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# Groundwater Policy Research: Collaboration with Groundwater Conservation Districts in Texas

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The unique nature of the Ogallala Aquifer presents interesting and confounding problems for water policymakers who are coping with changing groundwater rules in Texas. The purpose of this article is to link previous efforts in water policy research for the Ogallala Aquifer in Texas with current collaborations that are ongoing with regional water planners. A chronological progression of economic water modeling efforts for the region is reviewed. The results of two recent collaborative studies are presented that provide estimates of impacts of alternative policies on groundwater saturated thickness, water use, net farm income, and regional economic activities.

**Key Words:** groundwater economics, Ogallala Aquifer

**JEL Classifications:** Q30, Q32, Q38

The Ogallala Aquifer is a large aquifer underlying parts of eight states in the Great Plains region of the United States. The area overlying the southern portion of the aquifer in Texas,

Oklahoma, and New Mexico is a semiarid region that provides very little recharge. The unique nature of the aquifer, the region, and Texas groundwater law present some interesting and confounding problems for water policymakers. The purpose of this article is to link previous efforts in water policy research for the Ogallala Aquifer in Texas with current collaborations that are ongoing with regional water planners.

Texas groundwater law is based on the rule of capture and has been modified recently to allow local management through regional groundwater conservation districts (GCDs) (Texas Water Development Board, 2004). Until 1997, Texas groundwater conservation districts have been primarily involved with education, well-spacing enforcement, and groundwater level measurements. In 1997, the Texas Legislature passed Senate Bill 1, which gave GCDs more authority to manage groundwater through restrictive rules (Brown, Lucio, and Wentworth,

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1997). Senate Bill 2 in 2002 reinforced the GCD's authority and provided the ability for imposing water production fees (Brown and Lewis, 2001). Texas House Bill 1763 in 2005 required GCDs to set goals, known as desired future conditions (DFC), for the district (Cook and Hope, 2005). The desired future condition of groundwater resources is a quantitative management goal established by the groundwater management area council and, in the areas overlying the Ogallala Aquifer, is generally understood to be an amount of groundwater remaining in the aquifer after a period of time, usually 50 years to coincide with state water plans.

This increasing level of water management authority for the GCDs has led to recent opportunities for collaborative work for researchers in water policy. Before this, water policy research has focused on improving policy models. With the identified DFCs has come increased interest in the results of water policy analysis by policymakers. Currently the North Plains GCD, Panhandle GCD, and Groundwater Management Area 2, comprised of seven GCDs, are working with researchers to analyze the economic impacts of specific water policies that their boards of directors are considering. The economic analysis is only one part of the policy decision, but it is a critical piece of information necessary to evaluate impacts on agricultural producers and regional economies.

This article outlines the progression of economic water modeling efforts through time. First is a literature review of previous water policy studies. This is followed by a discussion of how previous studies have led to the method under which current water policy research is being conducted. Then, the results of recent water modeling studies are given. The first study was conducted on a rather large regional scale, whereas the second study was conducted on a small scale, both with close coordination with groundwater districts in Texas. The fast-paced change of current water policy research is examined using these recent studies.

## **Previous Water Policy Studies**

Studies focusing on the efficient management of groundwater can be found for the Ogallala

Aquifer and other aquifers across the country and around the world. These studies show different results as to the effectiveness of groundwater management policies.

Much of the water policy work from the Texas High Plains and the High Plains Aquifer stems from Burt's seminal work on the economics of water use. Burt authored several studies in the 1960s and 1970s concerning the control and allocation of groundwater resources. Three of the studies are reviewed here. The first evaluates economic controls of groundwater reserves. Burt (1966) suggests two economic factors tend to keep withdrawals from exceeding average recharge: 1) increasing pumping costs as the water table lowers; and 2) the value of the water stock as a contingency against uncertain recharge. The rate of use beyond recharge, as is the case with the Ogallala Aquifer, is caused by the present value of water used for production being of greater economic value than in the future. Burt developed a decision model for temporal allocation of groundwater resources in which net present value of water is maximized as a function of expected net output from the region plus  $1/(1 + r)$  times the change in the stock from last period, in which  $r$  is the periodic discount rate.

In a second article, Burt (1967) further develops his earlier model and provides empirical examples for the use of the model in cases in which the initial assumptions of constant recharge and predicted levels are relaxed. In the third article, Burt (1970) relaxes the assumption of constant marginal productivity of water used in the previous article. His purpose was to elaborate on the problems associated with institutional constraints.

Renshaw (1963) evaluated the question of managed groundwater reserves in the Southern High Plains. The study considered two cases with different results. The first case of optimal mining, in which aquifer recharge is negligible relative to withdrawals, used data from the High Plains Underground Water Conservation District for the case study. Renshaw recommended that nonprice rationing be used, which can include agreements among irrigators to limit withdrawal. Renshaw found that with 1960s technology and current withdrawal rates, the economic life of the aquifer was 30 years. By reducing

withdrawal by 15%, irrigators would realize a return on foregone income of 7.5% and by reducing withdrawals by 50%, the return would be 4%.

Bekure and Eidman (1971) studied the intertemporal allocation in the Central Ogallala Formation and concluded that misallocation of groundwater was not necessarily a direct result of its common property stock resources attribute. Other factors such as discount rate, market and government program conditions, and limited availability of capital and labor impact an individual irrigator's decision-making so that groundwater pumpage may not result in automatic intertemporal misallocation. The implication of this study is that imposing conservation measures on a system in which resources are not misallocated will result in a loss of present income greater than the economic benefit of the conserved water resource.

Lacewell and Grubb (1971) investigated the implications of alternative levels of irrigation water use from the Ogallala Aquifer in the Texas High Plains. Their study focused on an individual's decision concerning how much land to irrigate each year and how to develop capital-valuation estimates of the aquifer. Lacewell and Grubb stated that the objective of the farmer should be to develop water use plans that maximize the monetary value of the water supply. Their study analyzed the impacts of selected financial factors on aquifer use through time. They specifically considered the impacts that specific discount rates and crop prices had on optimal aquifer management. Linear programming was used to estimate the optimal allocation of dryland and irrigated crops subject to a water availability constraint. The model developed by Lacewell and Grubb showed that the discount rate used had a significant effect in determining the optimal rate of water use. As the discount rate falls, so does water use in the current period. In conclusion, they noted that a producer's goal is to maximize profit in the short run. When considering the long run, the producer will often underestimate the value of the resource and continue to deplete the water supply to maximize short-run profit.

Hardin and Lacewell (1980), in a study of irrigation pumping from the Ogallala Aquifer,

found that both producers and society benefit from limiting annual withdrawal of groundwater from an exhaustible aquifer. The objectives of the study were to examine the effects of the economic life of the water supply of the Ogallala Aquifer and compute breakeven discount rates for unlimited water use and for various levels of limited annual rates of water withdrawal for the aquifer. The authors used a recursive linear programming model to develop annual net returns from various rates of groundwater use. The model included corn, grain sorghum, soybeans, cotton, and wheat in dryland and irrigated systems. Crop budgets from the Texas Agricultural Extension Service were used to develop technical coefficients for the model. Yield data were developed for dryland and furrow irrigated products from estimated production functions. Water use data for sprinkler-irrigated production were calculated as 33% of furrow irrigation water use. The study considered unrestricted water use and limitations of pumping, which would result in water level declines of two feet, three feet, and four feet.

The results showed that, with sprinkler irrigation, the number of years that the initial number of acres can continue to be irrigated is 86 years for the limitation of a 2-foot decline, 38 years for the limitation of a 3-foot decline, 44 years for the limitation of a 4-foot decline, and 38 years for unlimited water use. The 4-foot decline scenario included the elimination of one postplanting irrigation that the other scenarios did not include. The breakeven discount rate was 5.0% for the 4-foot limitation, 4.5% for the 3-foot limitation, and 0.5% for the 2-foot limitation. The results show that, with furrow irrigation, the number of years that the initial number of acres can continue to be irrigated is 28 years for the limitation of a 2-foot decline, 15 years for the limitation of a 3-foot decline, 32 years for the limitation of a 4-foot decline, and 10 years for unlimited water use. The 4-foot decline scenario for furrow irrigation also included the elimination of one postplanting irrigation. The breakeven discount rate was 6.5% for the 4-foot limitation, 11.5% for the 3-foot limitation, and 1.0% for the 2-foot limitation.

The results of the Hardin and Lacewell study show the effects on the individual farm of

the different levels of restricted water withdrawals. The authors cited other issues that must be addressed such as developing the institutions, both regulatory and economic, to provide incentives for individual irrigators to modify annual withdrawal rates with the objective of maximizing the value of the resource.

Warren et al. (1982) studied the economic impacts of the declining Ogallala Aquifer in western Oklahoma. The study area was in the Central Formation of the Ogallala Aquifer similar to the Texas Northern High Plains. The study found that irrigation acreage would increase in the near- and midterm and that the future of irrigated agriculture in the study region was positive.

Lansford et al. (1983) evaluated the on-farm economic impacts of the declining Ogallala Aquifer in New Mexico. The findings indicated that the Southern High Plains of New Mexico, bounded in the north by the Canadian River, will transition from irrigated to dryland cropping patterns between the years 2000 and 2020 for a majority of the cropland acres. They found no significant difference in water use between voluntary and mandatory irrigation water conservation measures.

Estimated income effects were also considered along with employment effects from the declining irrigated crop production. Osborn (1973) concluded that because producers' focus is on profit maximization, the water supply would be economically exhausted and as a consequence, the economy is likely to suffer significantly in all areas analyzed. It was evident from his estimations that economic development in the region would inevitably decline as a result of water exhaustion and the interrelation of industries in the economy. Osborn recommended natural resource management policies be implemented to stabilize the economy. However, he warned that any management practices would likely not strike a balance between withdrawals and recharge and that the Ogallala will inevitably be exhausted.

Feng (1992) developed a model to derive the dynamically efficient rate of depletion of groundwater in the Texas High Plains that maximized the net present value of returns to water, land, capital, management, risk, and

overhead using the study area of Lubbock County, TX. The study evaluated the effects of changing parameters such as pump lift, saturated thickness, discount rate, crop price, energy price, technology change, and crop acreage. Feng formulated a dynamic optimization model over a 50-year planning horizon to estimate the dynamically efficient path of groundwater withdrawal, marginal user cost of groundwater stock, cropping pattern, and irrigation and tillage technology adoption. A recursive profit maximization model was used to represent the competitive use of a common property resource and a dynamic quadratic programming model to represent efficient sets of irrigation and crop combination decisions under different levels of risk aversion.

Consistent with economic theory, Feng found that scarcer water supply scenarios resulted in less water and acreage to be allocated to irrigated crops; higher crop price and lower energy cost increased water use and irrigated acreage; higher discount rates increased the rate of decline of irrigated acres; and irrigation technology with greater efficiency increased the proportion of total irrigated acres and the proportion of irrigated acres of corn. Feng found that the current proportion of irrigated system use was far from optimal and that higher crop prices, lower energy costs, and flexible government programs would favor higher rates of adoption of efficient irrigation technology. With respect to groundwater withdrawal, the study found that the adoption of more efficient irrigation technology and higher crop prices would result in more groundwater being pumped throughout the planning horizon and that discount rates have very little effect on withdrawals. The study also found that the proportion of irrigated acres decreased as producer risk aversion increased, suggesting that irrigation does not reduce yield variation but increases the impact of price variation.

Feng also found that the efficient crop combination was related to the initial groundwater supply condition and that saturated thickness had a greater impact than pump lift on crop combination and irrigated acreage. This study illustrated that the competitive use of groundwater as a common property resource results in

greater than efficient amounts of groundwater use in the early part of the planning horizon and less than efficient amounts used in the later part of the planning horizon. Public policies could be designed to modify marginal user cost to the irrigator's cost to move the depletion rate to the optimal path; however, the benefit from government regulation and management of groundwater in agricultural production is likely to be small. The small benefit is the result of the increases in profitability of irrigated crops leading to more acreage dedicated to irrigation, thus spreading the irrigation water over more acres instead of decreasing the amount of water pumped for irrigation.

The National Research Council (1996) published a book entitled "A New Era for Irrigation," which addresses the impact of irrigated agriculture's effect on the settlement of the western United States, the current role of irrigated agriculture in the country, and how it is expected to change in the future. The authors identified the underlying premise of the study as being increased competition for water supplies from sources other than agriculture and how irrigated agriculture will change to cope. The authors note that irrigation is not just a practice that takes place in certain areas of the country; rather, it is a culture and a way of life that has helped settle, transform, and support large regions of the United States.

There are many forces leading to change for irrigation, including increased urbanization of the country, increasing energy costs, competitors such as urban areas and the environment, and globalization. The authors conclude that availability and costs of water will remain the key determinants of the extent and viability of irrigation in the United States. The National Research Council concluded that, although irrigation has been an asset to the country for the past several decades, "to continue in a new era... irrigation must evolve" (National Research Council, 1996, p. 7).

Arabiyat (1998) studied the role of adoption of biotechnological and irrigation advances on the agricultural sustainability on the Texas High Plains. The study used a dynamic optimization model to analyze the water use and net present value of returns for three counties of

the region under three scenarios of improved irrigation technology, improved biotechnology, and improvements in both areas while holding net returns constant.

The results of her study showed that in all three counties, farm profitability would improve with the adoption of advanced irrigation technologies and improved biotechnological advances. The study showed that to achieve groundwater stability, producers in two of the counties would experience a 3–4% loss of returns and in the third county, producers would experience a gain of 4% in returns. The conclusions of the study explained that net returns could be improved and/or groundwater stability could be achieved by the adoption of advancements in irrigation technology and biotechnology.

Terrell, Johnson, and Segarra (2002) used optimization models and expanded Feng's (1992) model to focus on the economic impacts to the High Plains of Texas as the Ogallala Aquifer is exhausted and irrigated agriculture declines. She used dynamic linear programming and the input–output model IMPLAN to forecast groundwater depletion, cropping patterns, and subsequent economic impacts over a 30-year planning horizon in 19 counties of the Texas High Plains. The research focused on the fact that the current cropping patterns are not optimal. Terrell noted that in the original runs of the model, the optimal cropping pattern switched to cotton almost immediately in all 19 counties. Knowing that this outcome was not likely to be feasible, she added a constraint limiting the amount of acres that could be converted to cotton annually.

The study concluded that as the water supply decreases, producers would transition from irrigated crops to dryland cotton, and the net revenue of the surrounding economy would suffer. As a result of the interrelation among industries in the region, Terrell found that almost all sectors of the economy would be adversely affected by the decreased agricultural production. One limitation of Terrell's research is that she assumed producers would produce what is optimal in the long run. However, producers are likely not to produce optimally because their goal generally is to maximize short-run profit, not long-run profitability.

Johnson et al. (2009) expanded on the works of Feng (1992) and Terrell, Johnson, and Segarra (2002) by considering nonlinear crop production functions. He used a dynamic optimization model and an input–output model to look at the effect of different policy alternatives on the Texas High Plains economy and the saturated thickness of the Ogallala Aquifer. The study included a baseline scenario and three policy alternatives in response to the depletion of the aquifer using a 50-year planning horizon. The policy alternatives were: 1) a production fee on water extracted; 2) a water pumping quota restriction; and 3) a water drawdown restriction.

As expected, the baseline scenario, or status quo policy, resulted in the most rapid exhaustion of the water supply and caused the most dramatic decrease in net income for the economy over time. The first policy alternative, a production fee, showed little change from the baseline as a result of the fact that Senate Bill 2 placed a \$1 per acre-foot cap on possible production fees. A \$1 per acre-foot fee was insufficient to induce producers to significantly decrease their water use. This alternative also showed a similar drop in net revenue at the point of exhaustion. A water pumping quota restriction that placed a 50% reduction relative to current annual water use revealed that the aquifer's depletion could be pushed back by approximately 10 years. A drawdown restriction requiring aquifer saturated thickness levels to be greater than or equal to 50% of the present saturated thickness resulted in a slightly lower net income than the quota restriction. However, it was found that the water supply would be preserved throughout the planning horizon. Johnson concluded that possibly the most effective alternative to conserve the water supply may be the aquifer drawdown restriction because it likely strikes the best balance among producer profit, water conservation, and effects to the regional economy.

Das, Willis, and Johnson (2010) expanded the work of Johnson et al. (2009) in a study focusing on the Ogallala Aquifer using a dynamic economic water planning model to compare simulated economic and hydrologic implications with output from a water policy

model that links a dynamic model to a temporally disaggregated hydrology model. The goal of his study was to provide water policy analysts with a tool for targeting specific areas and water users of the aquifer to better implement conservation policies.

Wheeler et al. (2008) furthered the work by Das, Willis, and Johnson (2010) and evaluated the economic and hydrologic implications of four water conservation policy alternatives in the southern portion of the Ogallala Aquifer in 22 Texas counties and two eastern New Mexico counties. Specifically, a baseline scenario calculated total water use, net revenue per acre, and saturated thickness of the aquifer for a 60-year period assuming no change in water use practices. Wheeler et al. then evaluated the effects of policies that limited drawdown of the aquifer over the planning horizon relative to drawdown in the baseline scenario for each of the 24 counties in the study area.

The policies evaluated were a 0% drawdown policy, a 50% drawdown policy, a 75% drawdown policy, and a 50% annual drawdown policy. The results from Wheeler et al.'s study indicated that because of the significant differences in hydrologic characteristics and current irrigation levels across the study area, blanket water conservation policies for the region as a whole are likely to be inefficient. They found that the cost of conserving an additional acre-foot of water in low water use counties is extremely high. Legislative time and tax money would be more efficiently spent enacting policies to conserve water in those counties that significantly use the aquifer underlying the county.

Wheeler et al. concluded that water conservation policies should focus on counties that deplete the aquifer to less than 30 feet of saturated thickness in the unconstrained baseline scenario, where the implicit cost of conserving a foot of saturated thickness is relatively low. These are the most heavily irrigated counties in the study region, and society as a whole would most likely benefit from the focus of water conservation being in these high-water-use counties.

Golden (2005) conducted a study in which he attempted to determine the value of water rights in the Rattlesnake Creek subbasin region

in western Kansas using a spatial-hedonic analysis to establish a base value for the state to purchase water rights. If the value of the water rights can be established, the state would be able to more accurately purchase the water right from willing landowners at an effective and efficient value. Similarly, the federal government determined the value of agricultural production on environmentally sensitive lands and offered to rent the land based on a fair market bid value for 10-year increments in the Conservation Reserve Program (CRP) program. According to Golden, at a minimum, landowners must feel they are receiving the fair market value of their asset to consider retiring their water right, either permanently or temporarily.

Similar to Feng (1992), Golden et al. (2006) discussed the problems with state policies in Kansas and federal policies that encourage the adoption of more efficient irrigation technologies but that do not necessarily achieve the goal of water use reduction and, in turn, aquifer conservation. The authors point out that more efficient technological adoption is important and should continue because it helps maintain the profitability of irrigated agriculture; however, it must be done in conjunction with a water conservation policy that will reduce water consumed from the Ogallala Aquifer for agricultural purposes.

Leatherman et al. (2006) discuss a policy alternative being considered in Kansas and used in other states including Nebraska and Idaho known as the Conservation Reserve Enhancement Program (CREP). The CREP is similar in structure to the CRP program in that it requires both federal and state partnerships and is a voluntary program. CREP allows willing landowners to temporarily retire water rights for periods of approximately 15 years. At the end of the buyout period, landowners can resume irrigation; however, as CREP is proposed in these states, no dryland production can take place during the buyout period and the land is subject to conventional CRP requirements.

The study conducted by Weinheimer (2008) evaluated the response of an 1,800-acre representative farm (95% irrigated and 5% dryland) in the Texas High Plains to the implementation of a water policy, which restricts the amount of

irrigation water available such that 50% of the current saturated thickness must remain in 50 years (50/50 water policy). Nonlinear dynamic optimization methods integrated with a stochastic simulation model were used to estimate crop and enterprise selection, change in cash positions, and probability of financial viability for the representative farm over a 10-year time horizon. The models were run under a baseline scenario with no water policy intervention and a scenario with the 50/50 water policy irrigation restriction for four levels of initial saturated thickness (120 feet, 100 feet, 80 feet, and 60 feet).

Results for the optimization models indicated that sprinkler irrigated cotton and dryland sorghum were the predominant crops that maximized net returns per acre under both the baseline and 50/50 water policy models. The effect of the 50/50 water policy on water conservation and net income was most pronounced on the higher initial saturated thickness scenarios. Shifts toward dryland production were already occurring without water policy intervention at the lower saturated thickness scenarios. The probability of negative net cash income and cumulative ending cash reserves increased for all saturated thickness scenarios under the 50/50 water policy with the greatest impacts being on the moderate to high saturated thickness levels.

Amosson, Guerrero, and Johnson (2009) reported the results of a study to assess the potential impacts on stakeholders in the study region overlying the Ogallala Aquifer of western Kansas and the Panhandle and South Plains of Texas from implementing alternative water conservation strategies. The results of the study were intended to be used in the consideration of water conservation policies in the future to ensure that any strategies implemented minimize detrimental effects on producer income and the economy while conserving water for future purposes. A survey of stakeholders identified five strategies to be analyzed: permanent conversion to dryland production, technology adoption, biotechnology, water use restriction, and temporary conversion to dryland production.

Economic optimization models were developed to estimate changes in the aquifer,

irrigated acreage, and net farm income over a 60-year planning period. Socioeconomic models were used to evaluate impacts on the regional economy. Each conservation strategy was then evaluated with respect to the change in saturated thickness, producer income, and impacts on the regional economy relative to the baseline.

The baseline scenario assumed no change in current water-conserving policies was implemented and producers operated in an unregulated profit-maximizing manner. In select counties, the baseline simulation indicated decreases in saturated thickness over the 60-year period to 84.4 feet in the Northern Region, 43.7 feet in the Central Region, and 34.2 feet in the Southern Region.

The enhanced adoption of biotechnology that increased yields 0.5% annually coupled with 1% annual water use restriction was the most effective policy analyzed. Saturated thickness increased an average of 12.3% over the region, whereas producer income increased 86.9% and the regional economy improved an average of 5%. A 1% annual water restriction produced similar results with respect to increasing saturated thickness (12.8%); however, producer income as well as industry output fell an average of 4.8% and 1.3%, respectively.

Permanently converting 10% of irrigated acreage to dryland (Plan A—idled 15 years before returning to dryland production) resulted in increasing saturated thickness an average of 3% relative to the baseline. Producer income overall improved slightly (1.1%); however, total industry output fell approximately 1.7%. A second permanent conversion to dryland scenario converting 10% of irrigated acreage to dryland (Plan B—acreage allowed to immediately convert to dryland production) resulted in the same impacts with respect to saturated thickness, however, improved in total industry output relative to Plan A (a decrease 1%). A temporary conversion of 10% of the irrigated acreage to dryland and the enhanced adoption of improved irrigation technology provided little impact. Temporary conversion increased ending saturated thickness an average of 1%, whereas adoption of improved irrigation technology actually decreased ending saturated thickness in two of the subregions. Impacts on producer income and the

regional economy were negligible for both policies.

Several implications can be derived from the results of this study. First, some form of long-term water-use restriction (percentage per year or permanent conversion) is necessary to achieve any meaningful water savings. Second, accelerated adoption of improved biotechnology or irrigation technology without restrictions will not save water and, in fact, could increase water use, lowering water availability in the future. However, using these strategies in combination with a water-use restriction policy can help negate the negative impacts to producer income and the regional economy. Finally, temporary conversion to dryland has little impact on long-term water savings and should not be pursued.

Several shortcomings in the study were identified. Implementation levels were set at a level and given time and funding; no sensitivity analysis was performed on these variables. No attempt was made, except for identifying the loss in producer income, to assess the cost of implementing the conservation strategies analyzed. Although individual policy alternatives have been compared with a baseline scenario, this research did not attempt to place a monetary value on the saved water or place monetary value on other benefits of water conservation. For reporting convenience, the modeling results for several counties were aggregated. This process may mask important differences between counties and underestimate the need for water conservation.

## **Results from Collaborative Studies with Groundwater Conservation Districts**

Following the Amosson et al. (2009) study, several opportunities arose to collaborate with regional groundwater conservation districts in analyzing potential water conservation policies and rules that would allow the districts to meet the desired future conditions required by Texas House Bill 1763. Two studies are reported here for the Panhandle Groundwater Conservation District and the North Plains Groundwater Conservation District of Texas. These studies represent a much higher degree of collaborative effort between economic researchers and groundwater

managers than has been previously reported for the Ogallala Aquifer in Texas.

The Panhandle Groundwater Conservation District (PGCD) has implemented management goals that allow them to meet a desired future condition of 50% of the current water supplies or saturated thickness available in 50 years, more commonly referred to as the 50/50 management standard. The objective of this study was to conduct an economic analysis of how the 50/50 management standard would impact agricultural producers and the overall economy within the region (Weinheimer *et al.*, 2010). The manager and board of directors of PGCD requested that the policy be analyzed at the county level for two counties within the district, at the study region level for two areas within the counties, and at the farm level for four representative farms within the counties.

The 50-year projections analyzed the change in farm profitability, irrigated acres, and hydrologic conditions for each county. Any changes that occurred within these two counties were then included in a regional analysis to determine how the 50/50 management standard in Carson and Donley Counties impacted the regional economy of the PGCD (eight-county area). Results indicate that the 50/50 management standard did not have a significant impact in either Carson or Donley County, thus having no impacts on the regional economy.

The two specific study areas were 20,480-acre blocks that represented areas within the county of similar hydrologic conditions and farming practices. The results for the study areas indicated no significant impact to either the area or the regional economy as a result of the 50/50 management standard.

An additional analysis using representative farms captured detailed changes that could occur to a typical farming operation within the region, specifically in the farm's ability to generate net cash income. Results show that the farms were not significantly impacted by the 50/50 management standard. However, in the case of the farms that represented scenarios with extreme drawdown in saturated thickness, there was a slight impact from the 50/50 standard as the present value of net returns declined by \$350 over the 50-year planning horizon.

The results of this study indicated that economic impacts to agriculture at the county, hydrologic area, or representative farm level were insignificant in this groundwater conservation district. However, areas of extremely high decline in saturated thickness could be impacted by such standards and should be monitored closely.

The North Plains Groundwater Conservation District (NPGCD) is facing similar critical decisions regarding potential water conservation policies but with different irrigation demands and aquifer characteristics than the PGCD. The objective of this study was to evaluate the short-term and long-term economic implications of alternative water conservation strategies being considered by the NPGCD (Amosson *et al.*, 2010). Specifically, water conservation strategies identified by the district were evaluated using economic models and compared with a status quo baseline scenario. The alternative strategies identified by the district to be included in the analysis were the designated desired future conditions and productivity advancement.

The desired future conditions strategy incorporates the implementation of conservation measures for the NPGCD including two separate DFCs. Two DFCs are analyzed as a result of substantial differences in water uses and aquifer conditions between the four western counties and the four eastern counties in the district. Specifically, the four western counties must achieve at least 40% of the current aquifer storage remaining in 60 years, whereas the eastern counties must have at least 50% of the baseline aquifer storage remaining in 60 years.

The productivity advancement strategy is one in which the district, through policies, goals, and working with agricultural producers and research partners, induces the development of a conservation method with increased productivity. This would allow agricultural producers to yield 200 bushels of corn per irrigated acre from 12 acre-inches of groundwater applied. The resultant changes in cost of other inputs are unknown at this time; therefore, no change in cost structure was assumed except with irrigation costs.

The baseline, which assumes no changes in current water policies, was run for both the

western and eastern four counties of the water district over a 60-year time horizon. The economic optimization models predicted a decrease in saturated thickness from 160–55 feet in the western counties of the district and a decrease from 201–166 feet in the eastern counties, respectively. The percentage of irrigated acres relative to total cropland in the baseline dropped from 73.7% to 31.2% and 34.7% to 34.4% in the western and eastern counties, respectively. The projected net income per acre decreased from \$271.62 to \$83.90 in the western counties and actually increased (\$134.22–\$146.01) in the east. The total economic output over the 60 years for the western counties was estimated at \$33.2 billion, which is more than double the eastern counties (\$16.4 billion).

By year 50, Dallam and Hartley Counties had less than 40% of saturated thickness remaining with 31.8% and 37.0%, respectively. By year 60, all four western counties, Dallam, Hartley, Sherman, and Moore, had less than 40% of saturated thickness remaining: 27.4%, 32.3%, 39.5%, and 38.1%, respectively. The eastern four counties did not have the severity of decrease in saturated thickness. The lowest remaining saturated thicknesses among these counties were 71.1% in 50 years and 65.2% in 60 years for Hansford County.

The DFCs were actually modeled to constrain water use to have a minimum of 40% saturated thickness remaining in the western four counties and 50% in the eastern counties. This scenario had a major impact on the western counties but no impact on the eastern counties because their baseline water policies and use were unaffected by the restriction. In year 60, the western counties were projected to have ten more feet of saturated thickness relative to the baseline and the percentage of land irrigated was expected to drop 3.2%. Producer income, which was originally estimated to be \$271.62 per acre in year 1, was expected to fall from \$83.90 per acre (baseline) to \$62.95 per acre (DFC) in year 60. Overall, the economy of the four counties is expected to lose a total \$1.8 billion in economic activity over the 60 years from implementing the DFC policy.

The second scenario (Productivity Advancement) assumed that 200 bushel corn

could be produced on 12 acre-inches pumped. No additional cost changes were assumed. In addition, it was assumed that no more than 2% of acreage could change from one crop to another in any given year. This scenario relative to the baseline resulted in saturated thickness improving 16.39% by year 60 in the western counties and 3.5% in the eastern counties. However, it should be noted that the restriction on acreage shifts between crops may have biased the results. Even with the acreage shift restriction, Dallam and Hartley fell below 40% remaining saturated thickness by year 60. Correspondingly, the percentage of irrigated acres remaining improved 73.19% and producer income increased 59.07% over the baseline in year 60 for the western counties. Total economic activity increased 2% or approximately \$775 million over the baseline for the 60 years. However, examining the flow of economic output over time suggests this policy alternative tends to even out the impact of falling saturated thickness.

## **Summary**

The purpose of this article was to illustrate the linkages and transformations from early groundwater economic studies of the Ogallala Aquifer to the current state of active collaboration between researchers and practitioners at the water district level. Although significant studies in groundwater economics have been conducted in the region for the Ogallala Aquifer for over 40 years, technological advances in irrigation, genetics, and cultural practices in combination with continued withdrawals leading to depletion provide opportunities to refine and enhance the capabilities and accuracy of the models. The most significant change over this time has been the collaborative studies addressing the recent imposition of management goals by the groundwater conservation districts and their desire to understand the impacts of increasingly restrictive rules on agricultural producers and the regional economy. It is expected that more opportunities will arise to work closely with the regional water district managers and agricultural organizations as they continue to refine the management rules and policies to meet the

desired future conditions for the Ogallala Aquifer in Texas.

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