An Economic Analysis to Determine the Feasibility of Groundwater Supplementation from the Dockum Aquifer

Dr. Donna Mitchell
Department of Agricultural and Applied Economics
Texas Tech University
Box 42132
Lubbock, Texas 79409
donna.m.mitchell@ttu.edu

Dr. Ryan Williams
Department of Agricultural and Applied Economics
Texas Tech University
Box 42132
Lubbock, Texas 79409
ryan.b.williams@ttu.edu

Dr. Phillip Johnson
Department of Agricultural and Applied Economics
Texas Tech University
Box 42132
Lubbock, Texas 79409
phil.johnson@ttu.edu

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Introduction

As water resources from the Ogallala Aquifer continue to decline, alternative sources of water resources should be considered to extend the life of irrigated agriculture in the Southern High Plains. The Dockum is a minor aquifer located beneath the Ogallala at depths of up to 2,000 feet. The Dockum Aquifer may be a suitable water source for irrigation supplementation; however, the cost to pump from the Dockum may not be economically profitable due to deep pumping depths, poor water quality, and low well yields.

Figure 1 is a map of the major and minor aquifers in the Texas Southern High Plains. The Dockum is a minor aquifer that lies underneath the Ogallala. It is a confined aquifer with brackish water. Water quality is determined by the amount of total dissolved solids (TDS). The limit of TDS is 5,000 mg/l, but it ranges from 1,000 mg/l to 20,000 mg/l in the deepest areas of the aquifer (Ashworth and Hopkins, 1995). Andrews, Dallam, Deaf Smith, Gaines and Oldham Counties have the largest amount of water with the lowest amount of TDS (Bradley and Kalaswad, 2003). Well yields range from 6 gallons per minute in Howard County to 770 in Moore County. The Dockum has not been widely studied, and many of its characteristics are extremely variable.

The need for exploration of the aquifer has erupted from recent changes in water policy. Desired Future Conditions (DFCs) were established by the groundwater management districts to quantify the desired conditions of groundwater resources and represent a management goal that addresses how an aquifer will be managed (Mace, et. al, 2006). To meet the desired future conditions, the groundwater management districts have implemented rules and/or regulations to meet the specified management goal. The High Plains Underground Water Conservation District adopted a 50/50 DFC such that 50% of current water in the Ogallala aquifer would remain in 50 years. This was enforced by restricting the amount of water applied for irrigation, which could have significant impacts on producers. Results from Wright and Hudson (2011) show that the Dockum can mitigate the impact of policy restrictions on water use from the Ogallala.

The objective of this study is to perform an economic analysis to determine the benefits associated with supplemental pumping from the Dockum Aquifer via a non-linear optimization model. The results will provide an estimation of the optimal amount of water that can be withdrawn from the Ogallala using supplementation irrigation from the Dockum. The optimization model will provide an estimation of the optimal water use for each aquifer, crop mix, crop yield, and net returns over time.

Data and Methods

The study area for the project will be located in Deaf Smith County, which has a history of water production for irrigation from the Dockum aquifer. Price and cost data published in the Texas A&M Extension budgets for 2010-2014 were used. Crop yield and acreage data used in this study was from NASS statistics from 2010 to 2014 (USDA NASS, 2015). Hydrologic parameters for the Ogallala such as depth to water, saturated thickness, and well yield were from the High Plains Water District (HPWD, 2015). Specific yield, thickness, and well yield for the Dockum came from published studies (Bradley and Kalaswad, 2003; Ewing et al., 2008). Bradley and Kalaswad (2003) identify an area of the aquifer called the “Best Sandstone” unit that has good water quality. The parameters for this part of the aquifer will be modeled using those characteristics, so we will ignore blending rates in this analysis. It should be noted that some of the hydrologic data used in this study is old, and may not be accurate. As newer data sources become available, this study may not be valid.

This data will be used in a hydrologic/agronomic/economic optimization model that will maximize producer profit based on the costs of pumping from the Dockum in addition to the

Ogallala. We use 50-year forecasts so that we may determine when conversions to dryland may occur. We will also apply policy scenarios that include water use restrictions. The non-linear groundwater optimization model used in this analysis has an objective function (shown below) to maximize producer profit:

Maximize NPV=$\sum_{t=1}^{n} NR_t(1+r)^{-t}$, (1)

where NPV is net present value, *NR* is net revenue, and *r* is the social discount rate. Net revenue is defined as:

$$NR_t = \sum_i \sum_k \Theta_{ikt} \{P_i Y_{ikt}[WA_{iktj}, (WP_{iktj})] - C_{ikj}(WP_{iktj})\}, \quad (2)$$

where *i* represents the crops grown, *k* represents irrigation technology, Θ is the percentage of crop *i* produced using irrigation technology, *k,* during time *t*, P_i is the price of crop *i*, WA_{iktj} and WP_{iktj} are the water applied and water pumped per acre from aquifer *j*, Y_{ikt} is the yield production function estimated using DSSAT, and C_{itkj} are the costs per acre. The model equations and constraints are:

$$ST_{t+1} = ST_t - [(\Sigma_i \Sigma_k \Omega_{ikt} * WP_{iktj}) - R]PIA/SY \ , \quad (3)$$

$$X_{t+1} = X_t + [(\Sigma_i \Sigma_k \Omega_{ikt} * WP_{iktj}) - R]PIA/SY, \quad (4)$$

$$WT_t = \Sigma_i \Sigma_k \Theta_{ikt} * WP_{iktj}, \quad (5)$$

$$WT_t \leq GPC_t, \quad (6)$$

$$GPC_t = \left(\frac{ST_t}{IST}\right)^2 * (4.42 * \frac{WY}{AW}), \quad (7)$$

$$PC_{iktj} = \{[EF(X_t + 2.31 * PSI)EP]/EFF\} * WP_{iktj}, \quad (8)$$

$$C_{iktj} = VPC_{ik} + PC_{iktj} + HC_{ikt} + MC_{kj} + DP_{kj} + LC_{kj}, \quad (9)$$

$\Sigma_i \Sigma_k \Theta_{ikt} \leq 1$ for all t, (10)

$$\Omega_{ikt} \geq 0 \tag{11}$$

Equations 3 and 4 are the two state variables, saturated thickness, *ST*, and pumping lift, *X*, where *R* is the recharge rate, *PIA* is the percentage of irrigated acres expressed as the initial number of irrigated acres in the county divided by the area of the county above the aquifer, and *SY* is the specific yield of the aquifer. Equation 5 calculates the total water pumped per acre for each crop and Equation 6 restricts the total amount of water pumped to be less that or equal to the pumping capacity. Equation 7 represents the gross pumping capacity, where *IST* is the initial saturated thickness, *WY* is the well yield, and *AW* is the acres per well. Equation 8 calculates the pumping cost as a function of the energy use factor for electricity, *EF*, lift, *X*, price of electricity, *EP*, pump efficiency, *EFF*, and the water pumped, *WP*. The height of a column of water that will exert one pound per square inch (PSI) is 2.31 feet. Equation 9 is the total cost calculation, where *VPC* is the variable cost of production, *PC* is the pumping cost estimated in Equation 8, *HC* is the harvest cost per acre, *MC* is the irrigation system maintenance cost, *DP* represents the depreciation of the irrigation system, and *LC* is the labor cost. Equation 10 restricts the crop acreage percentage over all crops over all irrigation systems to be less than or equal to 1, and Equation 11 is a non-negativity constraint.

Quadratic production functions are used to estimate crop yield. Production functions are assumed to be identical for the Ogallala and Dockum Aquifers[1]. The crops that will be analyzed are cotton, corn, sorghum, and wheat. A baseline model will be estimated for water withdrawal from the Ogallala aquifer (no policy analysis will be included). A second model will incorporate the addition of the Dockum aquifer. Both models will be forecasted over a 50 year time horizon. The output will provide an estimation of the optimal amount of water that can be withdrawn

[1] The Authors realize due to quality differences, this assumption may not necessarily be true.

from the Ogallala using supplementation irrigation from the Dockum. The optimization model will provide an estimation of the optimal water use for each aquifer, crop mix, crop yield, and net returns over time.

Results

Saturated thickness, net returns, and the percentage of irrigated crops for the baseline and scenario analysis are shown in Tables 1 and 2, respectively. Baseline results show that saturated thickness of the Ogallala declines from 64 feet to 32 by the end of year 50. Results in Table 2 show that supplementation from the Dockum does not significantly affect water withdrawals from the Ogallala; however, the additional amount of water availability had a positive impact on extending irrigated acreage.

Figure 2 shows that in the baseline, irrigated acreage began to decline in year seven of the forecast, whereas when additional supplementation from the Dockum is used, irrigated acres was sustained until year 24. Figures 3 and 4 show the changes in crop mix from the baseline and supplemental pumping from the Dockum. In the baseline scenario, irrigated corn production increases to 27% by year ten, and then declines to 10% by the end of year 50. Dryland cotton production increases to 90% by the end of the forecast. In the second scenario when additional pumping is allowed, corn production rises steadily from 12% in year one to 24% in year 24, and declines to 18% by year 50. Dryland cotton reaches 50% by the end of the forecast.

Pumping from the Dockum increased the amount of water applied (Table 3), resulting in higher crop yields. The additional water resource had the biggest impact on water applied to corn, the most water thirsty crop. Cotton yields increased from an average of 1412 lb/acre to 1480 lbs/acre, corn increased from 263 bu/acre to 274 bu/acre, sorghum 7436 lbs/acre to 8200 lbs/acre, and wheat from 89 bu/acre to 98 bu/acre. The extra yield obtained is not enough to offset the cost of pumping. The cost of pumping from the Dockum reduces net returns (Figure 5), resulting in a loss in NPV of $1,300.

Discussion

As producers face challenges in water conservation and irrigation management, more attention will be directed into developing alternative water resources. This paper provides some insight into using the Dockum Aquifer as a viable water source for agricultural irrigation. These estimates may help producers in making decisions to invest in irrigation systems for the Dockum. Large areas of the Dockum have not been explored, and researches may find that it is generally not productive, or economically profitable to treat. These results from this study may help to provide a foundation for future research.

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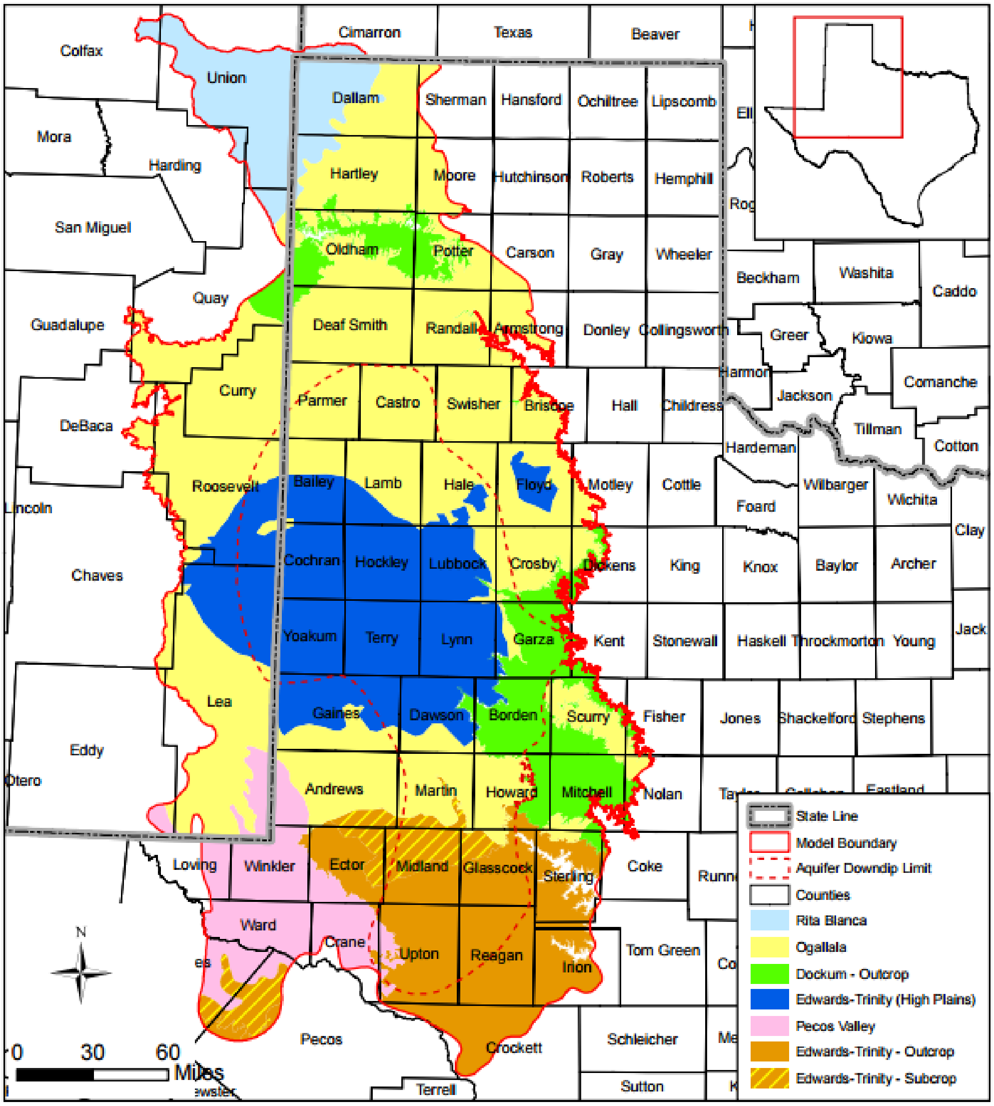

Figure 1. Map of Study Area
Source: Ewing et al., 2008

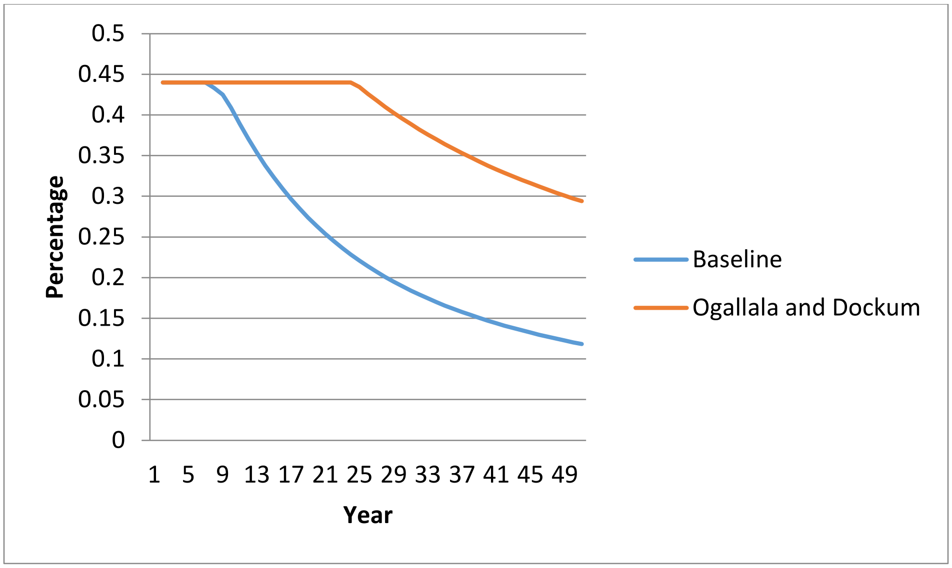

Figure 2. Crop Acreage Percentages for the Baseline and Supplementation from the Dockum

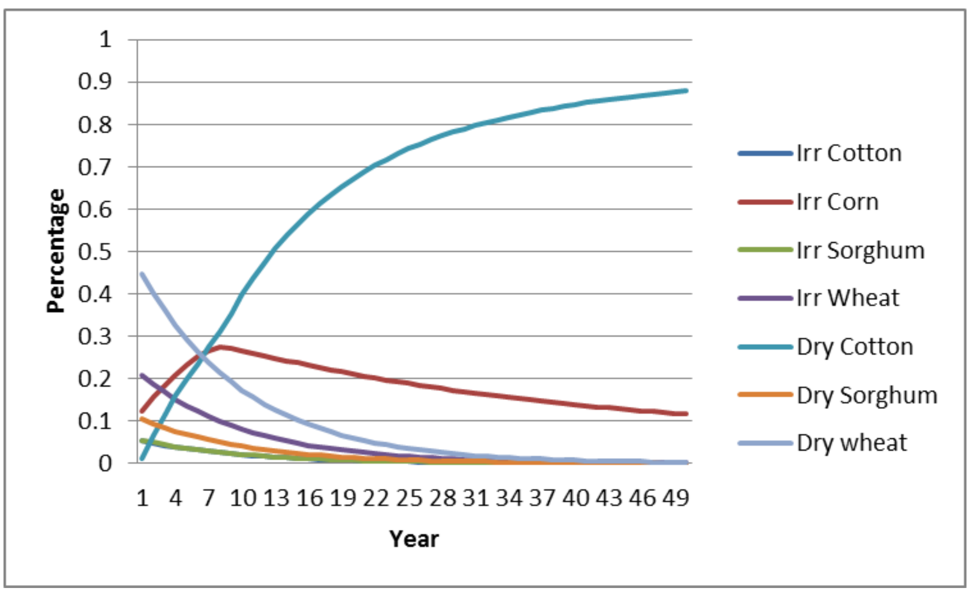

Figure 3. Crop Mix Results for the Baseline

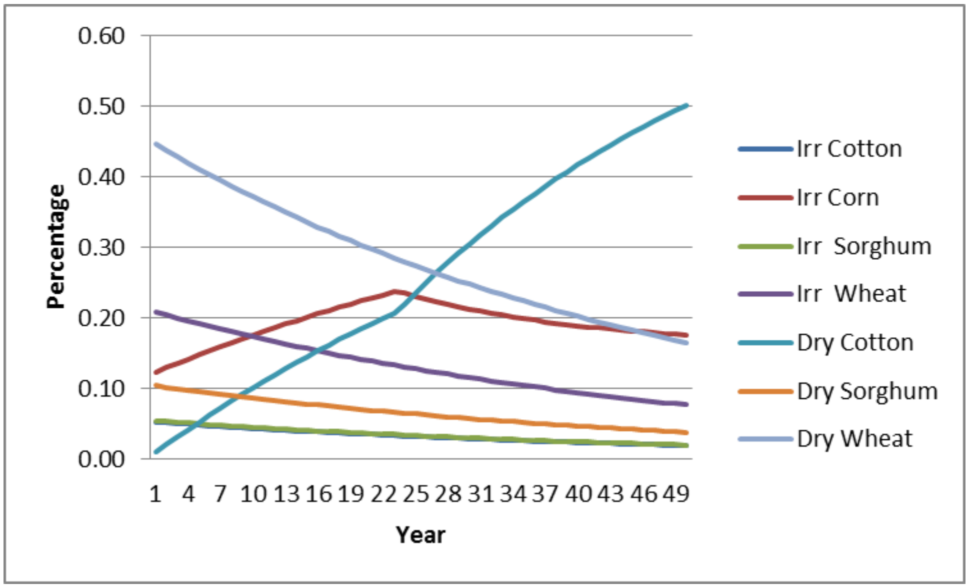

Figure 4. Crop Mix Results for Supplementation from the Dockum

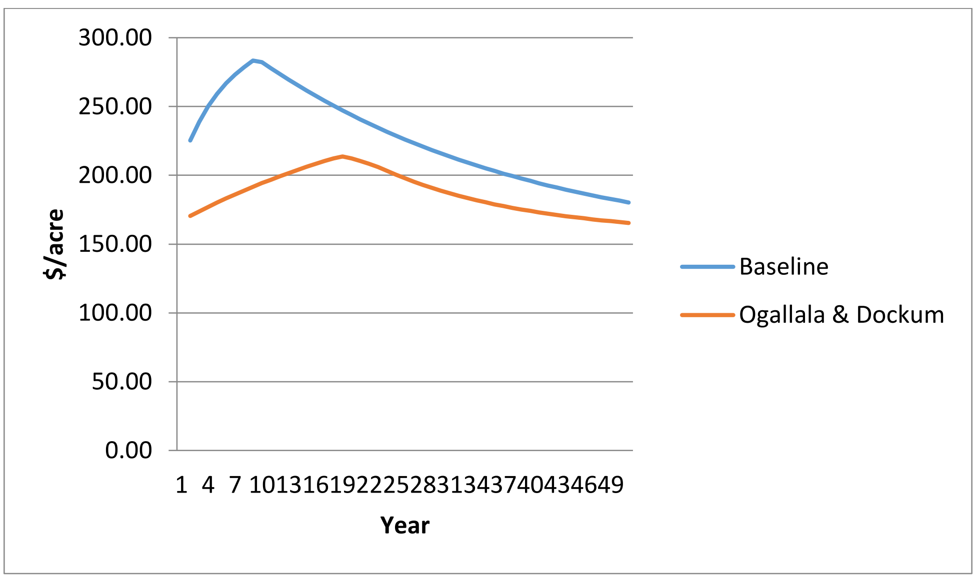

Figure 5. Net Revenues for the Baseline and Supplementation from the Dockum

Table 1. Forecasted Results for the Baseline

Baseline	Year 10	Year 20	Year 30	Year 40	Year 50
Saturated Thickness Year 1 = 64	54	45	39	35	32
Net Revenue Year 1 = $232	$273	$238	$212	$193	$180
Irrigated Crop Percentage Year 1 = 44%	38%	25%	18%	14%	12%

Table 2. Forecasted Results for Supplementation from the Dockum

Ogallala & Dockum	Year 10	Year 20	Year 30	Year 40	Year 50
Saturated Thickness Year 1 = 64	56	48	41	37	33
Net Revenue Year 1 = $170	$197	$211	$187	$173	$165
Irrigated Crop Percentage Year 1 = 44%	44%	44%	39%	33%	29%

Table 3. Water Pumped for Each Crop

	Baseline	Ogallala & Dockum
Cotton	16.6	18.0
Corn	24.5	27.0
Sorghum	13.0	15.0
Wheat	11.0	13.0