The Impact of Discount Rate and Price on Intertemporal Groundwater Models in Grant County, Kansas

Mallory K. Vestal, Ph.D., Bridget L. Guerrero, Ph.D., Bill B. Golden, Ph.D.,
and Logan D. Harkey, M.S.

Mallory K. Vestal is an Assistant Professor of Agricultural Business and Economics in the Department of Agricultural Sciences at West Texas A&M University.

Bridget L. Guerrero is an Assistant Professor of Agricultural Business and Economics in the Department of Agricultural Sciences at West Texas A&M University.

Bill B. Golden is a Research Assistant Professor in the Department of Agricultural Economics at Kansas State University.

Logan D. Harkey completed his Master of Science degree in the Department of Agricultural Sciences at West Texas A&M University.

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Contact Information:
Mallory K. Vestal
WTAMU Box 60998
Email: mvestal@wtamu.edu
Office: 806-651-2718

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Abstract

Agriculture plays a vital role in the growth and development of the High Plains Region of the United States. With the development and adoption of irrigation technology, this region was transformed into one of the most agriculturally productive regions in the world (Peterson et al., 2003). The primary source of irrigation in this region is the Ogallala Aquifer.

Currently, water from the aquifer is being used at a much faster rate than natural recharge can occur, resulting in a high rate of depletion from this finite resource. Depletion of scarce water resources will have a significant economic impact on the long-term sustainability of the region. The objective of this study is to evaluate the impact alternative prices and discount rates have on groundwater policy recommendations. Deterministic models of groundwater withdrawals were developed and used in order to analyze and evaluate the impact of high, average, and low crop prices in a status quo scenario as well as a policy scenario reducing irrigated acreage allocation. Furthermore, this study analyzes the effects and associated consequences of alternative discount rates on net and total revenue. As indicated by results of this study, alternative prices, costs, and discount rates utilized in a model have an effect on policy effectiveness.

Considering the declining levels of saturated thickness seen in the results of this study, the analysis of alternative discount rates and the associated policy recommendations is merited.

Keywords: *irrigation, acreage reduction, policy, Ogallala Aquifer*

Introduction

Agriculture has been a key factor in the overall evolution and expansion of the High Plains Region. The invention of affordable irrigation technology, has aided in the transformation of the High Plains into a more fertile farming region in which a large number of crops are grown annually (Peterson et al., 2003). The primary source of irrigation in the region is the Ogallala Aquifer (Figure 1). The Ogallala Aquifer is a body of water which lies underneath parts of Texas, New Mexico, Oklahoma, Colorado, Kansas, Nebraska, Wyoming, and South Dakota, spanning roughly 174,000 square miles (Torell et al., 1990).

The region produces corn, grain sorghum, soybeans, wheat, and alfalfa with irrigation drawn from the aquifer. More than ninety percent of the groundwater pumped from the Ogallala irrigates approximately one-fifth of all cropland in the United States (Guru et al., 2000). Subsequently, these crops are used as the primary feed source for livestock. In turn, this livestock becomes the principal input for a large number of concentrated animal feeding operations and meat processing facilities operated within the region. As of January 2016, approximately eighty percent of the nation's cattle on feed were located within the High Plains Region in states overlying the Ogallala Aquifer, such as Texas, New Mexico, Oklahoma, Kansas, Colorado, and Nebraska (United States Department of Agriculture (USDA) Cattle on Feed Report, January 22, 2016). The crop, livestock, and meat processing industries are at the heart of the regional economy and account for a large portion of the employment and gross output in the area (Peterson et al., 2003).

Before crop irrigation, the Ogallala Aquifer was left largely undisturbed. In this time, natural discharge from the aquifer was approximately equal to amounts of natural recharge. Natural recharge is a slow process which occurs from water percolating down through the soil

and eventually ending up in the aquifer. With the widespread use of crop irrigation, this is no longer the case. The Ogallala Aquifer is estimated to contain about 3.5 billion acre-feet of groundwater; however, the increase in irrigated agriculture and irrigated acres as well as the low amounts of natural recharge are impacting the aquifer. Under current production practices, water table levels in the Ogallala decline at a rate from approximately six inches to several feet annually. This holds particularly true in the southernmost portions of the Ogallala, where natural recharge is small in comparison to other areas (Torell et al., 1990).

Approximately ninety percent of the natural recharge to the aquifer is percolated through the soil from small playa lakes found on the landscape from Texas to Nebraska (Alley et al., 1999). The amount of natural recharge varies throughout the region, but amounts generally range from half an inch to several inches each year per surface acre (Wheeler, 2008). In the 1950s, approximately 480 million cubic feet of groundwater per day were extracted from the Ogallala Aquifer for irrigation purposes. By 1980, that amount increased exponentially to slightly over 2,150 million cubic feet per day (Alley et. al., 1999). Although pumping water from the aquifer takes seconds, actual recharge through percolation can take years to reach the aquifer. Furthermore, once evaporation and absorption rates are accounted for, only a small portion of rainfall and standing water actually reach the aquifer. When considering the rapid and overwhelming use of groundwater, the slow process of percolation, and the minimal amount of natural recharge occurring each year, it is safe to say the Ogallala Aquifer is an extremely finite resource (Peterson et al., 2003).

Specific Problem Description

Undoubtedly, the depletion of the Ogallala Aquifer has significant implications for the High Plains Region as a whole. With this issue in mind, the enactment of water conservation policies may effectively extend the life of the Ogallala Aquifer and the associated agricultural enterprises. In an effort to combat the bleak ultimatum of a depleted aquifer, the United States Department of Agriculture – Agricultural Research Service (USDA – ARS) has funded the Ogallala Aquifer Program (OAP) to conduct innovative scientific research in order to discover ways to improve the sustainability of agricultural industries and rural communities dependent upon this resource. The OAP is tasked with developing various water-saving scenarios which could have an impact upon the region. In this program, models have been created to evaluate these scenarios in order to determine the feasibility of implementation in order to conserve water and still provide sufficient cost savings and revenue procurement to producers currently utilizing water from the Ogallala.

Study Area

The focus of this study is on Grant County in Southwest Kansas. This area is rich in agriculture but has high groundwater depletion rates in comparison to low amounts of recharge. The southwest area of Kansas accounts for the production of over 370,000 acres of corn, more than 195,000 acres of sorghum, and over 23,000 acres of soybeans (The Water Information Management and Analysis System (WIMAS), Figure 2). Approximately 2.2 million acres sit on top of the Ogallala Aquifer in this area (Table 2). The groundwater stock in the aquifer is steadily declining largely due to the fact that the amount of water withdrawn for irrigation purposes far surpasses the minimal amount of natural recharge (Birkenfeld, 2003).

Objectives

This research analyzes how alternative discount rates applied to revenue and varied levels of crop prices can affect policies regarding the pumping of groundwater from the Ogallala Aquifer. Applying alternative discount rates to net and total revenue allows for a detailed examination of profits considering the difference in the value of receiving money now versus in the future. Various discount rates and price levels are applied to a status quo scenario as well as an acreage reduction scenario within the model. This is done to show how profit levels vary as prices fluctuate and the need to pump water increases and decreases throughout time. When the model is run under the acreage reduction scenario, an additional constraint is implemented into the code to allow for the reduction in irrigated acreage

While this study compares a status quo scenario to a groundwater conservation scenario, the purpose is not to justify one over the other. Instead, the focus of this study is on how alternative prices and discount rates impact the choice of policy. Discounting converts future revenue to present dollars. Typically a positive discount rate is used. This is indicative of present consumption holding higher value than future consumption. However, alternative discount rates should be considered when analyzing water use to reflect differences in stakeholder goals for water conservation. This information is relevant given the high prevalence of irrigated agriculture in the region, and the large number of irrigated acres in Grant County (Table 1).

The overall objective of this study is to evaluate groundwater policies in Grant County, with the following primary objectives:

- Analyze the impacts alternative discount rates have on groundwater policy recommendations.

- Examine how different levels of crop price affect the choice of groundwater policy.

Methodology

The effect of crop price and discount rate of revenues generated from groundwater withdrawal were evaluated in this study using county level deterministic models. Matrix Laboratory (MATLAB) (2015) was used in this study to solve the optimization models formulated and to evaluate the profits accrued and the levels of water withdrawn from the Ogallala in each scenario.

The model was utilized to generate outcomes for two alternative scenarios. The first policy, a status quo scenario, did not incorporate changes in current practices. This scenario was included to model outcome should irrigation continue at current rates without regulation. The four crops analyzed in the model were irrigated corn (C1), irrigated grain sorghum (C2), irrigated soybeans (C3), and crop 4 (C4) was used as an aggregate measure to take into account dryland crop production yields and subsequent revenues accrued, for the aforementioned three crops.

The second policy, factored in a 10% reduction of irrigated acreage for Grant County. Under both the status quo and the acreage reduction policy, alternative scenarios were run to allow for years of high, average, and low prices of C1, C2, and C3. This was done in an effort to discern how the output would change dependent on crop prices and yields. Furthermore, various discount rates were applied to revenues obtained under both the status quo scenario and the acreage reduction scenario. This step was taken in order to evaluate how the discount rate ultimately affects the model's results and consequently the choice of groundwater conservation policy. The discount rates applied to net and total revenues under both the status quo and the acreage reduction scenario were 5%, 2.5%, 0%, -2.5%, and -5%. The application of discount

rates converts future revenue to present dollars. Typically, a positive discount rate is used, indicating that present consumption is valued more than future consumption. However, alternative discount rates should be considered when analyzing water use in order to reflect differences in stakeholder goals for water conservation. A 0% discount rate means current and future consumption are valued equally, while a negative discount rate, such as -2.5% or -5%, reflects that future consumption is worth more.

Model Specification

The focus of this study is the examination of groundwater policy, and the impact alternative prices and discount rates have on policy recommendations. The goal of this study's county level, optimization models is to maximize net revenue accrued through irrigated crop production. This model assumes a profit maximizing producer will choose crop acreage allocation and crop-water application rates in such a manner as to maximize annual profits. The use of an optimization objective function based on maximizing producer net profits is consistent with past literature. Implicitly, this assumes that groundwater management should be based on what is best for the agriculture producer. In order to do this, subsequent costs incurred as well as overall drawdown of the Ogallala Aquifer must be minimized. The models were run over a fifty year planning horizon for a given county as a whole.

Data

Three irrigated crops were analyzed within this study. Crop 1 (C1) was irrigated corn, irrigated grain sorghum was crop 2 (C2), and crop 3 (C3) was irrigated soybeans. Of the three crops analyzed in the study, corn (C1) is the most prominent crop grown, with both sorghum (C2) and soybeans (C3) playing much smaller roles. The access to the aquifer helps account for

the production of greater than 95,000 acres of corn, over 12,000 acres of sorghum, and more than 1,000 acres of soybeans within Grant County (WIMAS). Crop 4 (C4) was used in the model as a representation of the overall dryland production of C1, C2, and C3, and the corresponding revenues obtained from growing those crops without the use of irrigation practices. A variety of different crops are actually grown in each county; however, only irrigated corn, irrigated grain sorghum, and irrigated soybeans were evaluated in this model. To do this, a normalized percentage was calculated for these three crops. This was done by figuring the percentage of overall production C1, C2, and C3 make up in acres. This percentage was then taken and applied to the total amount of available acres in each county in order to analyze how production would look if only C1, C2, and C3 were grown. The amount of irrigated acres allotted to each crop was assigned based on these values.

Specific data was compiled for Grant County. The county specific data included averages of planted irrigated acreages of cotton, grain sorghum, soybeans, and dryland production. Operating costs associated with irrigated agriculture were also collected for the aforementioned crops including variable expenses, irrigation fuel, seed, and fertilizer expenses, and harvesting and hauling expenses. Crop prices and costs used in this analysis represent a modification to the average 2011 through 2015 Cost-Return Budgets published by the Kansas State University Agricultural Experiment Station and Cooperative Extension Service (2015). The budgets were modified to reflect long-run average returns to land, management, and equipment. As yield changes, fertilizer, repairs and maintenance, and fuel expenses are adjusted appropriately. For example, overall repair and maintenance costs to equipment will go down in years of low yield, because farmers are not prompted to work their machines as hard as seen in years of high yield.

Likewise, fuel expenses decrease as less total fuel is needed to water and harvest a low yield crop in comparison to a high yield crop.

Hydrologic data collected included the area overlying the aquifer, basin surface area, depth to water, saturated thickness, hydraulic conductivity, and specific yield. The amount of natural recharge in the Ogallala is not known, and most estimates are considered controversial at best. For the purposes of this study, total annual recharge was left at zero feet and therefore not included in the parameters of the model. The saturated thickness, aquifer recharge, hydraulic conductivity, specific yield, and average decline in saturated thickness data was obtained from The Kansas Geological Survey High Plains Aquifer Section-Level Database (2015). The hydrologic data incorporated in this study is found in Table 3. The Water Information Management and Analysis System (WIMAS) provided data on water rights, water use, irrigated crop mix and type of irrigation technology used. These data are maintained by the Kansas Department of Agriculture, Division of Water Resources.

Results

The results of this study are indicative of a rapidly depleting aquifer, declining levels of saturated thickness, and ever increasing difficulty of earning profit in the farming industry. Figures of saturated thickness levels, total water use, and total revenue are included. Lines indicative of saturated thickness, total water use, and revenue under high, average, and low crop prices for both the status quo scenario (SQ) as well as the acreage reduction scenario (AR). All figures show a fifty year study horizon for which data has been evaluated under a 0% discount rate.

In Table 4, the relationship between discount rate (5%, 2.5%, 0%, -2.5%, and -5%) and net revenue is presented for under low, average, and high crop prices. These discount rates are evaluated for revenues accrued under both the status quo scenario as well as the acreage reduction scenario. The subsequent percent change from one scenario to the other is then calculated and displayed in the last column of the table.

Grant County

Grant County is not as large as nearby Finney County, but it has deeper levels of saturated thickness under its soil. Figure 3 shows the saturated thickness of Grant County declining at a constant rate under both the acreage reduction scenario and the status quo scenario; however, the acreage reduction scenario shows to preserve more water throughout the fifty year study. The saturated thickness begins at 199 feet, but declines to right around 55 feet under the status quo scenario. In comparison, the acreage reduction scenario shows to leave about 70 feet of saturated thickness in the aquifer in year fifty. This additional 15 feet of saturated thickness could prove vital for acquiring profits in years exceeding the fifty year study horizon.

As Figure 4 indicates, the status quo scenario will result in more total water use than will the acreage reduction scenario throughout the entirety of the study. Without imposing any type of water use regulation, the results show that total water use will begin to decrease significantly in year forty-six under the status quo scenario when prices are high or average. This same rapid decrease begins in year forty-eight for low prices under the status quo scenario. The total water use decreases because there is much less water to pump than was originally present. As the lines drop sharply, it is an indication of the forthcoming need to switch to dryland agriculture. This switch will become necessary as the water becomes increasingly more difficult and costly to

pump. The sharp downward trend does not become present within the fifty year parameter under the acreage reduction scenario, indicative of sufficient water amounts to continue pumping.

Total revenue is initially higher under the status quo scenario for each price category. However, results shown in Figure 5 indicate that the acreage reduction scenario will become more profitable beginning in year forty-six for high and average prices and in year forty-eight for low prices. This is because the aquifer is depleted more rapidly under the status quo scenario compared to the acreage reduction scenario. The acreage reduction scenario prolongs the ability to irrigate crops in Grant County for more years than does the status quo scenario. The ability to irrigate allows for future profits to be greater than does a depleted aquifer and dryland farming.

When analyzing net revenue under the status quo and acreage reduction scenario, it is evident that an absence of reduction in irrigated acreage will yield more total revenue throughout the study than an application of a mandatory irrigated acreage reduction. Table 4 shows that high prices in combination with a 5% and 2.5% discount rate applied to the revenue will generate the largest percent change between the two scenarios. The smallest percent change between the status quo scenario and the acreage reduction scenario is evident when a -2.5% discount rate is applied to the revenue in combination with low prices.

The discount rate applied to net revenue is of vital importance in this study. As shown in Table 4, revenue incurred grows larger as the discount rate becomes increasingly negative. This implies that obtaining future profits with a dwindling water supply will be of greater importance than current profits. The percent change in revenues received under the status quo scenario and the acreage reduction scenario are smallest under low prices and largest under high prices. The

percent change under average prices is shown to fall in between the low and high price categories

Conclusions

The study objective of evaluating how discount rate and price impact the recommendation of groundwater policy has a related, underlying question, “Should we choose groundwater policies with aquifer conservation in mind?” A policy reducing irrigated acreage by ten percent would reduce total water used; however, a larger, more sustained water reduction could potentially be affected by the amount of saturated thickness, this merits further investigation. It is hypothesized that in counties with high levels of saturated thickness, the water savings will be greater when a ten percent reduction in irrigated acreage is imposed than the savings in a county with lower levels of saturated thickness. Less saturated thickness results in less water saving ability; therefore a policy of acreage reduction is most likely beneficial in counties possessing at least normal amounts of saturated thickness such as Grant, and less effective in counties with low amounts of saturated thickness.

Production decisions are impacted by price. Higher prices incentivize producers to use more water to maximize yield and subsequent profit. However, results indicate little difference in water use when comparing high and average prices, indicating well capacity is the limiting factor. Prices have a large impact on projected producer revenue. High prices help producers justify utilizing any means necessary to pursue high yields and high returns. However, low prices have a negative impact upon the willingness of producers to spend money which will subsequently affect purchases with businesses located in the regional economy.

As discussed previously, discounting converts future revenue into present dollars. Typically a positive discount rate is used, indicating that present consumption is valued more than future consumption. However, alternative discount rates should be considered when analyzing water use to reflect differences in stakeholder goals for water conservation. A 0% discount rate means current and future consumption are valued equally, while a negative discount rate, such as -2.5% or -5%, reflects that future consumption is worth more. The producer who values current consumption would be impacted to a greater degree by the policy than the producer valuing future consumption, regardless of price present in the market.

The values of revenues accrued rise sharply as the discount rate becomes increasingly negative. This is indicative of future profits becoming increasingly difficult to obtain with a dwindling aquifer and increasing costs of pumping water for irrigation purposes. As seen in the revenue figure (Figure5), the acreage reduction scenario allows for profits to remain more constant over the fifty year study period than does the status quo scenario. This is due to the fact that implementing an acreage reduction policy of ten percent each year will allow for saturated thickness levels to remain deep enough to justify the use of irrigation pumping for more years than does the status quo scenario. The acreage reduction policy would help preserve the Ogallala as a whole for future generations.

While this analysis compares a status quo scenario to a groundwater conservation scenario, the purpose was not to justify one over the other. Instead the focus was on alternative prices and discount rates. The use of alternative prices does not have as large of an effect on results as the selection of a discount rate because the discount rate applied to revenues in a given area is directly dependent upon the hydrology in that area. In order to focus on prices and

discount rates, the model was somewhat simplified. As an example, technologic growth in crop yields was not included. Amosson et al. (2009) illustrated that a groundwater conservation policy provides significant benefits when technologic growth in crop yields was included in the model.

Shortcomings exist with every study. This study, much like Amosson et al. (2009), bases decisions largely on loss in producer income to assess the overall cost of implementing the conservation strategy analyzed. Also, yields stay the same throughout the model as static yield growth is not assumed for any year. This helps keep everything level and equivalent within the study. While the implementation of the irrigated acreage reduction scenario was compared to a status quo scenario, this research does not attempt to place a monetary value on the water conserved by policy implementation. Furthermore, the cost must be weighed against the benefit of generating water savings. To accomplish this, however, a ‘price tag’ needs to be given to the conserved water (Golden and Johnson, 2013). If a price tag was developed for the conserved water, this detail would allow for further discussion regarding whether or not to implement a water conservation policy.

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Table 1. Production Acreage by County

County	LEPA System Acres	Furrow Irrigation Acres	Dryland Acres	LEPA Percentage	Total Irrigated Acres
Grant	97,308	24,761	89,665	79.7%	122,069

Source: The Water Information Management and Analysis System (WIMAS)

Table 2. Acreage by County

County	Land Area Acres	Acres Overlying the Aquifer
Grant	368,115	368,115

Source: The Water Information Management and Analysis System (WIMAS)

Table 3. County Hydrologic Parameters

County	Recharge (in/ac)	Pump Lift (Feet)	Saturated Thickness (Feet)	Well Yield (GPM)	Acres Per Well	Specific Yield (ft^3)	Hydraulic Conductivity (ft/day)
Grant	0	233	199	1000	126	0.133	55.36

Source: The Kansas Geological Survey High Plains Aquifer Section-Level Database

Table 4. Discount Rate Analysis for Grant County

Discount Rate	Price	Revenue Status Quo Scenario	Revenue Acreage Reduction Scenario	Percent Change
5.0%	Low	$357,815,339	$342,679,751	4.23%
5.0%	Average	$833,621,493	$776,332,481	6.87%
5.0%	High	$1,311,888,924	$1,212,080,334	7.61%
2.5%	Low	$540,898,601	$520,472,060	3.78%
2.5%	Average	$1,278,012,967	$1,193,990,663	6.57%
2.5%	High	$2,020,051,674	$1,871,678,085	7.35%
0.0%	Low	$922,310,320	$892,950,020	3.18%
0.0%	Average	$2,215,582,401	$2,079,774,109	6.13%
0.0%	High	$3,519,959,408	$3,275,938,098	6.93%
-2.5%	Low	$1,813,124,767	$1,767,931,581	2.49%
-2.5%	Average	$4,429,402,281	$4,184,174,464	5.54%
-2.5%	High	$7,073,708,515	$6,623,796,750	6.36%
-5.0%	Low	$4,133,121,713	$4,059,330,459	1.79%
-5.0%	Average	$10,243,570,281	$9,748,001,580	4.84%
-5.0%	High	$16,432,243,599	$15,501,234,915	5.67%

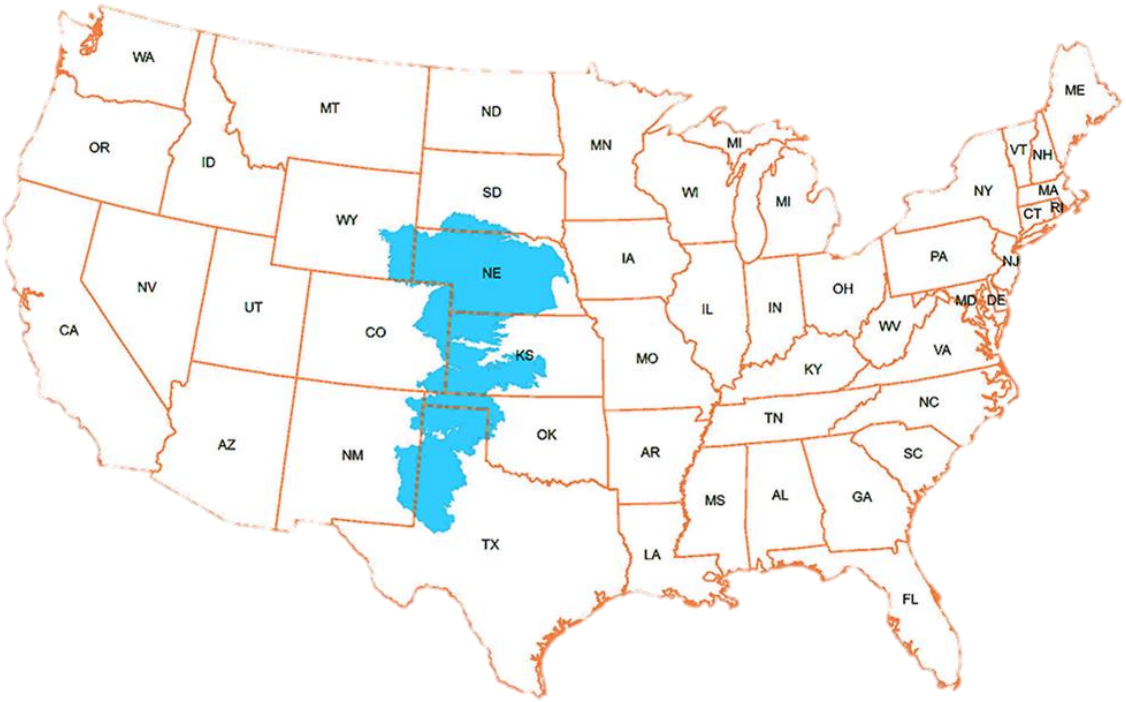

Figure 1. The Ogallala Aquifer
Source: United States Geological Survey (USGS)

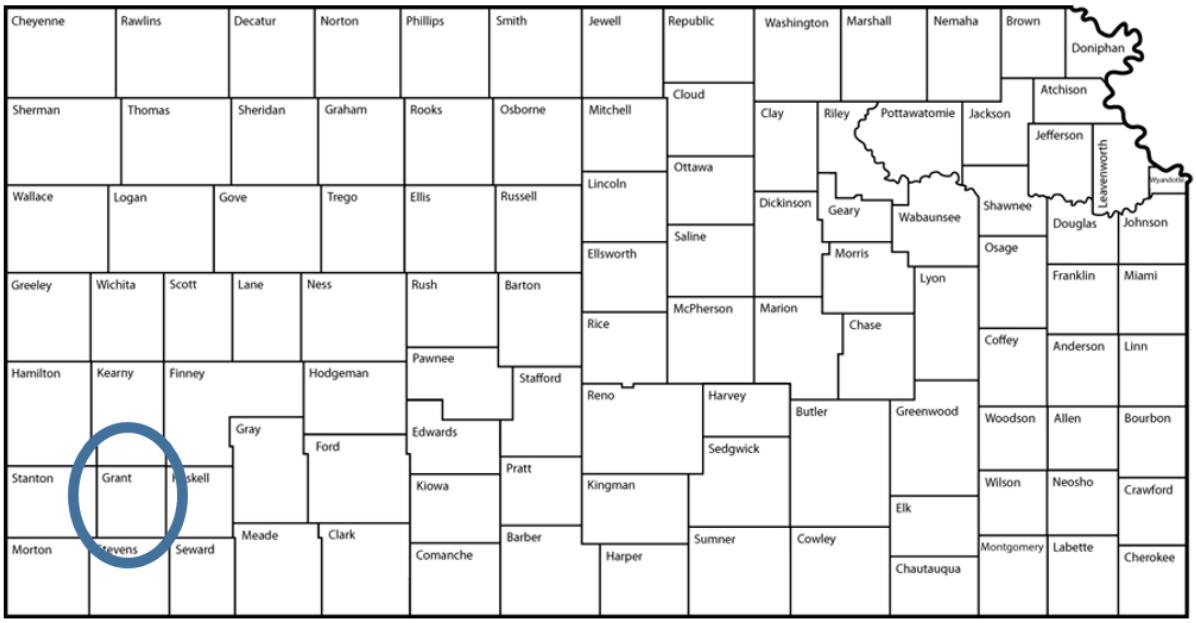

Figure 2. Grant County Location

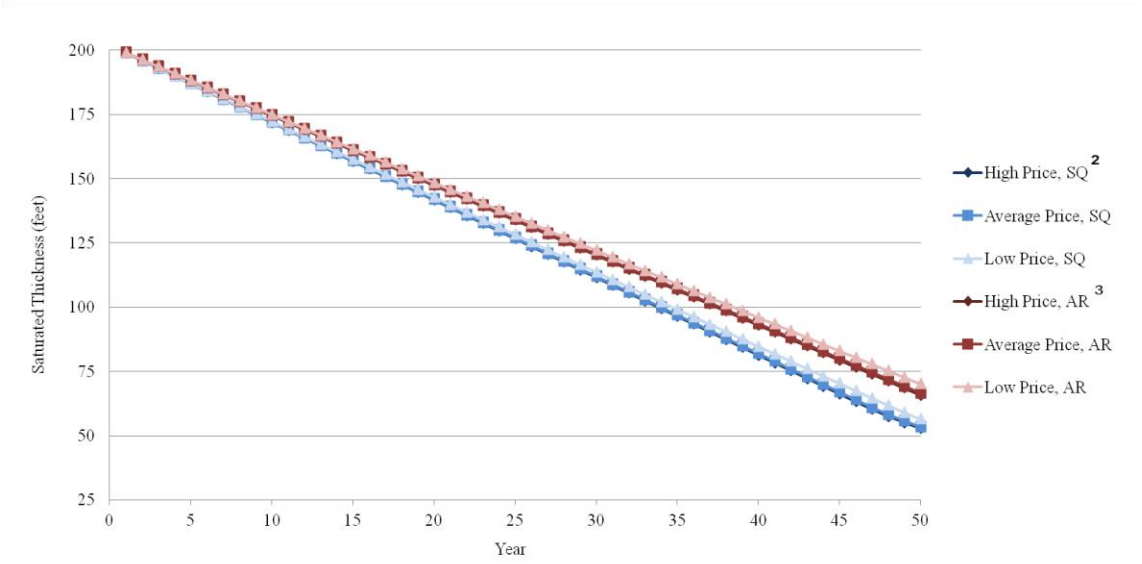

Figure 3. Grant County Saturated Thickness[1]

[1] Results obtained under a 0% Discount Rate

[2] SQ-Status Quo Scenario

[3] AR-Acreage Reduction Scenario

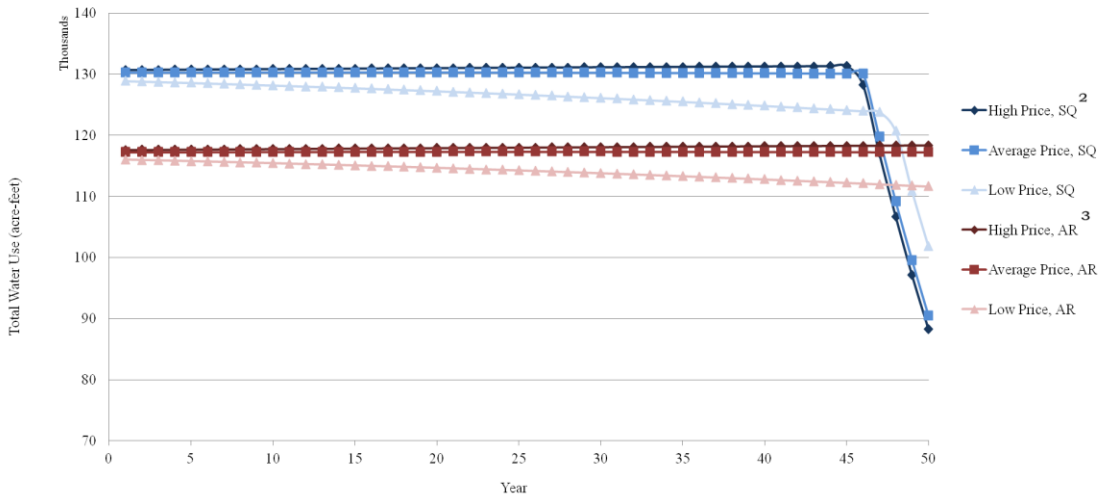

Figure 4. Grant County Total Water Use[1]

[1] Results obtained under a 0% Discount Rate

[2] SQ-Status Quo Scenario

[3] AR-Acreage Reduction Scenario

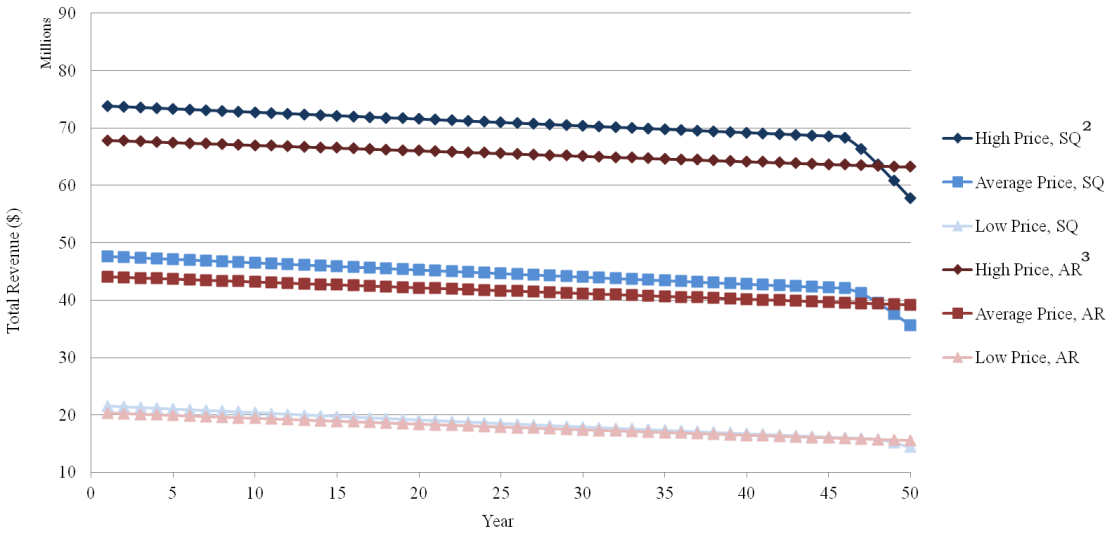

Figure 5. Grant County Total Revenue[1]

[1] Results obtained under a 0% Discount Rate

[2] SQ-Status Quo Scenario

[3] AR-Acreage Reduction Scenario