

**The Effect of Water Use and Water Availability on Net Revenues and Optimal Cropping
Patterns on the Texas High Plains**

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Introduction

Agricultural production on the High Plains region of Texas is a part of the foundation of the region's economy. Part of the reason for this is the availability of groundwater for irrigation. The High Plains is a semi-arid region that receives little rainfall annually; therefore, farmers must rely on water from the Ogallala for use in production. The aquifer, which underlies most of the Panhandle and South Plains (see figure 1), has been the primary source for water used in agriculture since the early part of the twentieth century, but recent attempts to conserve water in the aquifer may curb its use.

To conserve water in the aquifer, the Texas Water Development Board has mandated the development of Desired Future Conditions (DFCs), or goals for the future of the aquifer, that counties in the region are required to work toward. All else equal, limiting or ceasing the use of the Ogallala will have a negative effect on regional production and the regional economy (Guerrero, Wright, Hudson, & Amosson, 2010), but the High Plains is home to other ground water resources. The Dockum Aquifer lies underneath the Ogallala in the western part of the region (see figure 2), and may be able to replace the Ogallala as a viable source for irrigation in a limited capacity. The aquifer has not seen extensive use, and the aquifer's physical characteristics, such as quality and depth, increase the average cost associated with its use over that of the Ogallala; therefore, it would not be able to replace the Ogallala perfectly. How well the Dockum works as a replacement will depend on the available technology for pumping and treating the water as well as the prevailing commodity prices.

The purpose of this paper is to begin to understand how to best use groundwater resources on the Texas High Plains when producers can pump water from two different sources. Within this problem the questions of how much water to use, what irrigation technology is available, and which crops to produce are implied. While other studies have looked at these problems in the context of the Ogallala Aquifer only (Almas, Collete, & Park, 2006; Amosson, et al, 2009; Wheeler, et al, 2006) this

study will incorporate the Dockum Aquifer. Therefore, this paper will look at how producer net revenue, water use, and cropping patterns change as the use of the Ogallala is restricted and the Dockum Aquifer is included as a resource.

Using the Dockum Aquifer for Irrigation

Pumping water from the Dockum Aquifer for irrigation will not work the same way as it does for the Ogallala. Physically, the aquifers are very different, both in terms of depth and in terms of structure. Deeper average pumping depths for the Dockum imply that the cost to pump from the aquifer will be greater than pumping from the Ogallala. At the same time, the marginal cost associated with pumping from the Dockum may be different due to differences in the structure of the aquifers. In other words, while pumping costs for the Ogallala are generally considered to increase linearly, this may not be the case for the Dockum. Finally, the Dockum holds significantly less water in storage than the Ogallala, so while it may be useful as a supplement to the Ogallala Aquifer it would not be able to fully replace the Ogallala.

Quality concerns are an issue when using the Dockum as well. Not all of the water contained in the aquifer is suitable for use in farm production, which limits the area for which the Dockum would be a viable resource. These quality issues will also affect the yield of crops irrigated using Dockum water. All else equal, the yield per acre of a crop irrigated using the Dockum would be less than that of the same crop irrigated using the Ogallala in many parts of the aquifer zone. While some of this difference could be avoided by treating the water to improve its quality, thus improving yields and widening the area where the Dockum is useful, treating the water would further increase the cost of using the aquifer, and would only be a viable option under specific conditions regarding available technology and commodity prices.

Data and Methods

As noted above, differences in the physical structure and quality of the Dockum compared to the Ogallala imply that not all of the counties in the Texas High Plains will be able to use the Dockum as a resource for groundwater under current technological and economic restraints. Under these constraints, there are currently six counties in the northern portion of the High Plains and one county in the southern portion that could use the Dockum aquifer. For use in agriculture, water needs to have less than 5000 mg/l total dissolved solids (TDS). In the High Plains region, only the counties of Dallam, Deaf Smith, Hartley, Oldham, Potter, Randall, and Swisher have a significant amount of water that meets this standard, so the study area is limited to these counties (see figure 3). For each of these counties, a representative farm was established where corn, cotton, sorghum, and wheat were grown. For corn only irrigated production was considered, while for cotton, sorghum, and wheat both dryland and irrigated production was allowed; thus, there were seven different crops considered in the study.

Information for the crops and counties came from seven primary sources. First, crop budgets published by the Texas A&M Extension Service for the years 2008 to 2010 provided information on crop prices and per acre costs. For the price and input cost data, the average over all three budgets was used. Second, to calculate per acre yield, functions were obtained from previous studies that had been performed on the High Plains and from personal communication with experts (Wheeler et al., 2006; New, 2010). NASS statistics for the years 2000 to 2009 planted acres, harvested acres, and yields for each crop in each county were used to provide realistic bounds for our calculations. Information on water storage for the Ogallala was accessed from the Texas Tech Center for Geospatial Technology website while information about Dockum was found in a Texas Water Development Board (TWDB) report (Bradley & Kalaswad, 2003). Finally, to calculate pumping costs for both aquifers, information from well level reports by the TWDB was used to find the average well depth for wells pumping from

the Ogallala and the Dockum. These depth were then input into an irrigation cost calculator developed by the University of Nebraska to determine the cost of irrigation per acre-inch of water applied.

Using the above information, a non-linear programming model using the Excel Premium Solver add-in was developed that maximizes net revenue in each county. The objective function of the model is specified as:

$$(1) \quad \text{Max} \quad NR_i = \sum_j (R_j - C_j).$$

Where: NR_i is net revenue in county i , R_j is the revenue from crop j , and C_j is the total cost to produce crop j .

Cost in the function is defined for each crop as:

$$(2) \quad C_j = a_j [c_j + \sum_{nj} (w_n x_{nj})].$$

Where: a_j is the number of acres of crop j planted in a county, c_j is the per acre specified costs for crop j according to the extension service budgets, excluding irrigation costs, w_n is the cost associated with pumping from aquifer n , and x_{nj} is the number of acre inches from aquifer n applied to crop j . In the equation, c_j is reduced to sixty percent of the amount in the extension budget for two reasons. First, the calculations do not include government supports, therefore, reducing the costs account for this. Second, the extension service budgets tend to overestimate the amount of inputs that farmers will use during production; therefore, reducing the specified cost accounts for this as well. The terms in the parentheses calculate the irrigation cost per acre. Irrigation costs are calculated separate from other costs so that the amount of water applied to each crop can be calculated in the model.

Revenue is defined as:

$$(3) \quad R_j = h_j (y_j p_j).$$

Where: h_j is the number of acres of crop j harvested in a county, y_j is the per acre yield for crop j and p_j is the unit price for crop j . Harvested acreage is itself calculated using the ratio of the mean harvested acres to the mean planted acres for each crop in each county according to NASS data. Multiplying this ratio by the number of planted acres in a county gives the number of harvested acres in the county. The yield functions for each crop are quadratic functions that relate crop yield to water use in each county. Since the yield functions come from previous studies there were some counties for which yield functions did not exist. In such a case, the functions from an adjacent county were used. It is assumed that neighboring counties would share enough of the same characteristics that the two county's yield functions would be similar. For dryland crops the mean yield for the crop is assumed to be the average yield reported by NASS.

The yield functions for the Ogallala and the Dockum are assumed to be the same in this study. Although yields for the Dockum would likely be lower due to differences in quality compared to the Ogallala, the limited amount of information concerning the Dockum makes calculating yield functions for the aquifer difficult. Because the counties in the study area have been identified as an area where the Dockum could be used under current technological and economic conditions, it is assumed that the yield associated with water from the Dockum would not be too different from the yield associated with water from the Ogallala.

The constraints of the model are as follows:

- (4) $0 \leq a_j \leq a_jmax,$
- (5) $\sum a_j \geq \sum a_jmin,$
- (6) $y_jmin \leq y_j,$
- (7) $0 \leq x_{nj} \leq 23,$ for irrigated crops, and
- (8) $x_{nj} = 0,$ for non-irrigated crops.

Equations 4 and 5 constrain the amount of acres of each individual crop planted in each county so that the amount planted does not exceed the maximum amount planted in a year according to NASS during the ten year period from 2000 to 2009, and so that the total amount of acres planted is not below the minimum total amount planted. Equation 6 constrains the yield for each crop so that it is at least equal to the minimum yield reported by NASS. Finally, equation 7 restricts the amount of water applied to each crop between zero and twenty-three acre inches for irrigated crops, and restricts the amount of water applied to non-irrigated crops to zero. In the first and second run n is always equal to one since there is only one aquifer being considered

Using this specification an initial run of the model provided a baseline estimate for net revenue, planted acres, and water use. The second run of the model restricted the amount of water that could be used a county to one percent of the total volume of water contained in the aquifer beneath the county. This amount was chosen to reflect the DFC used by most counties in the region that fifty percent of the Ogallala's current volume still be contained in the aquifer in fifty years. Thus, one more constraint was added in the second run:

$$(9) \quad \sum a_j x_{nj} \leq .01 V_i.$$

Where V_i is the total amount of water stored in the Ogallala aquifer in county i in acre inches. In the final run of the model, the Dockum Aquifer is included as a source for irrigation. The new constraints included for this run are:

$$(10) \quad a_j x_1 \leq .01 V_{1i},$$

$$(11) \quad a_j x_2 \leq .03 V_{2i},$$

$$(12) \quad 0 \leq x_{nj}, \text{ for irrigated crops,}$$

$$(13) \quad 0 = x_{nj}, \text{ for non-irrigated crops,}$$

$$(14) \quad 0 \leq \sum x_{nj} \leq 23, \text{ for irrigated crops.}$$

Equations 10 and 11 restrict the amount of water that can be pumped from the two aquifers. Equation 10 restricts the Ogallala Aquifer and replaces Equation 9 from the second run of the model, and Equation 11 restricts the use of the Dockum to three percent of its total volume in each county. Equations 12, 13, and 14 constrain the amount of water that can be applied to a crop from either aquifer, and replaces Equations 7 and 8 from the original model. Equation 12 requires that the water applied from either aquifer to an irrigated crop be either a positive amount or zero, Equation 13 restricts the amount of water applied to dryland crops to zero, and Equation 14 requires that the total amount of water applied to a crop from both aquifers be between zero and twenty three. Results from these three runs are detailed in the next section.

Results

Figure 4 is a map of the study area that shows how net revenues are affected in each county when the use of the Ogallala is restricted to one percent of its current volume. The two most affected counties were Deaf Smith County which saw a seventy-five percent reduction in net revenues, and Dallam County which saw a thirty-eight percent reduction in net revenues. The rest of the counties showed little change as a result of this restriction. These counties either did not use more than one percent of the starting volume of the aquifer or were approximately equal to this volume, so for these counties the one percent constraint on the Ogallala aquifer in the second scenario was not binding.

The effect that including the Dockum had in the model is illustrated in figure 5, which is a map of the area that shows the percent change in net revenue between the baseline and third scenario of the model. Using the Dockum mitigates the effect of restricting the Ogallala in both Dallam and Deaf Smith Counties. In Dallam County the percent change from the baseline was only nine percent compared with thirty eight percent previously, and in Deaf Smith, the percent change was twenty-one percent, as opposed to seventy-five percent in the second scenario. In the other counties, the model

shows that using the Dockum could actually have a positive effect on net revenue. These counties are either not constrained in their current use of the Ogallala or not significantly constrained, or the estimated cost of using the Dockum is not substantially different from that of using the Ogallala based on well depth. For instance, the percent change in the cost to pump in Oldham County was five percent, and in Hartley was four percent. These counties were able to add water from the Dockum to what they were already pumping from the Ogallala, or in some cases replace Ogallala water with Dockum water, and increase their yields. While this may prove to be an interesting result, it should be noted that the cost of using the Dockum is an estimate based on the current level of information on the aquifer, and that as the characteristics of the Dockum are better understood in the future this result may no longer be valid. At best it can be said that restricting the Ogallala and including the Dockum as a resource should have little to no effect on these counties.

Tables 1 and 2 reports the individual results for Dallam and Deaf Smith counties, where the Dockum had the greatest effect. In Dallam County, restricting the water that could be pumped from the Ogallala had the effect of reducing the amount of water applied per acre and reducing the amount of corn and wheat planted. Adding the Dockum increased the amount of water applied per acre approximately equal to the unconstrained amount, and increased the number of acres for both corn and wheat, although not equal to their unconstrained levels. In the third run of the model, the amount of water applied per acre of corn is about equal for the two aquifers, while the majority of the water applied to wheat and sorghum comes from the Dockum Aquifer. The total volume of water used does not increase to the unconstrained level because less corn and wheat are planted.

The results for Deaf Smith County are similar to those for Dallam County. Restricting the Ogallala reduces the total acreage and the total amount of water applied; in the case of wheat the amount of applied water almost declines to zero. While total acreage does decrease, restricting the

Ogallala actually has the effect of increasing the amount of acres of corn planted. Essentially, the model is shifting production from other crops to corn. This result is unique to this county in the model. In the other counties, there is no change in acreage or the acreage for all of the crops decreases. Adding the Dockum increases the acreage and water applied for corn and cotton to their unconstrained levels; while the acreage and amount of water applied to sorghum and wheat increase, they do not reach their unconstrained levels. In the third run, all of the water applied to corn comes from the Ogallala while the majority of the water applied to the other crops is pumped from the Dockum.

Table 3 shows the results for each run of the model aggregated across all seven counties. Net revenue, total water use, and acreage all decline when the use of the Ogallala is constrained; however, the drop in corn acreage is negligible due in part to the acreage in Deaf Smith County increasing. Adding the Dockum increases net revenue compared to the second run, but not to the unconstrained amount, so the small increases in net revenue above the baseline in some of the counties do not outweigh the decreases present in Dallam and Deaf Smith Counties. Like net revenue, acreage for each crop increases when the Dockum is considered as a resource. Irrigated cotton and non-irrigated sorghum actually increase to their unconstrained levels, while the other crops do not quite reach their unconstrained amounts. Total water used in the third run of the model actually increases above the baseline amount drawn from the Ogallala, and almost two-thirds of this amount is pumped from the Dockum. This result is due to five of the seven counties not being bound by the one percent constraint in their use of the Ogallala and relatively cheap pumping costs for the Dockum. These counties were able to keep pumping the same amount from the Ogallala in all three runs of the model and add in water from the Dockum in the final run. As was already stated, this result is only as good as the assumptions made about the Dockum for the region. More information on water quality and pumping costs are needed.

Discussion and Conclusion

Limitations on farmer's traditional resource for groundwater on the Texas High Plains necessitate the development of new resources and technology if net revenues and production are to be kept at their current levels. Farmers in parts of the area are already beginning to use the Dockum, thus it is important for researchers to begin to consider the aquifer in their study of the area. The results of this study show that by using the water found in the Dockum Aquifer, counties in the Texas High Plains area could supplement water pumped from the Ogallala, thus abating the effect that restricting the use of the Ogallala might have. How much of an effect the Dockum would have is still questionable. The model used in this study indicates that the impact of the Dockum for a county is related to how much water is being pumped from the Ogallala and whether or not this amount is limited by legal constraints on using the aquifer. In the two counties where the Dockum had the most impact, the amount of water used in the baseline run was double or triple the amount that could be accessed under a one percent constraint while water use in all the other counties was either under or right at the constraint.

Regionally, the Dockum Aquifer could be an important resource in the future. By constraining the ability of farmers to use the Ogallala, net revenue for the region is reduced by twenty-one percent. Adding the Dockum to the model reduces this effect to an eight percent change. Furthermore, adding the Dockum allows output in terms of acreage to remain relatively unchanged when the use of the Ogallala is restricted. In an area where agriculture is vital to the economic health of the region and the use of groundwater is a vital component of agricultural production, using the Dockum as a resource would provide at least some relief from restricting the area's main source of groundwater.

As is stated multiple times throughout this paper, our understanding of the Dockum Aquifer is not perfect, thus further research on this topic will be required to gain a better understanding of the

issue. Further study of the topic should include updated yield functions specifically relating yield to water from the Dockum Aquifer and more accurate estimates for the cost of pumping water from the Dockum Aquifer. Another avenue of research that would be interesting is how the use of the Dockum might change as economic conditions change. This study only looks at the effect of the aquifer where it is most likely to be used under current conditions, but the number of counties that use the aquifer and the extent of their use would depend on commodity prices and pumping costs. Understanding how the use of the Dockum might change with these conditions would be a useful policy tool in the future.

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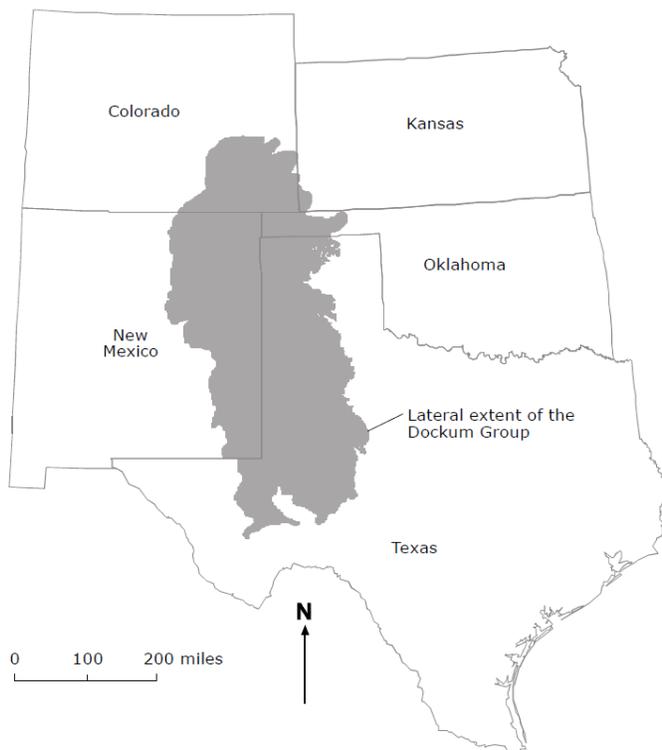
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Figure 1. The Ogallala Aquifer.



Source: HPWD 1

Figure 2. The Dockum Aquifer.



Source: Bradley & Kalaswad (2003)

Figure 3. Map of Texas with the study area highlighted.

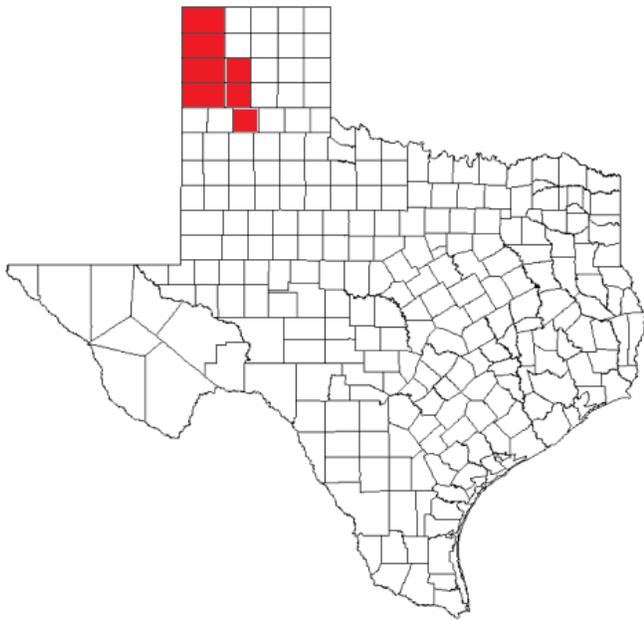


Figure 4. Percent change in net revenue when use of the Ogallala is restricted to 1% of current volume in storage.

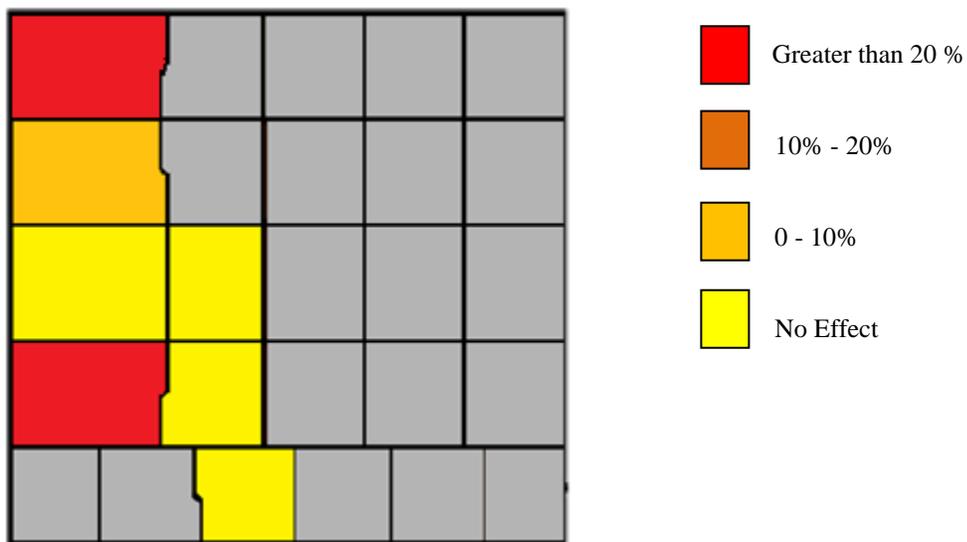


Figure 5. Percent change in net revenue when both the Ogallala and Dockum are considered as a resource and use of the Ogallala is restricted to 1% of current volume in storage.

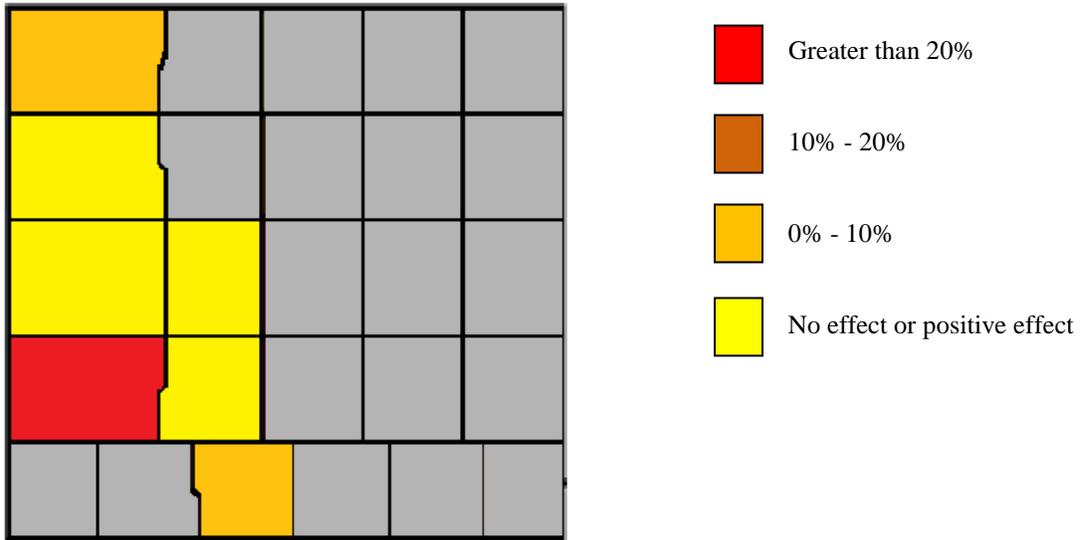


Table 1. Results for Dallam County.

Change in net revenue & water use (in acre-inches)

	Baseline	Ogallala	Ogallala & Dockum		
		Constrained	Total	Ogallala	Dockum
Net Revenue	\$72,197,467	\$44,952,096	\$65,733,455		
Water Use	4,527,166	2,262,336	4,374,933	2,012,685	2,362,248

Change in acreage for irrigated crops

	Baseline	Ogallala	Ogallala &
		Constrained	Dockum
Corn	103,509	91,288	99,847
Sorghum	12,500	12,500	12,500
Wheat	103,621	91,288	99,847

Change in amount of water applied per acre (in acre-inches)

	Baseline	Ogallala	Ogallala & Dockum		
		Constrained	Total	Ogallala	Dockum
Corn	23.00	19.74	23.00	12.80	10.20
Sorghum	23.00	7.51	23.00	5.47	17.53
Wheat	17.94	4.02	17.94	6.68	11.26

Table 2. Results for Deaf Smith County.

Change in net revenue & water use (in acre-inches)

	Baseline	Ogallala	Ogallala & Dockum		
		Constrained	Total	Ogallala	Dockum
Net Revenue	\$34,952,400	\$8,818,592	\$27,729,990		
Water Use	3,033,543	1,009,754	2,558,816	1,009,754	1,549,062

Change in acreage for irrigated crops

	Baseline	Ogallala	Ogallala &
		Constrained	Dockum
Corn	34,461	44,533	32,087
Cotton	45,200	21,214	45,200
Sorghum	25,208	18,419	21,559
Wheat	35,021	20,891	33,751

Change in amount of water applied per acre (in acre-inches)

	Baseline	Ogallala	Ogallala & Dockum		
		Constrained	Total	Ogallala	Dockum
Corn	23.00	12.34	23.00	23.00	0.00
Cotton	23.00	10.84	23.00	4.26	18.74
Sorghum	23.00	12.39	13.35	3.68	9.68
Wheat	17.75	0.09	14.62	0.00	14.62

Table 3. Changes in net revenue, water use (in acre-inches), and crop acreage aggregated across the region.

	Baseline	Ogallala	Ogallala & Dockum		
		Constrained	Total	Ogallala	Dockum
Net Revenue	\$252,791,961	\$198,875,351	\$232,650,671		
Total Water Use	11,599,108	6,929,015	12,361,603	4,619,462	7,742,141
Corn	232,470	230,322	226,932		
Dry Cotton	59,000	51,860	53,147		
Irr. Cotton	140,000	116,014	140,000		
Dry Sorghum	130,770	124,681	130,807		
Irr. Sorghum	96,208	87,015	90,576		
Dry Wheat	321,342	314,906	316,998		
Irr. Wheat	260,342	233,878	255,622		