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

HPWD Final Report

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Photo by Kelly Lange, Texas Tech University

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Executive Summary

As water resources from the Ogallala Aquifer continue to decline, alternative sources of water should be considered to extend the life of irrigated agriculture in the Southern High Plains. The Dockum Aquifer may be a suitable water source for irrigation supplementation; however, the ability to pump from the Dockum may not be economically profitable due to deep pumping depths, poor water quality, and low well yields. An economic analysis was performed to determine the costs associated with supplemental pumping from the Dockum and the impact of irrigation from the Dockum on water availability, crop mix, and producer net returns over time.

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, ability 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 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. Well yields range from 6 gallons per minute (GPM) in Howard County to 770 GPM in Moore County (Bradley and Kalaswad, 2003).

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).

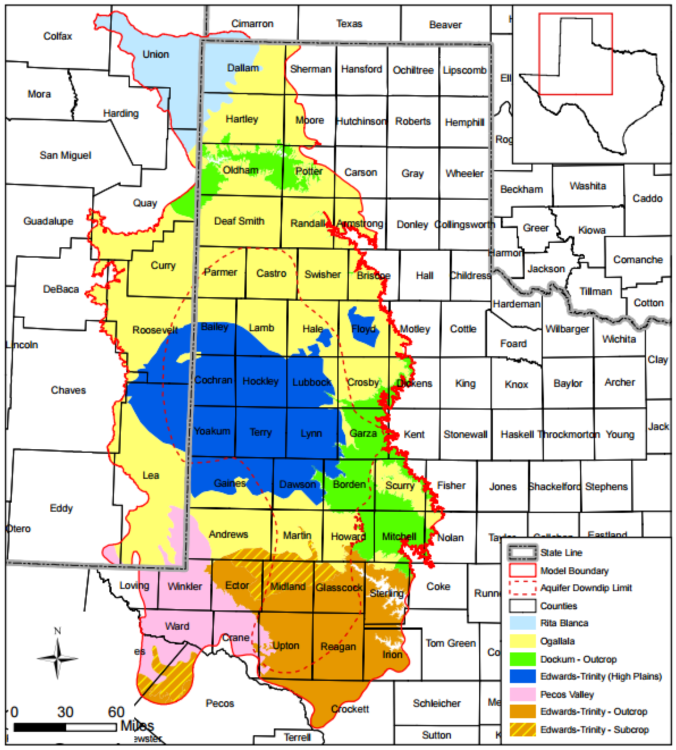

Figure 1. Map of Study Area
Source: Ewing et al., 2008

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 level of saturated thickness in the Ogallala aquifer would remain in 50 years. This was enforced by restricting the amount of water applied for irrigation. 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 Dockum to supplement pumping from the Ogallala under status quo and policy scenarios. The optimization model will provide an estimation of the optimal water use for each aquifer, crop mix, and net returns over time.

General 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 averaged. 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 were from the High Plains Water District (HPWD, 2015; HPWD, 2016). Specific yield, thickness, and well yield for the Dockum came from published studies (Bradley and Kalaswad, 2003; Ewing et al., 2008) and from the High Plains Water District (HPWD, 2016). Table 1 illustrates the baseline parameters for the Ogallala aquifer. The county characteristics needed for the model include the amount of irrigated, dryland, and total acres within the county. Also required is initial acreage for each crop in the analysis. The aquifer characteristics required in the model are the average saturated thickness, specific yield, recharge, well yield, and depth to water. To estimate pumping costs, we assume a pumping season of 2,000 hours.

Table 1. Deaf Smith County Characteristics

County Characteristics	**Deaf Smith**
Irrigated Acres	148,412
Dryland	188,991
Total Cultivated Acres	337,403
Irrigated Crop Allocation (acres)	
Corn	33,358
Cotton	14,275
Sorghum	14,848
Wheat	56,223
Dryland Crop Allocation (acres)	
Cotton	2,926
Sorghum	30,234
Wheat	129,015
Average Dryland Yields	
Cotton (lb)	489
Sorghum (lb)	1,792
Wheat (bu)	20
Hydrologic Characteristics (Ogallala)	
Saturated Thickness	64
Specific Yield	0.15
Recharge	1.03
Average Well Yield (GPM)	191
Pumping Lift (ft)	223
Pumping Season (hours)	2,000

Economic Model

The data will be used in a hydrologic/agronomic/economic optimization model that will maximize the net present value of net returns (producer profit) based on the cost of pumping. We use 50-year forecasts so that we can determine when conversions to dryland may occur. It should be noted that the mathematical methods used in this study are derived from a model developed in the General Algebraic Modeling System (GAMS). This should not be confused with any reference to the Groundwater Availability Model (GAM) that is utilized within water planning and consulting processes at the TWDB to estimate groundwater and hydrologic interactions.

Pumping Cost

Cost of pumping for natural gas powered pumping plants was estimated using the energy price and energy requirements in accordance with pumping lift. The pumping costs change as depth to water increases over the planning period. One of the unique aspects of this model is that water demand incorporates costs of pumping, changes in depth to water, and changing yields and crop mix as they respond to changing water availability over time. Water demand is driven by economic forces in conjunction with the ability of the underlying hydrology to provide irrigation water.

To demonstrate the difference in pumping cost between the Ogallala and Dockum, pumping costs were estimated at various levels of lift. Pumping costs vary from $5.00 per acre inch for a 200 foot well to $20.00 per acre inch for a well over 900 feet deep.

Table 2. Irrigation Pumping Costs

Lift (feet)	**Cost/ac in**	**Cost/ac ft**
200	$5.00	$60.00
500	$11.41	$136.90
700	$15.65	$187.80
900	$19.89	$238.68

Production Functions

Quadratic production functions for a LEPA irrigation system are used to estimate crop yield within the economic model and are assumed to be identical for the Ogallala and Dockum Aquifers. The production functions estimate yield as a response to irrigation water applied. As irrigation water application rates change, the crop yield per acre adjusts accordingly.

Estimating Dockum Drawdown

The Dockum aquifer is a confined aquifer and must be modeled differently than the Ogallala. To correctly model the Dockum, a cone of depression must be estimated so that an accurate steady-state drawdown can be calculated. A cone of depression forms when pumping from an aquifer.

In long-term pumping of a confined aquifer, the water levels reach an equilibrium point where the cone of depression ceases to expand, creating a steady-state where recharge equals pumping (Fetter, 2014). Under these conditions, the saturated thickness and the pumping lift of the confined aquifer do not change. To calculate a steady-state drawdown, we assume that the aquifer is confined both top and bottom, with no source of recharge. The aquifer is compressible and the well pumps at constant rate (Fetter, 2014). The *Cooper-Jacob method* was used to calculate drawdown using the initial conditions identified in Table 3 below. Once the drawdown has been calculated, the steady-state pumping lift can be estimated. The calculated pumping lift, saturated thickness (as identified by the screened interval), and the pumping capacity in GPM (Q) are used as inputs into the economic model.

Table 3. Initial Dockum Characteristics for Deaf Smith County

Dockum Characteristics	**Deaf Smith**
Q (gpm)	582
Transmissivity (m2/day)	117.69
Storage Coefficient	.000075
Screened Interval (feet)	641-860
Calculated Drawdown	156
Calculated Depth to Water	573

Sensitivity Analysis of Hydrologic Characteristics

Transmissivity and storage are variables that determine the cone of depression. Table 4 explains how pumping capacity, transmissivity, and storage impact drawdown. Low values of transmissivity create deep and narrow cones of depression leading to greater drawdown and high values of transmissivity create shallow and wide cones with less drawdown. Lower storage values create deeper and wide cones leading to more drawdown than compared to higher storage values.

Table 4. Sensitivity Analysis of Drawdown Characteristics

Characteristics	**Drawdown (feet)**
GPM	
200	53.73
300	80.59
400	107.46
500	134.32
600	161.19
Transmissivity (ft2/day)	
500	379.57
1000	195.96
2000	101.07
3000	68.58
Storage	
.00001	170.52
.00005	159.20
.0001	154.33
.0002	149.50

Water Quality

The Dockum is characterized by having poor water quality, and therefore must be blended to ensure acceptable levels of TDS for irrigation. Hillel (2000) classifies water quality based on salt concentrations. Fresh water for drinking and irrigation are described as having total parts per million (ppm) of less than 500. Slightly brackish water that can be used for irrigation has TDS levels between 500 and 1,000 ppm. Brackish water that should be used with caution in irrigating, has TDS levels between 1,000 and 2,000 ppm. Moderately Saline to Brine water will not be considered in the analysis. Due to the well-to-well variation in TDS content, a variety of TDS levels will be used in the analysis (Hillel, 2000).

Model Scenarios

First, a baseline estimate was determined for the years 2015-2065, which represents the status quo where no irrigation management standards were implemented. The baseline scenario projects the economic, agronomic, and hydrologic variables under the assumption that no

Table 5. Water Quality Designations for Total Dissolved Solids

Designation	TDS (ppm)
Fresh Water	<500
Slightly Brackish	500-1,000
Brackish	1,000-2,000
Moderately Saline	2,000-5,000
Saline	5,000-10,000
Highly Saline	10,000-35,000
Brine	>35,000

Source: Hillel (2000)

management techniques are employed and farmers irrigate under an environment with no pumping restrictions and no blending requirements. Second, the baseline scenario was then compared to a constrained scenario, in which the 50/50 management standard was implemented from 2015 to 2065. Then, two scenarios were estimated based on various data sources. Scenario 1 used published hydrologic Dockum data from Bradley and Kalaswad (2003) and Ewing et al. (2008) as shown in Table 3. Although the data from these studies are not recent, all necessary hydrologic data required for this analysis was provided. Scenario 2 used average well data collected by the High Plains Water District for Deaf Smith County (HPWD, 2015). Lastly, a sensitivity analysis was performed on pumping lift, saturated thickness, and pumping capacity of the Dockum to determine how each of these variables impact the results.

Results

The results presented below summarize the estimates from each of the model scenarios. Results from the baseline estimation will be presented first followed by the 50/50 policy analysis. Then, the results from Scenario 1 and 2 under varying levels of TDS will be presented, ending with results from the sensitivity analysis on the most important Dockum variables.

Baseline

The results presented below represent model estimates for a baseline that does not include irrigation supplementation or policy constraints. Saturated thickness, net returns, and the percentage of irrigated crops for the baseline and scenario analysis are shown in Table 6. Initial saturated thickness of the Ogallala in Deaf Smith County begins at 64 feet and declines to 32 feet by year 50 of the forecast. Net revenues begin at $232 per acre and decline to $180 by year 50. The net present value (NPV) of net returns (NR) by the end of the period is $6,320.78. Total irrigated acreage begins at 44% and declines to 12% by year 50. Figure 1A (located in the Appendix) graphically represents the percentage of predicted crop mix over time. Water is being allocated for the production of corn until Year 7, when it begins to decline and dryland cotton production reaches 90% by the end of year 50.

Table 6. Forecasted Results for the Baseline – Ogallala only

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

Policy Analysis

The desired future condition for Deaf Smith County under the 50/50 management standard requires a minimum saturated thickness of 32 feet remaining by the end of the planning horizon in 2065. An analysis of the 50/50 DFC shows no change compared to the baseline results. The 50/50 policy is reached naturally, therefore represents an unbinding constraint in the model. The 50/50 policy was not applied on any of the Dockum scenarios because the Dockum reduces the water pumped from the Ogallala and would not have any impact on the results.

Dockum Scenario 1

Forecasted results for saturated thickness of the Ogallala, net revenues, and the percentage of irrigated crops are presented under TDS levels of 700, 1000, 1500, and 2000 ppm for Scenario 1 as shown in Table 7. Baseline results show that saturated thickness of the Ogallala declines from 64 feet to 32 by the end of year 50. Results in Table 7 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 by 13%. Due to a difference in pumping depth of 350 feet compared to the Ogallala, net revenues decline from $188/ac in Year 1 to $168/ac in Scenario 1. Figure 2A (Appendix) shows a comparison of the net returns for the baseline and each of the TDS levels in Scenario 1. As the water quality declines from 700 ppm to 2,000 ppm, net revenues also decline. Figure 3A (Appendix) shows a comparison of the percentage of irrigated acres for the baseline and various Dockum blending levels. Irrigated acreage in the baseline begins to decline in Year 8 of the forecast. Supplementing with water containing TDS levels of 700 ppm can extend irrigated acreage to Year 23.

Table 8 compares results on the net present value of net returns for each TDS level. The NPV for the baseline was $6,321. Pumping from the Dockum immediately reduces the NPV of NR by almost $1,000. As the water quality declines, the NPV of NR declines to $4,883 with TDS levels of 2,000 ppm, resulting in a 23% reduction in NR.

Table 7. Scenario 1 Results from Supplementation from the Dockum at Various Blending Rates

Scenario 1 –TDS 700	**Year 10**	**Year 20**	**Year 30**	**Year 40**	**Year 50**
Saturated Thickness (Ogallala) **Year 1=64 feet**	57	49	42	37	34
Net Revenue **Year 1=$188/ac**	$214	$236	$205	$181	$168
Irrigated Crop Percentage **Year 1=44%**	44%	44%	38%	31%	25%
Scenario 1 – TDS 1,000					
Saturated Thickness (Ogallala) **Year 1=64 feet**	55	46	40	36	33
Net Revenue **Year 1=$198/ac**	$222	$196	$169	$155	$147
Irrigated Crop Percentage **Year 1=44%**	44%	38%	31%	25%	21%
Scenario 1 – TDS 1,500					
Saturated Thickness (Ogallala) **Year 1=64 feet**	54	46	40	36	33
Net Revenue **Year 1=$202/ac**	$223	$183	$159	$147	$141
Irrigated Crop Percentage **Year 1=44%**	44%	36%	29%	24%	20%
Scenario 1 – TDS 2,000					
Saturated Thickness (Ogallala) **Year 1=64 feet**	54	46	40	36	32
Net Revenue **Year 1=$203/ac**	$217	$178	$156	$145	$140
Irrigated Crop Percentage **Year 1=44%**	43%	35%	29%	23%	19%

Table 8. Comparison of NPV of NR for each level of TDS

TDS	NPV NR	Ending Saturated Thickness	Ending Crop Percentage
700	$5,484	33.75	25.11%
1000	$5,108	32.74	20.82%
1500	$4,943	32.50	19.58%
2000	$4,883	32.44	19.19%

The average water pumped for each crop from each aquifer is shown below. As water quality degrades, the amount of water pumped from the Ogallala increases and less water is pumped from the Dockum.

Table 9. Average Water Pumped from each Aquifer in Scenario 1

Scenario 1 – TDS 700	**Ogallala**	**Dockum**
Cotton	12.14	6.07
Corn	17.66	8.83
Sorghum	10.10	5.05
Wheat	8.65	4.32
Scenario 1 – TDS 1,000		
Cotton	14.43	2.89
Corn	21.15	4.23
Sorghum	11.63	2.33
Wheat	9.90	1.98
Scenario 1 – TDS 1,500		
Cotton	15.45	1.54
Corn	22.72	2.27
Sorghum	12.29	1.23
Wheat	10.44	1.04
Scenario 1 – TDS 2,000		
Cotton	15.82	1.06
Corn	23.30	1.55
Sorghum	12.54	0.84
Wheat	10.64	0.71

Dockum Scenario 2

Data from the HPWD (2016) for average pumping, depth to water, and saturated thickness for the Dockum was used in Scenario 2. The transmissivity and storage coefficient were assumed to be 92.9 m2/day and .000075, respectively. Using this data, drawdown for the Dockum was estimated to be 168 feet with a pumping lift of 769 feet.

Table 10. Dockum Data from HPWD

Dockum Characteristics	**Deaf Smith**
Q (gpm)	500
Transmissivity (m2/day)	92.90
Storage Coefficient	.000075
Screened Interval (feet)	785-908
Calculated Drawdown	168
Calculated Depth to Water	769

Table 11 shows the results from Scenario 2 with TDS levels of 700, 1,000, 1,500 and 2,000 ppm. Despite the different data sources used, the results for the saturated thickness of the Ogallala and the percent of irrigated acreage remains the same as Scenario 1. These variables were not sensitive to the changes in saturated thickness and pumping capacity because the blending requirements are keeping the model constrained. The average water pumped for each crop in Table 13 are also the same for this reason. Achieved net returns were less under Scenario 2 due to a deeper pumping lift, creating a reduction in the NPV of NR in Table 12. No figures were included in the Appendix as both Scenarios had similar results.

Table 11. Scenario 2 Results from Supplementation from the Dockum at Various Blending Rates

Scenario 2 – TDS 700	Year 10	Year 20	Year 30	Year 40	Year 50
Saturated Thickness (Ogallala) Year 1=64 feet	57	49	42	37	34
Net Revenue Year 1=$174/ac	$201	$222	$196	$174	$162
Irrigated Crop Percentage Year 1=44%	44%	44%	38%	31%	25%
Scenario 2 – TDS 1,000					
Saturated Thickness (Ogallala) Year 1=64 feet	55	47	40	36	33
Net Revenue Year 1=$191/ac	$215	$192	$166	$152	$145
Irrigated Crop Percentage Year 1=44%	44%	38%	31%	25%	21%
Scenario 2 – TDS 1,500					
Saturated Thickness (Ogallala) Year 1=64 feet	54	46	40	36	33
Net Revenue Year 1=$198/ac	$220	$180	$158	$146	$140
Irrigated Crop Percentage Year 1=44%	44%	36%	29%	24%	20%
Scenario 2 – TDS 2,000					
Saturated Thickness (Ogallala) Year 1=64 feet	54	46	40	36	32
Net Revenue Year 1=$201/ac	$215	$177	$155	$144	$139
Irrigated Crop Percentage Year 1=44%	43%	35%	29%	23%	19%

Table 12. Comparison of NPV of NR for each level of TDS

TDS	NPV NR	Ending Saturated Thickness	Ending Crop Percentage
700	$5,175	33.83	25.23%
1000	$4,976	32.76	20.83%
1500	$4,876	32.51	19.59%
2000	$4,838	32.44	19.19%

Table 13. Average water pumped from Each Aquifer in Scenario 2

Scenario 2 – TDS 700	**Ogallala**	**Dockum**
Cotton	12.09	6.05
Corn	17.60	8.80
Sorghum	10.03	5.02
Wheat	8.59	4.29
Scenario 2 – TDS 1,000		
Cotton	14.42	2.88
Corn	21.14	4.23
Sorghum	11.61	2.32
Wheat	9.88	1.98
Scenario 2 – TDS 1,500		
Cotton	15.44	1.54
Corn	22.71	2.27
Sorghum	12.28	1.23
Wheat	10.43	1.04
Scenario 2 – TDS 2,000		
Cotton	15.82	1.05
Corn	23.29	1.55
Sorghum	12.53	0.84
Wheat	10.63	0.71

Sensitivity Analysis on Pump Lift, Saturated Thickness, and Pumping Capacity

While it is important to correctly estimate the drawdown for the Dockum using the most accurate hydrologic estimates, the economic model only incorporates the saturated thickness of the Dockum, calculated drawdown, and the pumping capacity. In Scenario 1 and 2, we used actual well data from two different sources to estimate the behavior of producers. However, with the lack of data and the highly variable nature of the Dockum, we felt it necessary to perform additional sensitivity analysis on these parameters to determine how these variables influence producer profitability. Only the NPV of NR, ending saturated thickness of the Ogallala aquifer, and ending crop percentage are reported.

Table 14. Sensitivity Analysis on Pumping Lift, Saturated Thickness and Pumping Capacity

Lift	ST	GPM	TDS	NPV NR	Ending Saturated Thickness	Ending Crop Percentage
900	100	300	1000	$4,888	33	21%
900	100	300	1500	$4,830	33	20%
1000	100	300	1000	$4,821	33	21%
1000	100	800	700	$4,813	34	25%
1000	100	800	1000	$4,820	33	21%
1000	300	800	700	$4,813	33	26%

Conclusions

The objective of this study was to evaluate the economic feasibility of supplementation with the Dockum Aquifer in Deaf Smith County. A county level analysis was performed to estimate the economic impacts of the 50/50 management policy and water quality of the Dockum on producer profitability.

The overall results indicate that the Dockum aquifer may be used as an irrigation supplement to the Ogallala in Deaf Smith County, which is considered to have the most volume and best water quality in the Dockum. Pumping from the Dockum has the ability to extend the life of irrigated agriculture in Deaf Smith by slowing the transition to dryland crop production. However, the deep pumping depths of the Dockum may make it financially challenging to producers. Losses in net returns should be expected due to increased variable costs. The 50/50 management policy was shown to have no impact on the results as the required decline is saturated thickness is reached naturally.

Limitations to this Study

The results and projections in this study are based upon a given set of data points and assumptions. As with any projection analysis there are limitations to the results based on the assumptions, data, and time frame used in the modeling process. Through the course of this study the input data and assumptions utilized were considered accurate to the best ability of the parties involved in its collection. This study was only able to make projections from an aggregated or representative level, relying heavily on average values for input data.

The quadratic production functions used to estimate crop yield in this analysis were assumed to be identical for the Ogallala and Dockum Aquifers, but due to water quality differences, this is unlikely to be true. A separate analysis would have to be performed to determine how crops react to more saline water and is not part of this project.

Maintenance costs of both irrigation systems were assumed to be the same and did not reflect any deterioration of the wells due to saline water. This analysis also assumes no blending treatments were implemented to improve water quality.

Crop production and irrigation requirements were based on average annual weather patterns for the region and this analysis did not include any projections in climate or drought predictions.

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Appendix

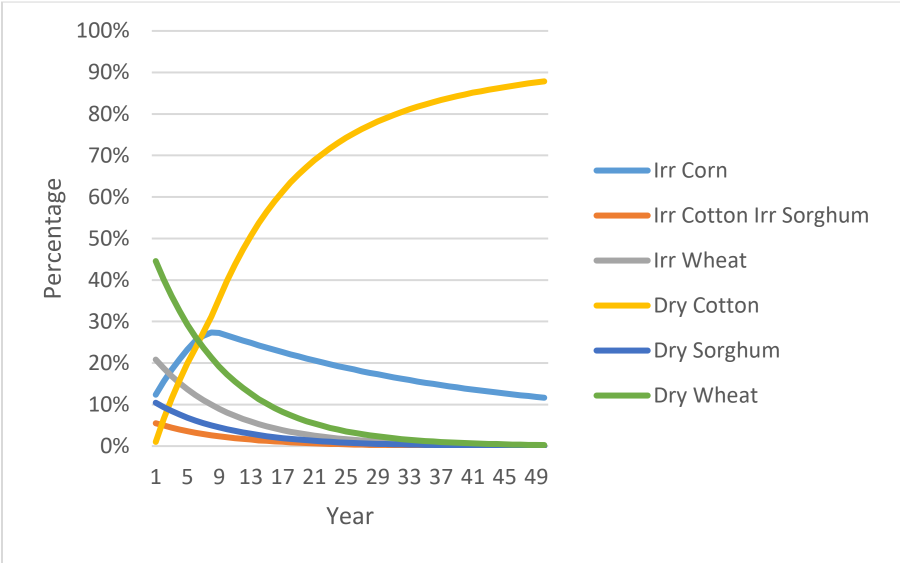

Figure 1A. Projected Crop Mix in the Baseline

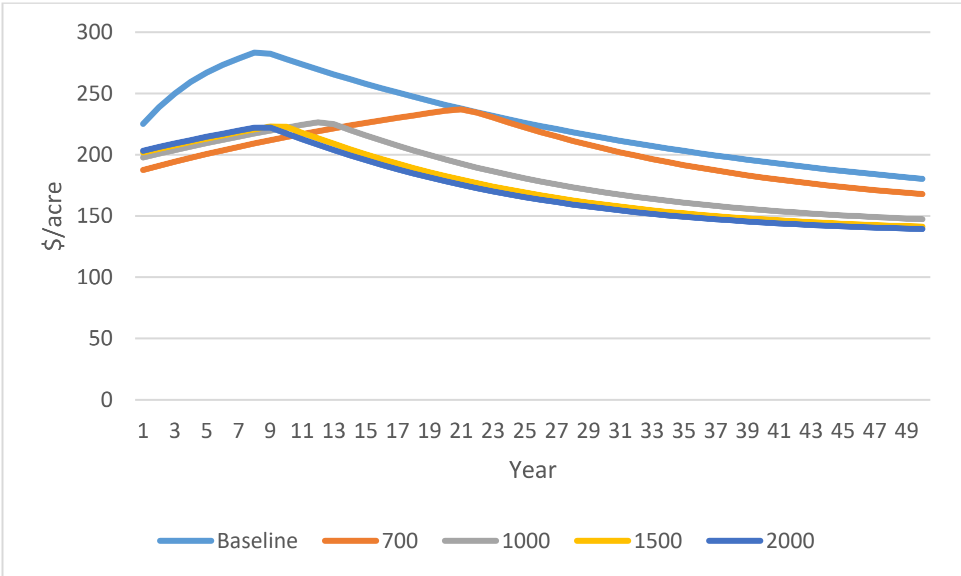

Figure 2A. Comparison of Net Returns for the Baseline and Various Dockum Blending Levels in Scenario 1

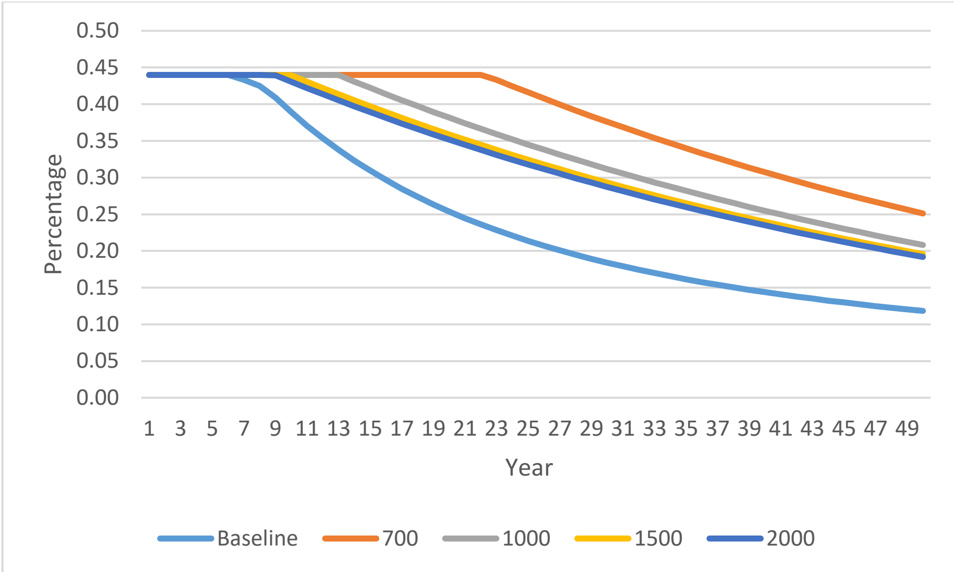

Figure 3A. Comparison of the Percentage of Irrigated Acres for the Baseline and Various Dockum Blending Levels in Scenario 1

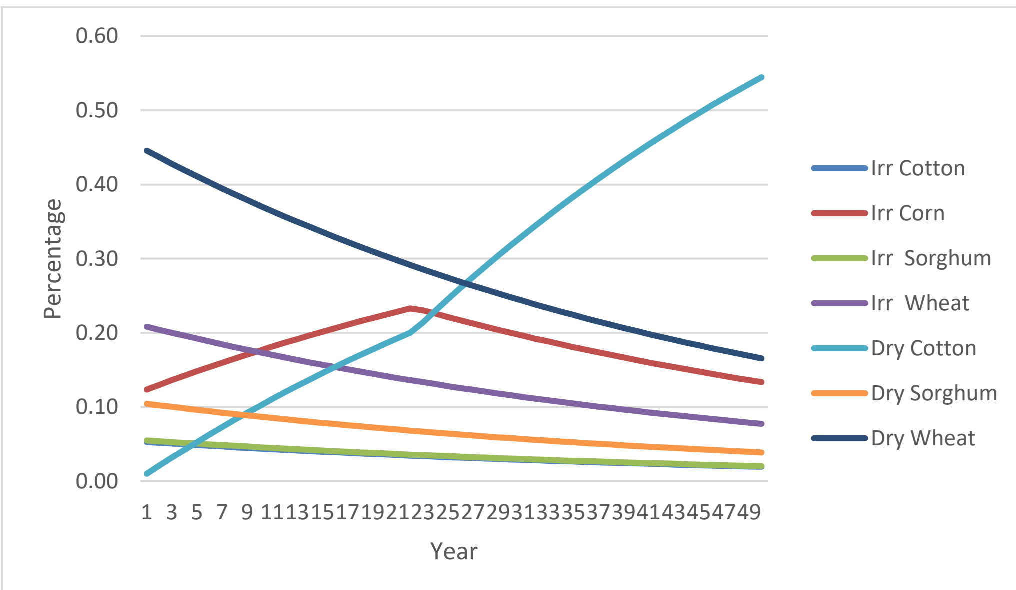

Figure 4A. Projected Crop mix with TDS of 700 ppm in Scenario 1

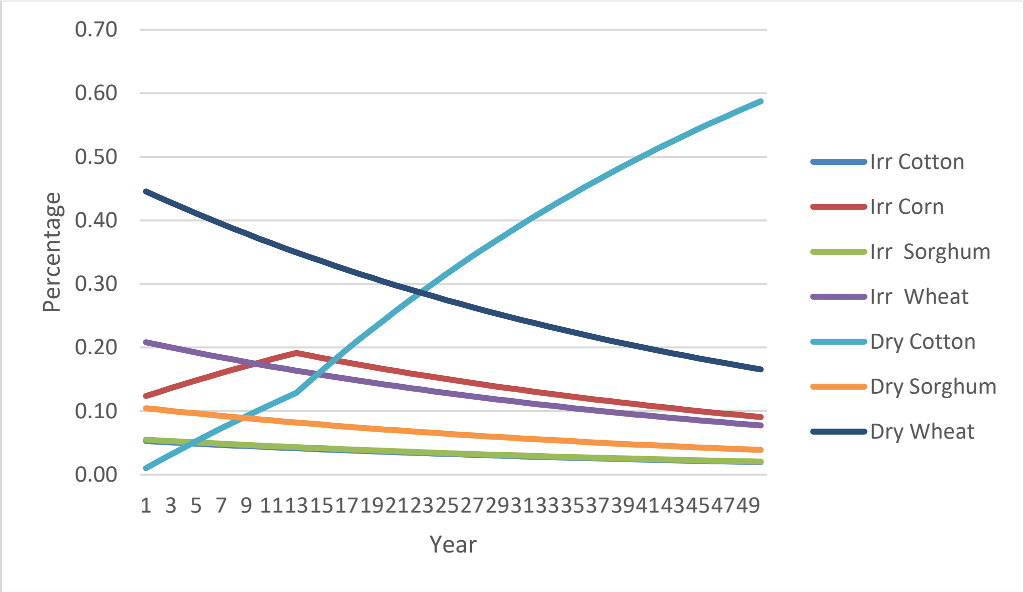

Figure 5A. Projected Crop Mix with TDS of 1,000 ppm in Scenario 1

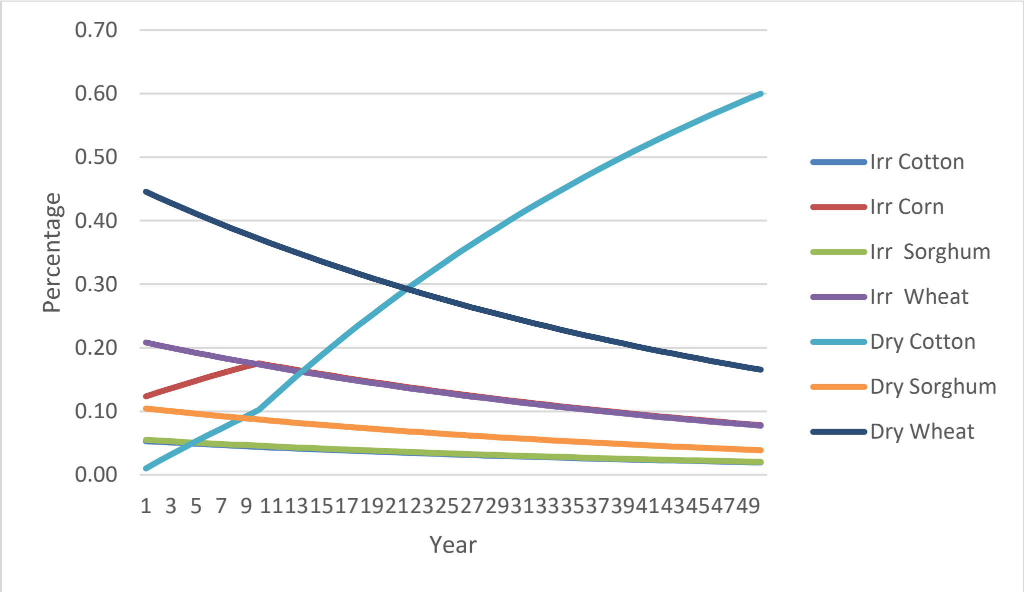

Figure 6A. Projected Crop Mix with TDS of 1,500 ppm in Scenario 1

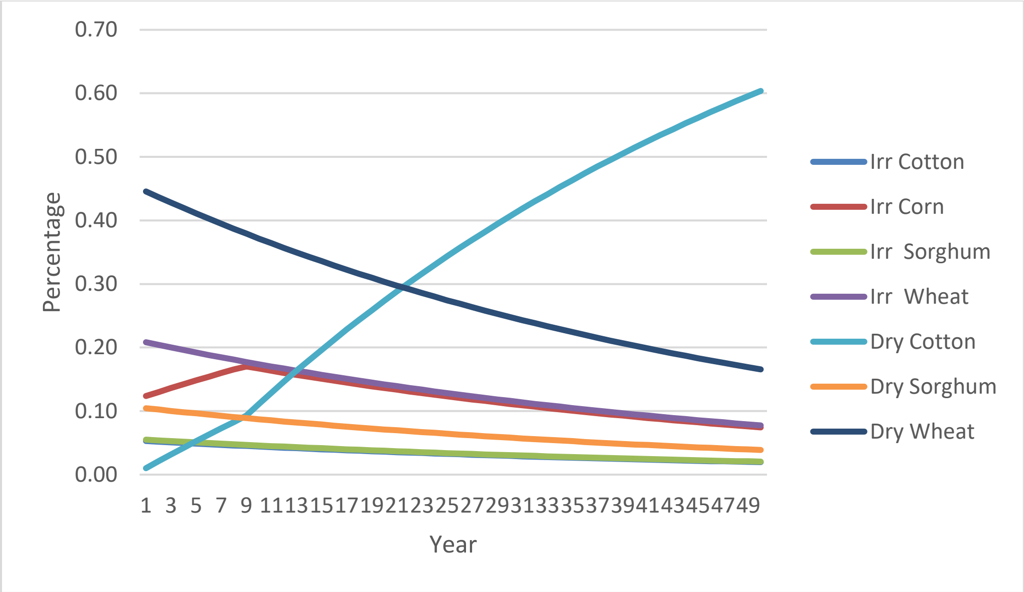

Figure 7A. Projected Crop Mix with TDS of 2,000 ppm in Scenario 1