the annual per acre maintenance cost for the irrigation system *i*, plus DP_i the annual per acre depreciation cost for irrigation system *i*, and LC_i the per acre irrigation labor cost for irrigation system *i*.

Equation 11 limits the sum of the percentage of area for all crops *c* produced by all irrigation systems *i* for each period *t* to be less than or equal to 1. Equation 12 ensures that the percentage of acres irrigated does not increase above the initial percentage at the beginning of the planning horizon in each county. Without this restriction and given the time value of money the optimization procedure found it more profitable to increase irrigated acreage in the short-run. However, increasing irrigation acreage in the short-run is inconsistent with the fact that irrigated acreage has been decreasing over time in the study region.

Equation 13 limits the annual reduction in crop acreage under a specific irrigation technology to be no more than 33.33% of the previous year’s acreage. This limit on the rate of transition between crop enterprises controls the rate at which the model switches from one enterprise to another in order to replicate an orderly transition between crop enterprises. Equation 14 ensures that the values of the decision variables, Θ_{cit} , the amount of acreage devoted to a given crop and irrigation technology are non-negative.

Equations 15 and 16 respectively calculate total ground water within a given county in each time period t, and constrain total county ground water groundwater withdrawals a pre-specified policy level for the 50-year planning horizon. Total water use in period t is calculated as the average quantity of groundwater withdrawn and applied per acre of cropland multiplied by the total quantity of cropped acres in the initial time period. Total cropped acreage in a county is the sum of irrigated and non-irrigated acres in the initial period. As the quantity of water applied to an irrigated crop decreases and or the percent of land in dryland crop production increases the average quantity of water applied per cropped acre decreases. Equation 16 calculates total county level water use for the 50 year planning horizon. Though not included in the above model specification, irrigated peanut acreage was restricted to be no more than one-third irrigated acreage at any point in time. This restriction ensured that peanuts, which are exclusively grown under irrigation, are rotated with another crop four years in six to control for potential agronomic disease problems.

Initially, for a given irrigation technology and government payment scenario the value for maximum water use is treated as a variable. After the *Maximum Water Use* value is determined for a given irrigation technology-government program scenario the Maximum Water Use variable is treated as a parameter whose value is decreased downward in 10 percent increments from its unconstrained value to estimate the average and marginal cost of decreasing agricultural groundwater withdrawals from the appropriate baseline level.

EMPIRICAL RESULTS

A dynamic 50-year baseline for expected annual groundwater withdrawals is established in each county for the four combinations of irrigation technology (either furrow or LEPA) and government program (LDP or no LDP). The baseline status quo extraction time path is derived under the assumption that agricultural producers will optimally adjust annual groundwater withdrawals in response to increasing water scarcity over time given current water policy regulations, private economic incentives, existing irrigation technology, and initial hydrologic conditions within each county. This efficient dynamic baseline condition is subsequently used as the frame of reference to analyze the average and marginal cost imposed on irrigated agricultural if ground water withdrawals were reduced by a given percentage from their baseline level for a specific irrigation and government program combination. All economic values are reported in net present value.

Baseline Situation

As reported in Table, between 2000 and 2004, the average number of acres in crop production for the 19 county study region was 5.78 million acres with irrigated acreage accounted for 52.68 percent of the acreage (3.04 million acres). However, within a given county the percentage of land in irrigation ranged from a low of 12.07 percent in Dawson County to a high of 84.20 percent in Hale County. Regionally, 69.33 percent of the irrigated acreage is irrigated using LEPA technology. However, considerable variation also exists among the counties regarding the percentage of land irrigated using

LEPA at a irrigation efficiency of 90 percent versus furrow irrigation with an irrigation efficiency of 70 percent. In Gaines County, 100 percent of the irrigation systems are LEPA systems whereas only 31.97 percent of the systems in Floyd County are LEPA.

Under the four scenarios considered, derived from the four combinations of irrigation technology (LEPA and furrow) and government programs (LDP program and no LDP program), baseline regional per acre net present value (NPV) is largest for LEPA technology in combination with the LDP, and smallest for furrow irrigation technology without the LDP. As reported in Table 2, for a given irrigation technology, per acre regional NPV is two and a half to three times larger with the LDP program than without the program. Moreover, though more variable at the county level, the regional per acre NPV results are consistent with the results simulated for each of the 19 counties within the region.

As shown in Table 3, the presence of the LDP has a greater impact on total regional water use then irrigation technology. Regardless of which irrigation technology employed, total regional water use is nearly equal when the LDP program is available (184.2 million acre feet (maf) for LEPA versus 184.9 maf for furrow). Without the LDP program, total regional water use is about 3.6 percent less under LEPA technology than furrow technology (163.06 maf for LEPA versus 169.22 maf for furrow). Over the 50-year planning horizon, the LDP results in a total regional water use increase of 13.0 percent under LEPA irrigation, and 9.2 percent under furrow irrigation.

Generally speaking, the relative impact of technology and the LDP on individual county water use is consistent with the regional finding except for three counties: Castro, Dawson, and Parmer. In the absence of LDP, water use in Dawson county decreases by

93.7 percent under LEPA irrigation (2.56 maf to 0.16 maf), and increases by 44.3 percent under furrow irrigation (3.13maf to 4.52 maf). The water reduction under LEPA occurs because without the cotton LDP, all irrigated baseline cotton acreage goes out of production in favor of more profitable dryland sorghum production. When the LDP is available, all initial year LEPA irrigated cotton acreage remained in production over the 50-year planning horizon. Without the LDP, total water use increases under furrow irrigation as all irrigated cotton acreage is replaced by irrigated wheat which the optimization model irrigates to a higher per acre level.

In contrast to Dawson County situation, the loss of the LDP significantly decreases total groundwater withdrawals in Parmer County regardless of the irrigation technology used. Groundwater withdrawals decreased by 89.5 percent under LEPA irrigation (10.4 maf to 1.09 maf), and by 88.9 percent under furrow irrigation (10.4 maf to 1.15 maf). When the LDP is available, irrigated cotton is the dominant irrigated crop grown within the county, however, without the dryland sorghum becomes the dominant crop grown within the region regardless of the irrigation technology available. A similar outcome was also observed in Castro County.

The next section reports regional average and marginal cost estimates for decreasing ground water withdrawals below the baseline level. The reductions are specified as a given percentage point reduction below the estimated baseline withdrawal level for the four scenarios considered.

Regional Conservation Costs

Despite the fact that more ground water is withdrawn with the LDP than without the payment, the average and marginal cost imposed on irrigated agriculture is greater under the LDP scenarios regardless of the irrigation technology employed. Moreover, relative to each respective scenario baseline withdrawal level, both the average and marginal cost for a given percentage reduction in baseline groundwater withdrawals increases as the percentage reduction is increased as reported in Table 4. The marginal cost of achieving a given percentage reduction is about 50 percent greater than the average cost of achieving a given percentage reduction in regional groundwater all four scenarios examined.

County Conservation Costs

Tables 5 and 6 respectively report the average and marginal cost of achieving a pre-specified percentage reduction in baseline ground water use withdrawals under each scenario for three selected counties; Gaines, Hale, and Castro. Similar to the aggregate regional outcome, the average and marginal cost of ground water conservation in each county is greater under the LDP than without the LDP regardless of the irrigation technology employed. Generally speaking both the average and marginal cost of groundwater conservation is higher than their respective regional values in Gains and Hale counties and below their regional values in Castro County. In contrast to the percentage reduction in the average and marginal cost of conservation estimated for Gaines and Hale counties, the percentage reduction in cost is much greater in Castro County without the LDP than for the two other counties. This occurs because Castro county tends to concentrate in irrigated cotton acreage when the LDP is available, but rapidly converts its irrigated cotton acreage to dryland sorghum acreage and some irrigated wheat acreage regardless of the irrigation system available. Irrigated wheat in this county is a very marginal endeavor and irrigated wheat can be taken out at a low marginal cost in response to a reduction in allowed ground water withdrawals.

POLICY IMPLICATIONS

The marginal cost of reducing ground water withdrawals to irrigated agriculture generally is about 50% greater than the average cost to achieve a given percentage reduction in baseline withdrawal level. Increases in irrigation efficiency and the LDP increase the marginal cost of achieving the specified conservation target reduction. Thus, greater economic incentives must be paid to irrigators using more efficient irrigation technologies and or receiving LDP to induce them to voluntarily participate in groundwater conservation. Compensating producers for all units conserved at their marginal cost will leave agriculture better off than if the water was used in agricultural production. Compensating agriculture at their average cost of conservation would leave them no worse off then if they used the water in irrigated production but likely would require stricter enforcement. This analysis provides policy makers with a tool to target low cost counties for water conservation programs.

References

Das, B. and D.B. Willis. "Towards a Comprehensive Water Policy Model for the Texas High Plains." *Journal of Agricultural and Applied Economics*. Vol. 36(2):510, (2004).

Green, D.E. *Land of the Underground Rain: Irrigation on the Texas High Plains, 1910-1970*. Austin: University of Texas Press, 1973.

Gerik, T., J. Williams, L. Francis, J. Greiner, M. Magre, A. Meinardus, and E. Steglich. "User's Guide: CroPMan (Crop Production and Management Model)". Blackland Research and Extension Center. Temple, TX. 2003.

Guru, M.V. and J.E. Horne. "The Ogallala Aquifer." Kerr Center for Sustainable Agriculture. 2000. www.kerrcenter.com/publications/ogallala_aquifer.pdf.

High Plains Underground Water Conservation Distinct No. 1. "The Ogallala Aquifer." Information Paper. Undated. http://www.hpwd.com/ogallala/ogallala.asp Last visited November 20, 2004.

Huffaker, R. & Whittlesey, N. (1995) "Agricultural Water Conservation Legislation: Will It Save Water?" *Choices*, Fourth Quarter, pp. 24-28.

Lewis, J. "The Ogallala Aquifer: An Underground Sea", *EPA Journal*, 16, Nov-Dec, p.42-44, 1990

Ogallala Commons, Press Release, October 10th Conference on Water in Ogallala, NE. Undated. http://ogallalacommons.org/docs/ogallala_pr1.doc Last visited on July 13, 2004.

Stovall, J.N. "Groundwater Modeling for the Southern High Plains." Unpublished dissertation. Texas Tech University, Lubbock, TX. 2001.

Underwood, Randy. 2007. Lubbock, Texas NRCS office. Personal Communication.

Terrell, B. (1998). *Economic Impacts of the Depletion of the Ogallala Aquifer: An Application to the Texas High Plains.* Unpublished masters thesis. Texas Tech University, Lubbock, TX.

Texas Water Development Board. *Water for Texas – 2007.* Document No. GP-8-1. Austin, TX. 2007. http://www.twdb.state.tx.us.

Table 1. Total Crop Acres, Percent Dryland Acres, Percent Irrigated Acres, and Percent Irrigated Acres by Irrigation System

County	Total Crop Acres	Percent Acres Dryland	Percent Acres Irrigated	Irrigated Acreage by System Percent LEPA	Percent Furrow
Bailey	218,100	58.83%	41.17%	93.98%	6.02%
Briscoe	95,233	67.20%	32.80%	43.21%	56.79%
Castro	373,134	25.21%	74.79%	55.14%	44.86%
Cochran	212,566	57.22%	42.78%	99.53%	0.47%
Crosby	272,866	45.09%	54.91%	61.40%	38.60%
Dawson	388,400	87.93%	12.07%	97.11%	2.89%
Deaf Smith	340,967	54.17%	45.83%	54.06%	45.94%
Floyd	334,867	39.89%	60.11%	31.97%	68.03%
Gaines	443,767	38.75%	61.25%	100.00%	0.00%
Garza	51,267	75.88%	24.12%	64.29%	35.71%
Hale	403,466	15.80%	84.20%	56.72%	43.28%
Hockley	370,167	54.43%	45.57%	75.21%	24.79%
Lamb	350,600	29.76%	70.24%	80.51%	19.49%
Lubbock	358,284	38.79%	61.21%	41.54%	58.46%
Lynn	370,100	77.49%	22.51%	78.14%	21.86%
Parmer	339,933	30.83%	69.17%	83.15%	16.85%
Swisher	290,300	51.35%	48.65%	36.96%	63.04%
Terry	357,500	50.41%	49.59%	99.88%	0.12%
Yoakum	207,833	49.91%	50.09%	99.47%	0.53%
19 County Region	5,779,350	47.32%	52.68%	69.33%	30.67%

Table 2. Baseline 50-Year per Acre Net Present Value by Irrigation Technology and Government Program ($'s/per acre)

County	Government Program LEPA System	Government Program Furrow System	No Government Program LEPA System	No Government Program Furrow System
Bailey	1,031	950	-212	120
Briscoe	3,652	2,927	2,142	1,614
Castro	2,162	1,460	173	138
Cochran	2,803	1,891	1,212	1,065
Crosby	1,220	554	-280	-218
Dawson	91	74	-394	-315
Deaf Smith	1,886	1,090	652	49
Floyd	3,847	2,873	725	281
Gaines	5,323	3,335	3,992	2,325
Garza	1,866	1,590	666	619
Hale	3,796	2,777	977	542
Hockley	2,095	1,691	30	-101
Lamb	1,935	1,667	85	348
Lubbock	2,841	2,232	318	174
Lynn	1,247	948	209	210
Parmer	1,182	666	104	68
Swisher	2,599	1,866	466	161
Terry	3,338	2,607	2,968	1,927
Yoakum	5,946	4,145	4,567	3,434
19 County Region[1]	2,558	2,054	922	756

[1] The 19 County Regional Average is a weighted average weighted by the total number of acres in each county.

Table 3. Baseline Ground Water Withdrawals by Irrigation Technology and Government Program by County over 50-Year Planning Horizon (Acre-feet)

County	Government Program LEPA System	Government Program Furrow System	No Government Program LEPA System	No Government Program Furrow System
Bailey	7,278,238	8,067,757	7,073,403	7,160,221
Briscoe	3,170,408	3,609,417	3,079,498	3,496,109
Castro	10,945,240	10,957,192	6,588,879	6,205,761
Cochran	7,030,858	7,106,031	7,326,662	6,841,005
Crosby	10,436,847	10,919,382	7,999,044	10,397,631
Dawson	2,559,049	3,132,617	156,398	4,519,971
Deaf Smith	14,796,464	14,422,397	18,012,059	10,439,947
Floyd	14,567,157	14,676,692	14,644,199	13,907,834
Gaines	19,003,569	17,514,210	18,892,235	19,243,329
Garza	903,321	962,019	883,417	1,182,652
Hale	12,567,819	12,576,336	12,580,832	12,587,983
Hockley	11,007,283	10,938,610	11,081,668	11,008,866
Lamb	14,719,038	14,697,032	8,626,882	14,860,514
Lubbock	12,822,926	12,831,016	12,849,551	12,840,374
Lynn	6,308,442	6,504,981	6,212,234	7,598,220
Parmer	10,354,591	10,363,514	1,092,011	1,148,266
Swisher	8,426,821	8,475,353	8,469,084	8,502,391
Terry	9,312,547	9,310,119	9,451,295	9,333,214
Yoakum	8,021,913	7,820,843	8,043,886	7,942,478
19 County Region	184,232,531	184,885,520	163,063,237	169,216,766

Table 4. Regional Average and Marginal Cost of Alternative Water Use Levels over 50-year Planning Horizon by Irrigation Technology and Government Program ($'s/acre-foot)

Ground Water Extraction Scenario	Government Program LEPA System	Government Program Furrow System	No Government Program LEPA System	No Government Program Furrow System
	Average Cost			
100%	0.00	0.00	0.00	0.00
90%	29.83	22.68	10.97	9.75
80%	37.15	28.31	13.51	11.74
70%	42.99	33.05	16.13	13.49
60%	48.24	37.71	18.74	15.40
50%	53.36	42.14	21.34	17.53
40%	58.74	46.74	24.03	19.79
	Marginal Cost			
100%	0.00	0.00	0.00	0.00
90%	38.36	29.19	13.58	12.18
80%	49.78	38.20	18.56	15.32
70%	59.42	47.48	24.14	18.90
60%	68.87	55.35	29.35	23.53
50%	79.28	64.54	34.79	28.64
40%	92.20	75.38	41.17	34.19

Note: Percentage values reported for the ground water extraction scenarios correspond to percentage of baseline value reported in Table 3 for a given combination of irrigation technology and government program access.

Table 5. Average Cost for Gaines, Hale and Castro Counties of Alternative Water Use Levels over 50-year Planning Horizon by Irrigation Technology and Government Program ($'s/acre-foot)

	Gaines County			
Ground Water Extraction Scenario	Government Program LEPA System	Government Program Furrow System	No Government Program LEPA System	No Government Program Furrow System
100%	0.00	0.00	0.00	0.00
90%	37.59	6.93	18.16	12.96
80%	49.94	13.87	25.74	16.16
70%	59.32	22.16	34.90	19.37
60%	67.23	31.92	43.30	23.31
50%	75.14	40.27	51.08	27.87
40%	83.66	48.56	59.15	32.48
	Hale County			
100%	0.00	0.00	0.00	0.00
90%	50.24	34.83	8.95	2.79
80%	60.88	42.48	11.04	3.54
70%	71.42	50.25	13.32	4.46
60%	80.37	57.17	15.61	5.57
50%	87.69	62.85	17.70	6.75
40%	94.43	67.95	19.67	7.97
	Castro County			
100%	0.00	0.00	0.00	0.00
90%	31.77	20.04	0.17	0.20
80%	38.71	24.62	0.38	0.37
70%	45.34	29.11	0.56	0.55
60%	50.83	33.13	0.72	0.71
50%	55.46	36.32	0.91	0.87
40%	59.75	39.44	1.12	1.07

Note: Percentage values reported for the ground water extraction scenarios correspond to percentage of baseline value reported in Table 3 for a given combination of irrigation technology and government program access.

Table 6. Marginal Cost for Gaines, Hale and Castro Counties of Alternative Water Use Levels over 50-year Planning Horizon by Irrigation Technology and Government Program ($'s/acre-foot)

Ground Water Extraction Scenario	Government Program LEPA System	Government Program Furrow System	No Government Program LEPA System	No Government Program Furrow System
	Gaines County			
100%	0.00	0.00	0.00	0.00
90%	50.98	13.86	25.45	16.65
80%	72.06	27.98	42.29	22.27
70%	83.67	53.60	62.74	29.78
60%	99.07	66.55	75.31	41.43
50%	115.28	81.61	90.05	50.45
40%	138.25	100.74	109.72	61.96
	Hale County			
100%	0.00	0.00	0.00	0.00
90%	60.51	41.85	10.78	3.46
80%	81.76	58.33	15.33	5.22
70%	101.58	72.75	20.40	7.58
60%	112.44	80.96	24.56	10.14
50%	120.95	90.16	27.73	12.53
40%	133.65	97.35	31.19	15.18
	Castro County			
100%	0.00	0.00	0.00	0.00
90%	38.86	24.43	0.42	0.36
80%	52.72	33.34	0.75	0.70
70%	64.02	41.98	1.00	0.99
60%	71.25	47.23	1.48	1.31
50%	76.90	53.08	1.94	1.79
40%	85.51	58.48	2.81	2.36

Note: Percentage values reported for the ground water extraction scenarios correspond to percentage of baseline value reported in Table 3 for a given combination of irrigation technology and government program access.

Figure 1. The Ogallala Aquifer System

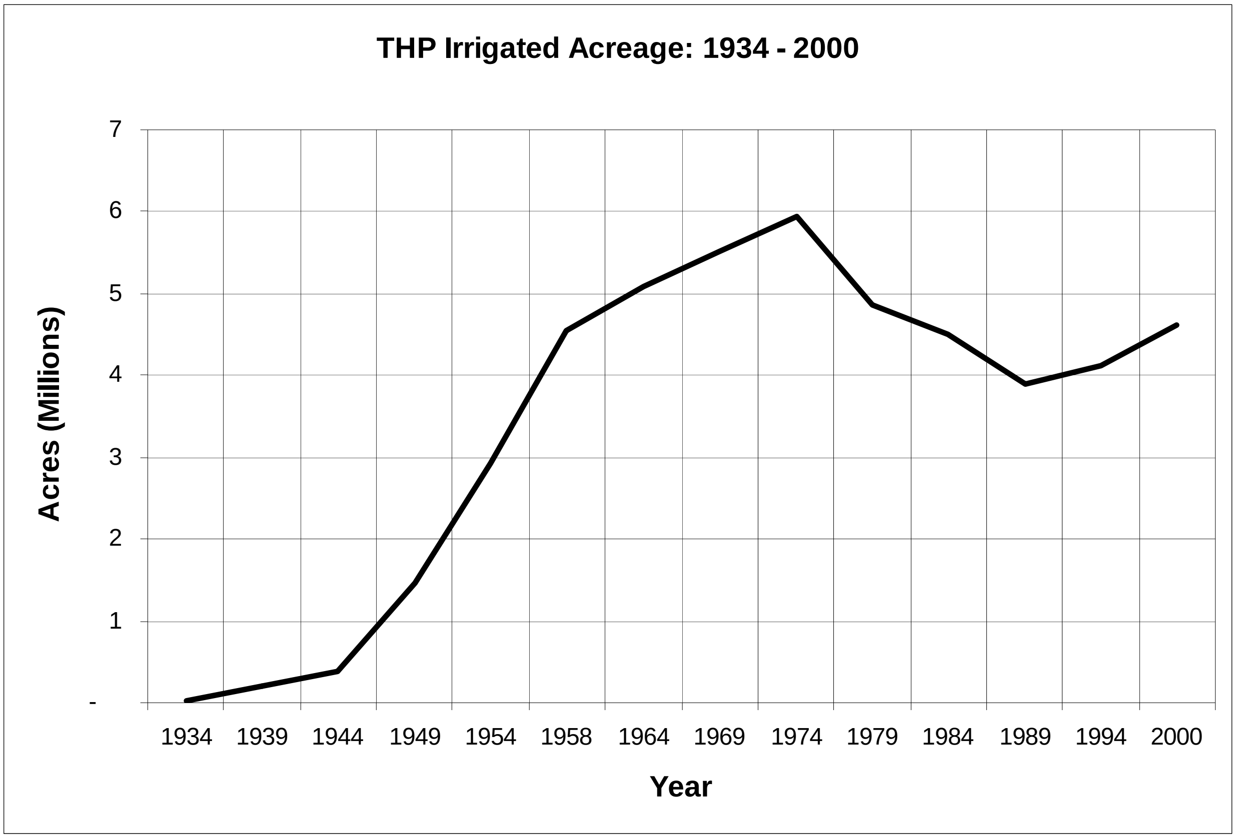

Figure 2. Irrigated Crop Acreage in the Texas High Plains: 1934-2000

Data Sources:
United States Census of Agriculture. 1935 (Table VI), 1940 (Table I), 1945 (Table 1), 1950 (Table 1), 1955 (Table 1a).
Texas Water Development Board. Surveys of Irrigation in Texas - Report 347. Austin, Texas. August 2001. 1958, 1964, 1969, 1974, 1979, 1984, 1989, 1994, and 2000 data.

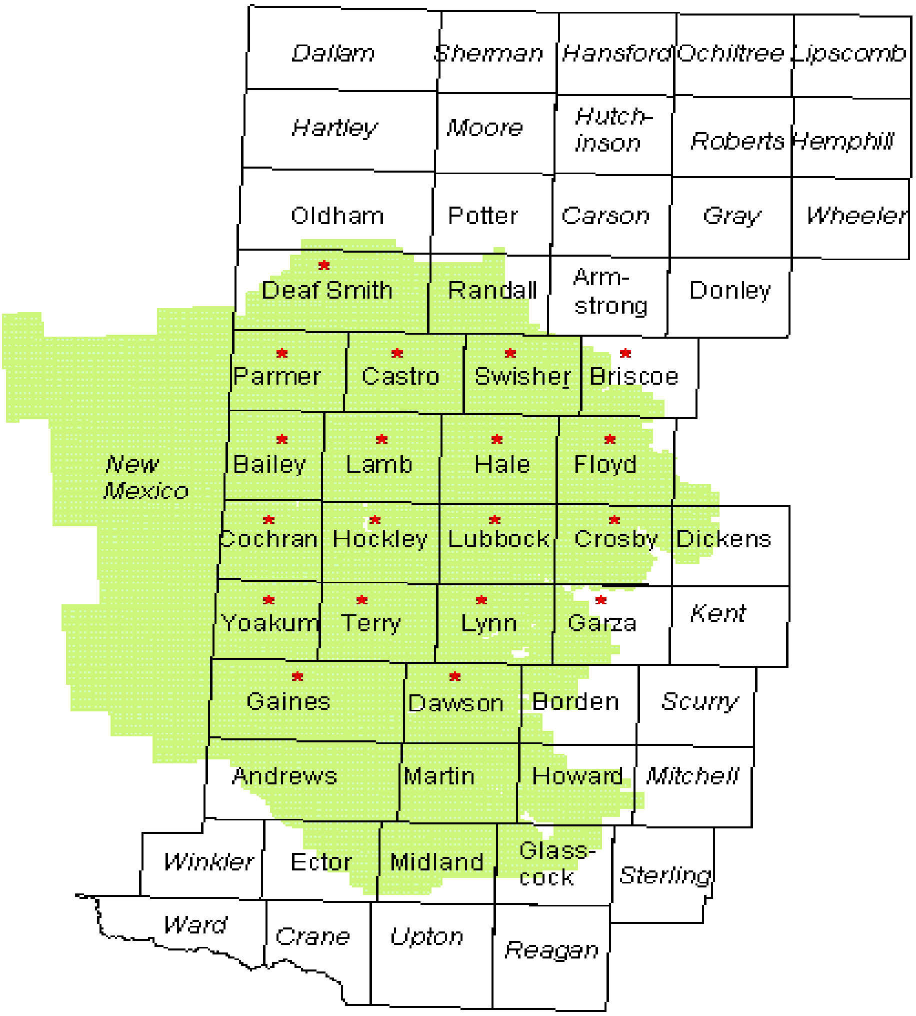

Figure 3. The Southern Ogallala Aquifer

Solid colored area identifies Southern Ogallala Aquifer

Star identifies the 19 heavy agricultural water using counties in the Texas High Plains above the aquifer