

## **Will the Water Last? Groundwater Use Trends and Forecasts in Western Kansas**

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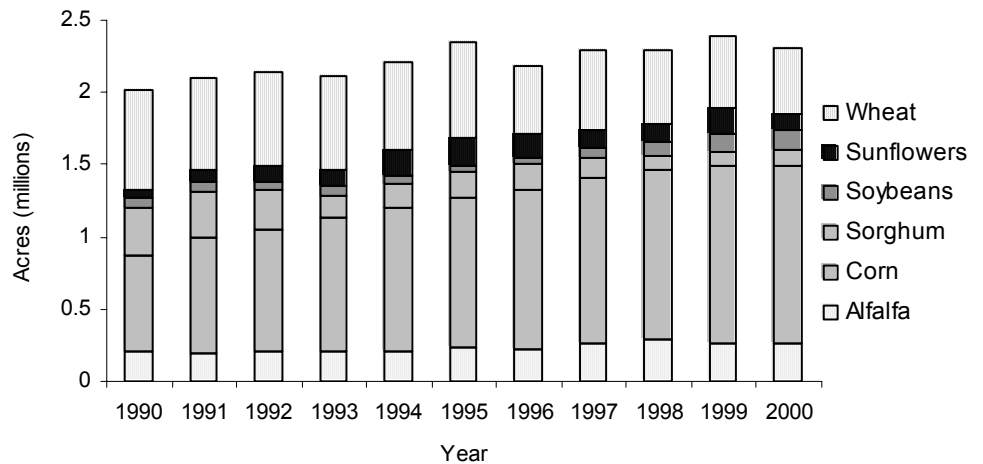
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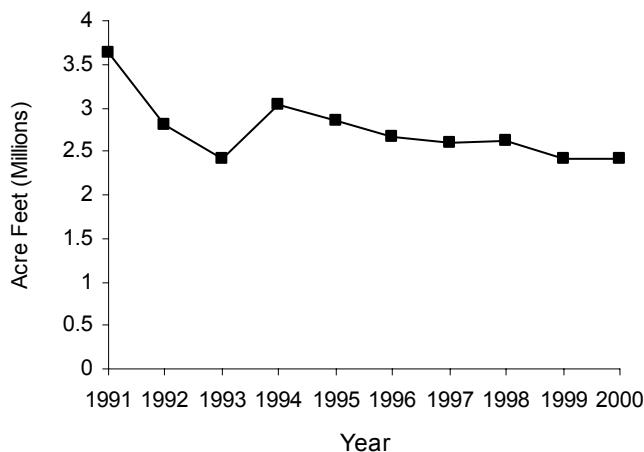
## Will the Water Last? Groundwater Use Trends and Forecasts in Western Kansas

It is often said that the economy in western Kansas “runs on water.” Irrigated crops, livestock production, and meat processing are vertically linked industries along the food supply chain and are the primary drivers of development in the regional economy. One study estimated that irrigation accounted for a \$795 million incremental boost to the Western Kansas economy in 1999 (Leatherman). All these industries are water intensive and together account for almost all water consumption in the region; irrigation alone accounts for 87% of total water use in western Kansas.

By far the largest single source of water in western Kansas is the Ogallala Aquifer. The Ogallala, which is the largest freshwater aquifer in the world, underlies approximately 33,500 square miles of 46 counties in Kansas and is present in seven other states in the Great Plains. It has been a viable irrigation source for producers in the area since the 1930s, eventually transforming 16 million acres of dry cropland and range into highly productive land. With the development of new irrigation technology in the 1950s and 60s, irrigated crop production expanded considerably. Given the limited rainfall in the Ogallala region, the withdrawals from the aquifer for irrigation soon came to exceed the natural rate of recharge. By the 1970s decline rates in excess of 2.5 feet per year had been observed.

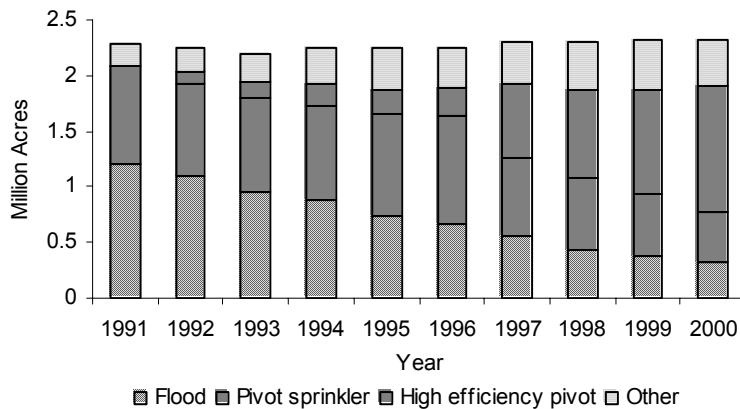


Declines in the water table continued through the 1980s and 1990s but at a slowing rate. During the same period, several dramatic shifts were observed in irrigation patterns. Three trends in particular stand out during the 1990s.



First, although irrigated acreage has remained relatively stable, a rapidly growing share of irrigated land has been planted to corn (see graph above). This is significant because corn is the most water intensive crop alternative in most areas of western Kansas. Second, despite the increase in corn acreage, total water use exhibited a declining trend (graph at left); year-to-year variations in this trend are due to differences in rainfall over time. Third, irrigators in western Kansas quickly

adopted more efficient irrigation technologies (graph below). Inefficient flood systems were used on over half of irrigated acreage in 1991 but on less than 20% of acreage in 2000; highly efficient low-pressure center pivot systems are now used on more than 1 million acres.



What are the underlying causes of these trends? How are the trends related to each other? To what extent are policies responsible for what we have observed and how might policies affect water use in the future? Are more efficient technologies overcoming the water scarcity problem? These are the central questions in an ongoing research project funded by the Kansas Water

Resources Research Institute. In this paper, we present some preliminary findings and analysis from this project. We begin by briefly describing the methods and data which are being used to address the research questions. We then focus on the results of the research and their implications for policy makers and irrigators.

### Methods and data

The research method is based on a mathematical representation, or model, of the decisions made by a typical irrigator. In particular, an irrigator’s decisions regarding water use each year can be viewed as a two stage process: the irrigator first selects which crop to grow on a parcel and then decides how much water to apply to the selected crop. Each of these decisions is influenced by several variables, including hydrologic conditions, the installed irrigation technology, policies, and the prices of crops and an energy.

The model can be expressed mathematically as follows:

$$\text{Probability of planting crop } x = f(\text{hydrology, technology, prices, weather})$$

$$\text{Water use on crop } x = f(\text{hydrology, technology, prices, weather})$$

That is, there are two types of equations in the model for each crop, one representing the likelihood that a crop is planted, and the other representing water use on that crop.

These equations were estimated using regression analysis of water-use report data for Sheridan County during the period 1991-2000. All irrigators in Kansas are required to report their water use on each point of diversion to the Division of Water Resources annually, together with the crop grown and type of irrigation system. This dataset was augmented with other information to complete the data requirements for the model. Hydrologic conditions (depth to water, saturated thickness, hydraulic conductivity) and weather data were obtained from the Kansas Geological

Survey. Prices of crops, energy, and other crop inputs were obtained from the USDA and the Bureau of Labor Statistics. The specific variables included in the final dataset are described in the table below; summary statistics are reported by crop in the appendix.

## Data Description

Variable	Description	Units
Hydrologic variables		
<i>DTW</i>	Depth to groundwater	Feet
<i>ST</i>	Aquifer saturated thickness	Feet
<i>HYDRACOND</i>	Hydraulic conductivity	Feet/day
<i>MAXGPM</i>	Maximum well capacity given hydrologic conditions	Gallons per minute
Technology and resource variables		
<i>METER</i>	Binary variable for metered well	(1=yes, 0=no)
<i>FLOOD</i>	Binary variable for flood system	(1=yes, 0=no)
<i>HPIVOT</i>	Binary variable for high-pressure center pivot system	(1=yes, 0=no)
<i>LPIVOT</i>	Binary variable for low-pressure center pivot system	(1=yes, 0=no)
<i>OTHER</i>	Binary variable for other system type	(1=yes, 0=no)
<i>SPRINKLER</i>	Binary variable for fixed sprinkler system	(1=yes, 0=no)
<i>ACRES_IRR</i>	Acres irrigated	Acres
<i>LAGCORN</i>	Binary variable for previous year corn	(1=yes, 0=no)
Price and policy variables		
<i>NUMYEAR</i>	Year (trend variable)	(1991=1, ... , 2000=10)
<i>EINDEX</i>	Index of energy prices	
<i>EPALF</i>	Expected alfalfa price	\$/ton
<i>EPCORN</i>	Expected corn price	\$/bushel
<i>EPMILO</i>	Expected grain sorghum price	\$/bushel
<i>EPSOY</i>	Expected soybean price	\$/bushel
<i>EPWHEAT</i>	Expected wheat price	\$/bushel
<i>PRICEINDEX</i>	Index of Prices Paid by producers	
<i>FAIR</i>	Binary variable for 1996 Farm Bill policies	(1=yes, 0=no)
Weather variables		
<i>RAIN_1</i>	Previous October-December rainfall	Inches
<i>RAIN_2</i>	January-March rainfall	Inches
<i>RAIN_3</i>	May-August rainfall	Inches
<i>WINRAIN</i>	Previous October-March rainfall ( <i>RAIN_1</i> + <i>RAIN_2</i> )	Inches
<i>TOTALET</i>	Growing season evapotranspiration	Inches

## Results

### *Crop choice equations*

In the present research, we concentrate on the five most commonly irrigated crops in western Kansas: alfalfa, corn, grain sorghum, soybean and wheat. These crops account for over 97

percent of irrigated acreage. The model is actually estimated for 6 categories of crops, because we include an ‘other’ category that represents all other crops besides the five major ones.

The crop choice equations were estimated using a multinomial logistic regression procedure, and the results of this estimation are summarized in the table below (complete statistical results can be obtained from the authors upon request). The values in this table are the marginal effects of different variables on the probability of a given crop being planted, or the change in probability resulting from independent one-unit changes. For instance, the value  $-0.00018$  in the upper-left cell means that a one-foot increase in depth to water will decrease the probability of planting alfalfa by 0.00018; if originally alfalfa was grown with probability 0.105 (i.e., 10.5%) then a one foot increase in depth to water will change the probability to 0.1048 (10.48%). This is of course a very small change, but a one-foot change in depth to water is a slight change as well. A 10-foot increase in depth to water would decrease the probability by about 0.2% and a 100-foot increase would reduce it by about 2%. This suggests that alfalfa is slightly more likely to be found growing in ‘shallower’ portions of the aquifer.

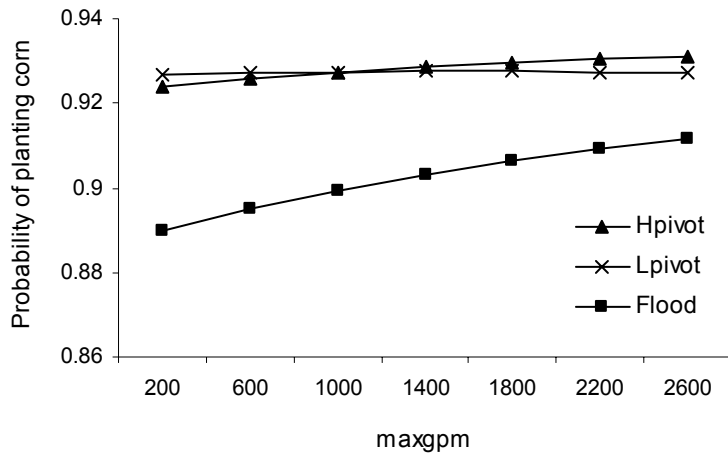
### Marginal effects on crop choice probabilities

Variable	Alfalfa	Corn	Sorghum	Soybeans	Wheat	Other
<i>DTW</i>	-0.00018	0.00028	-0.00011	0.000038	-0.000048	0.000024
<i>MAXGPM</i>	-0.0000004	0.0000078	-0.0000062	0.0000029	0.0000007	-0.0000048
<i>EPALF</i>	-0.000013	-0.0061	0.0022	0.0047	-0.00018	-0.00055
<i>EPCORN</i>	0.033	0.32	-0.20	-0.13	0.025	-0.053
<i>EPMILO</i>	-0.023	-0.10	0.13	0.074	-0.014	-0.068
<i>EPSOY</i>	-0.0014	0.038	-0.0048	-0.050	0.0081	0.011
<i>EPWHEAT</i>	0.0099	-0.20	-0.021	0.020	-0.0055	0.20
<i>EINDEX</i>	-0.014	-0.35	-0.013	0.037	-0.023	0.37
<i>PRICEINDEX</i>	-0.000092	0.017	-0.0021	-0.0046	0.00050	-0.011
<i>WINRAIN</i>	-0.00076	0.0080	-0.00072	-0.0076	0.0013	-0.00014
<i>FLOOD</i>	-0.0084	0.12	0.016	0.0093	-0.0077	-0.12
<i>HPIVOT</i>	-0.0015	0.16	-0.0014	0.0099	-0.0026	-0.17
<i>LPIVOT</i>	-0.0075	0.16	-0.020	0.015	-0.0046	-0.143
<i>LAG_CORN</i>	-0.021	0.57	-0.040	0.0028	-0.020	-0.50
<i>FAIR</i>	0.0094	-0.19	-0.021	0.012	-0.0074	0.20

Since corn is the dominant crop in western Kansas, accounting for more than half of the data points, the change of probability of growing corn would affect the whole cropping pattern. Corn is also the most water intensive crop and therefore has the largest impact on overall water use. Therefore, we will focus the discussion on the results pertaining to corn.

Observing the table of marginal effects, we can find out how the probability of choosing corn changes by the changes of different variables. As well capacity (*MAXGPM*) increases by 1 unit, the probability of choosing corn increases by 0.0000078. Corn is much more likely to be grown in years when the expected corn price is high (a change of 0.32 for each \$1 increase in *EPCORN*). As the price of energy (*EINDEX*) increases by \$1, the probability of choosing corn decreases by 0.35. The negative response to energy prices most likely occurs because corn is water intensive and consumes more energy for pumping compared to other crops. In years of

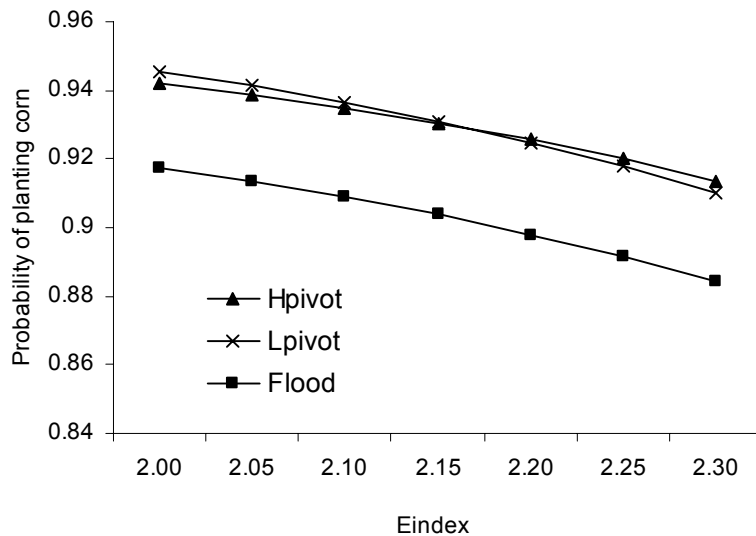
high energy prices, corn becomes less profitable relative to less water intensive alternatives. Interestingly, the 1996 Farm Act policies appeared to decrease the probability of selecting corn, all else held constant (the marginal effect of the *FAIR* variable was -0.19). This suggests that increased corn acreage in the late 1990s was due to changes in market conditions rather than policy changes *per se*.



A clearer way to examine the marginal effects for corn is to calculate the probability of choosing corn over a range of a variable. In the figure to the left, we depict how the probability of choosing corn changes by the well capacity (*MAXGPM*) under different irrigation systems. The graph shows that as the well capacity increases, the probability of choosing corn also increases. However the effects of well capacity are not the same

under different irrigation technologies. Farmers using high-pressure or low-pressure center pivot systems are more likely to choose corn than those with flood systems. This illustrates the possibility that improvements in technology may not reduce water use in the long run, because they may result in irrigators switching to more water intensive crops.

The figure to the right examines the relationship between the price of energy and the probability of choosing corn under different irrigation technologies. As expected, the probability of choosing corn decreases as the price of energy increases, since corn is the water intensive crop. Again farmers using flood systems generally have the lower probability of growing corn.



Both these graphs reveal the differences and similarities among irrigation systems. Interestingly, the two types of pivot systems appear to have nearly identical impacts on corn planting decisions, while they both differ significantly from the flood systems. Switching from a high-pressure to a low-pressure system would have almost no effect

on corn planting decisions, while switching from flood to either type of pivot would have a more substantial impact.

Another issue of interest about the crop selection equations is their prediction accuracy. The table below compares the actual and predicted crop choices. The rows in this table correspond to actual choices, while the columns correspond to predicted choices. For example, the first column accounts for all the data points which were predicted to be in alfalfa. There are a total of 182 such points; 40 of them were actually planted to alfalfa, 40 were in corn, 11 were in grain sorghum, 1 was in soybeans, and 84 were in other crops. The first row is an accounting of the data points which were actually planted to alfalfa. Of these 182 observations, the model predicted that 40 of them would be planted to alfalfa, 46 would be planted to corn, 13 to grain sorghum, 1 to soybeans, 6 to wheat, and 76 to other crops. The numbers on the ‘diagonal’ of this table reflect correct predictions. The sum of diagonal numbers is 3,742; dividing this figure by the total number of observations (6,035) reveals an overall prediction accuracy of 62%.

### **Cross tabulation of actual and predicted crop choices**

Actual	Predicted						Total
	Alfalfa	Corn	Sorghum	Soybean	Wheat	Other	
Alfalfa	40	46	13	1	6	76	182
Corn	40	2894	73	59	28	674	3768
Sorghum	11	74	28	2	6	106	227
Soybean	1	59	2	2	1	18	83
Wheat	6	27	6	1	3	42	84
Other	84	668	105	18	41	775	1691
Total	182	3768	227	83	85	1691	6035

### *Water use equations*

The estimation results for the water use equations are summarized in the table on the next page. This table reports the estimated elasticities of water use with respect to different variables; an elasticity value reflects the percentage change in water use in response to a 1% change of an independent variable, holding all else constant. (So, for instance, a 1% increase in *ACRES\_IRR* will increase alfalfa water use by 0.729%).

As one would expect, water use responds positively to changes in the expected output prices. A 1% increase in expected alfalfa prices, for example, increases water use on alfalfa acreage by 1.094%. Corn water use responds similarly; a 1 % increase in the expected corn price would increase corn water use by 1.045%. Water use on grain sorghum appears to be the most price sensitive among all crops, with an an elasticity of 1.479; the small elasticities for soybeans and wheat indicate that water use on those crops is not very price-sensitive.

Also consistent with expectations, water use is inversely related to changes in rainfall (*RAIN\_1*, *RAIN\_2*, *RAIN\_3*). In nearly all cases the elasticities on the rainfall variables are negative numbers, indicating that an increase in rainfall either before or during the growing season will reduce use. Evapotranspiration (*TOTALET*) has a positive elasticity in all equations, indicating

that water use increases with high temperature, low humidity growing conditions. Interestingly, the rainfall elasticities are all less than one in absolute value. This suggests that rainfall and irrigation water are not perfect (i.e., one-to-one) substitutes; a 1% increase in rainfall will reduce irrigation by less than 1%, all else held constant.

### Estimated elasticities of water use

Variable	Alfalfa	Corn	Sorghum	Soybeans	Wheat
<i>NUMYEAR</i>	0.451	0.296	0.383	0.141	-0.010
<i>ACRES_IRR</i>	0.729	0.817	0.889	0.787	0.927
<i>EPALF</i>	1.094	---	---	---	---
<i>EPCORN</i>	---	1.045	---	---	---
<i>EPMILO</i>	---	---	1.479	---	---
<i>EPSOY</i>	---	---	---	0.056	---
<i>EPWHEAT</i>	---	---	---	---	0.122
<i>ST</i>	0.074	0.094	0.127	0.010	0.083
<i>HYDRACOND</i>	-0.0224	0.002	0.049	-0.009	-0.133
<i>RAIN 1</i>	-0.128	-0.059	-0.102	-0.002	-0.019
<i>RAIN 2</i>	-0.077	-0.022	0.010	-0.015	-0.120
<i>RAIN 3</i>	-0.230	-0.249	-0.259	-0.379	-0.196
<i>TOTALET</i>	0.256	0.365	0.508	0.287	0.067
<i>METER</i>	-0.055	-0.075	-0.097	-0.014	-0.108
<i>PRICEINDEX</i>	-4.962	-2.995	-10.192	-0.902	-0.981
<i>HPIVOT</i>	0.043	0.847	1.175	0.634	-0.026
<i>LPIVOT</i>	0.110	1.026	0.452	-0.872	1.634
<i>OTHER</i>	-1.078	-0.014	-2.942	-0.737	-4.709
<i>SPRINKLER</i>	0.323	0.067	1.218	-5.401	-1.895
<i>DTW<sup>a</sup></i>					
<i>FLOOD</i>	0.060	0.249	0.174	0.093	0.131
<i>HPIVOT</i>	0.070	0.204	0.148	0.045	0.057
<i>LPIVOT</i>	0.046	0.222	0.149	0.071	0.095
<i>OTHER</i>	0.061	0.249	0.174	0.094	0.128
<i>SPRINKLER</i>	0.056	0.248	0.171	0.091	0.130
<i>EINDEX<sup>a</sup></i>					
<i>FLOOD</i>	-0.821	-2.502	-2.677	0.202	0.906
<i>HPIVOT</i>	-0.805	-2.729	-2.949	-0.062	0.947
<i>LPIVOT</i>	-0.807	-2.688	-2.680	0.496	0.692
<i>OTHER</i>	-0.811	-2.505	-2.651	0.213	0.980
<i>SPRINKLER</i>	-0.825	-2.503	-2.684	0.227	0.926

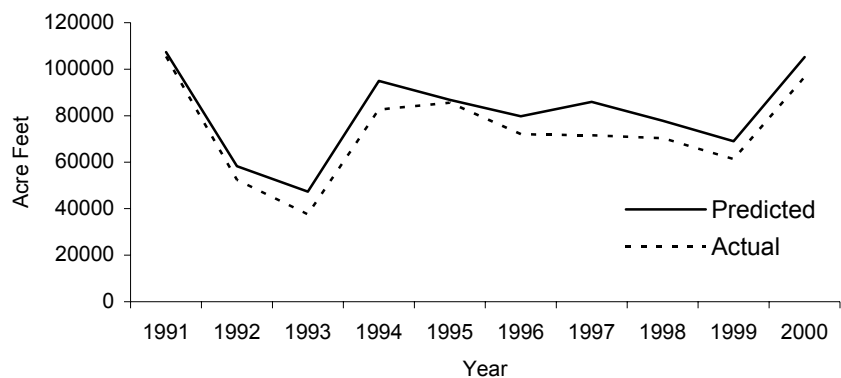
<sup>a</sup> Because of the interaction terms in the estimated equations, the elasticities for depth to water (*DTW*) and energy index depend (*EINDEX*) on the irrigation system.

Another interesting result is that the elasticities for the *METER* variable are negative for all crops. All else held constant, irrigators with metered wells report less water use. Assuming that meters are accurate, this finding suggests that irrigators with unmetered wells tend to over-report their water consumption.

The elasticities for the irrigation system variables (*HPIVOT* and *LPIVOT*) are generally positive numbers. Because flood irrigation was treated as the ‘base’ group of data points in the estimation procedure, these results imply that irrigators with center pivot systems generally apply more water than those with flood systems. This may seem a paradoxical result given that center pivot systems are more efficient—they can deliver the same amount of water to the crop as flood systems by applying less to the field. Nevertheless, similar results have been documented elsewhere. The economic logic is that improvements in irrigation efficiency reduce the effective cost of delivering water to the crop.

### Evaluating past water use trends

The equations discussed above allow us to compute predicted crop selections and crop water use for each point of diversion (POD) in the dataset. To accomplish this, the actual data on each POD was first inserted in the crop choice equations to determine which crop was most likely to be planted. After this was determined, the data was then inserted in the appropriate water use equation (e.g., the corn equation if corn was predicted to be selected), to obtain a predicted water use for that POD. Adding these predictions across PODs gives us predicted total water use for Sheridan County, which can then be compared to observed total water use to assess the overall prediction accuracy of the model. Predicted versus actual total water use is shown in the graph to the right; the overall prediction error of the model is 10.4%.

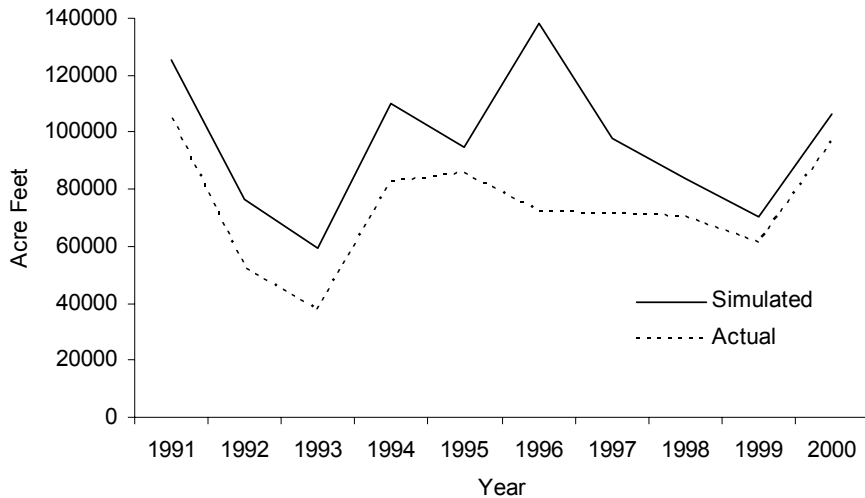


Aside from ‘reproducing’ the observed pattern, we can also use the model to gain insights about the relative contribution of different factors to total water use. The estimation results above illustrate that a given factor may influence water use in several different ways. Changes in prices, technology, or hydrologic conditions affect which crops are grown as well as how much water is applied to those crops. Often, the net effect of a change in some variable on water use cannot be easily determined by examining the estimation results alone. For example, if the expected price of grain sorghum increases, more irrigators will be likely to plant grain sorghum instead of corn, but on the other hand, all grain sorghum growers will use more water per acre. The overall effect on water use depends on which of these effects is stronger.

To assess the net impacts of different variables, we can perform ‘counter-factual’ simulations. That is, we compute predictions for crop selections and crop water use, after replacing the actual

values of certain variables with hypothetical values. This procedure allows us to shed light on questions of the form, “What would have happened if...”

Several of these simulations are underway and their final results will be available from the authors. Preliminary results for one simulation are illustrated below. The simulated water use in



this graph represents the effect of higher commodity prices; all expected crop prices were increased from their actual values by 20%. Not surprisingly, higher commodity prices would have increased water use for all years. Over the ten year period, the price change would have led to about a 31% increase in water use. This suggests that the observed declining trend

in water use over the past decade was at least partly due to the depressed commodity prices during that time period.

## Conclusions

Several dramatic shifts in irrigation patterns were observed during the 1990s. Preliminary results from research on irrigation data in Sheridan County suggest that these patterns can be attributed to a variety of interacting factors. Depressed commodity prices appear to be partly responsible for the relatively steady decline in water use, although irrigators also benefited from relatively low energy prices during most of the decade.

We found no evidence that the 1996 Farm Act was the primary cause of the rapid increase in corn acreage in the mid to late 1990s. Instead, the adoption of more efficient irrigation technology may be partly responsible for this change. In many cases, new delivery systems are capable of meeting the water demands for corn where flood systems were not. We also found that efficient irrigation systems lead to more intensive water use on virtually all crops. Evidently irrigators respond to the reduction in the effective cost of water delivery from more efficient systems.

As part of the ongoing research project, additional and more refined data on soils and climatic variables will be incorporated in the model. The method will also be extended to additional locations to isolate geographic differences in water use trends. Ultimately, the model will be linked to a hydrologic model which will allow water use and hydrologic trends to be forecasted for future periods.

**Appendix: Summary statistics of regression data**

Variable	Data Means (Standard Deviation)				
	Alfalfa	Corn	Sorghum	Soybeans	Wheat
<i>AF_USED</i>	220.93 (114.92)	185.47 (115.51)	103.23 (95.04)	139.47 (87.45)	110.61 (99.04)
<i>NUMYEAR</i>	5.24 (3.15)	5.68 (3.06)	3.57 (2.79)	5.96 (3.59)	4.10 (3.12)
<i>ACRES_IRR</i>	131.21 (50.86)	133.32 (65.09)	102.79 (62.42)	121.19 (59.07)	131.43 (61.78)
<i>EPALF</i>	46.56 (5.85)	---	---	---	---
<i>EPCORN</i>	---	1.76 (0.42)	---	---	---
<i>EPMILO</i>	---	---	3.00 (0.55)	---	---
<i>EPSOY</i>	---	---	---	3.96 (0.66)	---
<i>EPWHEAT</i>	---	---	---	---	2.08 (0.54)
<i>DTW</i>	117.97 (65.85)	143.44 (58.58)	124.62 (55.08)	132.50 (57.95)	132.54 (60.45)
<i>ST</i>	204.78 (96.36)	153.29 (102.84)	102.95 (88.23)	142.71 (94.73)	172.74 (106.31)
<i>HYDRACOND</i>	84.13 (23.20)	80.61 (24.27)	79.36 (25.76)	82.93 (23.83)	78.81 (25.87)
<i>EINDEX</i>	2.19 (0.12)	2.19 (0.11)	2.24 (0.11)	2.18 (0.13)	2.23 (0.12)
<i>RAIN_1</i>	2.06 (1.21)	1.91 (1.30)	2.04 (1.19)	1.91 (1.35)	1.99 (1.19)
<i>RAIN_2</i>	7.37 (2.64)	6.71 (2.59)	6.46 (2.84)	6.80 (2.61)	7.12 (2.94)
<i>RAIN_3</i>	9.51 (6.97)	10.09 (6.12)	8.99 (5.27)	8.82 (4.82)	8.81 (5.82)
<i>TOTALET</i>	36.46 (5.46)	39.13 (5.74)	32.39 (5.02)	35.44 (5.35)	48.02 (9.94)
<i>METER</i>	0.55 (0.50)	0.44 (0.50)	0.25 (0.43)	0.42 (0.49)	0.35 (0.48)
<i>PRICEINDEX</i>	108.86 (6.43)	109.80 (6.28)	105.81 (6.33)	109.31 (6.47)	106.71 (6.46)
<i>HPIVOT</i>	0.60 (0.49)	0.42 (0.49)	0.30 (0.46)	0.41 (0.49)	0.49 (0.50)
<i>LPIVOT</i>	0.22 (0.42)	0.28 (0.45)	0.06 (0.25)	0.32 (0.47)	0.17 (0.38)
<i>OTHER</i>	0.01 (0.10)	0.03 (0.18)	0.01 (0.11)	0.01 (0.12)	0.02 (0.13)
<i>SPRINKLER</i>	0.03 (0.17)	0.01 (0.07)	0.01 (0.09)	0.01 (0.06)	0.01 (0.11)
Observations	10,352	45,444	4,251	1,699	6,185