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# Commodity Prices, Climate and the High Plains Aquifer

Richard K. Perrin

Lilyan E. Fulginiti

Felipe Silva

Karina Schoengold

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# Cornhusker Economics

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Crop prices and energy prices can affect the water level in an aquifer? Absolutely, yes, because over time, they affect the amount withdrawn for irrigation. Our recent research confirms that effect and provides estimates of the size of the effect on the High Plains Aquifer (HPA). The HPA underlies parts of eight states and 208 counties in the west-central United States (see Figure 1). This region produces more than 9% of US crop sales and relies on the aquifer for irrigation. These withdrawals for irrigation have contributed to a diminished stock of water in the aquifer that varies considerably across counties, as indicated in the figure. Our research examined the relative contributions of prices and weather on HPA groundwater levels (Silva, et al, 2019). Since that article was published, petroleum price has increased by about 90% and the average of corn, soybean and wheat prices have increased by about 80%. Here we report how those price changes and climate change could be expected to affect groundwater levels in the HPA over the next decades.

***What we learned***

<u>Prices</u>

Our results indicate that on average across the region, a 90% increase in energy price alone over a decade or so would decrease the irrigation withdrawal rate by 0.34 ft per year and reduce the fraction of area irrigated slightly, which in turn would imply a reduction in the rate of water decline by 0.37 ft per year. This is a reduction of about 75% of the 1985-2005 average rate of decline of 0.49 ft per year. On the other hand, an 80% increase in crop price alone would increase average irrigation withdrawals by about 0.31 ft per year, which would increase the rate of water decline by about 0.23 ft per year (an increase of about 50% in the rate of decline). Note that these results reflect decisions farmers made over the 1985-2005 period, while future responses may be smaller because they will probably be more restricted by regulatory constraints.

As it happens then, increases of both energy and crop prices of these magnitudes over the next two decades would substantially offset one another (0.37 ft less decline per year due to higher energy prices, vs 0.23 ft more decline per year due to higher crop prices). Thus, if both current price levels were to persist into the future, the effect would be a slight reduction in the rate of decline of water levels in the HPA.

We have no consensus on price trends of crops versus energy over the next two decades. It seems likely to some of us that the higher energy price will persist into the future because of the pressures of climate change politics on limiting fossil fuel extraction. It also seems likely to some of us that the pressures of population and income growth will keep grain prices higher into the future, despite the robust short-term output response to higher prices that grain producers around the world have shown in the past. Hence, we don't have any clear conclusion about the effect prices will have on the rate of change in HPA levels by mid-century.

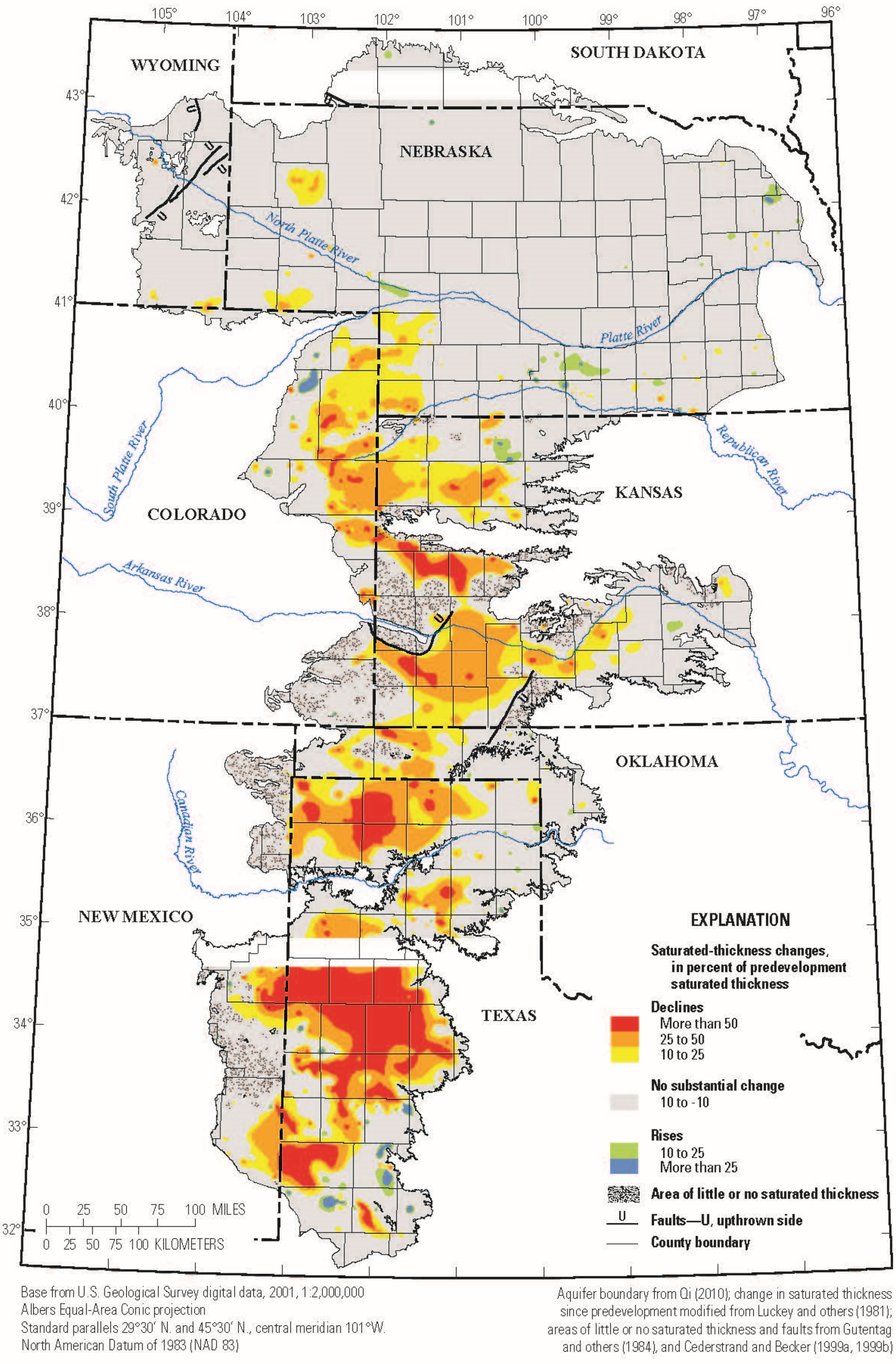


Figure 1. Change in saturated thickness of the High Plains aquifer, predevelopment (about 1950) to 2015. {From McGuire (2017)}

Climate change

We estimate that on average, across the HPA counties during 1985-2005, irrigation decreased groundwater levels by 1.24 feet per year, while rainfall recharged the level by 0.76 feet per year. These estimates varied considerably by county, with estimated changes ranging from -0.24 to +0.60 feet per year. These effects include simple hydrological relationships and farmers' irrigation responses to those relationships.

Our results imply that an extra inch of precipitation across a county will on average reduce groundwater depletion by 0.041 feet per year, while an extra 24 hours of temperatures above 36°C would lead to an additional 0.056 feet of depletion per year.

Climate change projections for northern Great Plains (Shafer, 2014; Kunkel, 2013) suggest an increase of about 50% in the number of hot days and a decrease of about 25% in precipitation. Given the results of our research, changes of these magnitudes would increase water application rates by 0.034 feet per year and increase the fraction of land irrigated by 0.5%. These human responses, along with the hydrological changes, would result in an increase in the rate of groundwater decline by 0.22 feet per year, from the current average rate of about 0.47 feet per year to about 0.69 feet per year.

***How did we learn this?***

We combined several relationships to identify what causes changes in the average county-wide aquifer level, then used past observations to estimate them empirically.

First is a simple hydrological relationship that relates change in aquifer level to rainfall, quantity of irrigation water withdrawn per acre irrigated, and fraction of area irrigated.

(1)

$$\delta = f(x_1, z_1, z_2)$$

Where δ is the volume of water withdrawn per acre irrigated, $x_1$ is the quantity of water applied per acre irrigated in the county, $z_1$ is fraction of the surface irrigated, and $z_2$ is county precipitation.

Second are two components of demand for irrigation water as functions of the price of energy for pumping and the price of crops, $\boldsymbol{x}=g(\boldsymbol{p},\boldsymbol{z})$. One is a short-run demand given that the fraction of irrigated acres is fixed at $z_1^*$, and the second is a long-run demand that also considers changes in number of acres irrigated, $z=h(\boldsymbol{p},\boldsymbol{z})$.

(2)

$$dx_1(\boldsymbol{p},\boldsymbol{z}) = g_p(\boldsymbol{p},\boldsymbol{z}*)d\boldsymbol{p} + g_z(\boldsymbol{p},\boldsymbol{z})d\boldsymbol{z}$$

$$dz_1(\boldsymbol{p},\boldsymbol{z}) = h_p(\boldsymbol{p},\boldsymbol{z})d\boldsymbol{p} + h_z(\boldsymbol{p},\boldsymbol{z})d\boldsymbol{z}$$

where bolded variables are vectors of more than one element and subscripts on *g(.)* and *h* (.) indicate derivatives.

Combining equation (2) with equation (1), we are able to predict the change in groundwater level with a single equation containing parameters from both, yielding an equation somewhat as follows:

(3)

$$d\delta = \left[f_{x1} g_p(\boldsymbol{p},\boldsymbol{z}*) + f_z(\boldsymbol{p},\boldsymbol{z}) h_p(\boldsymbol{p},\boldsymbol{z})\right] d\boldsymbol{p} + f_{x1}\, g_z(\boldsymbol{p},\boldsymbol{z}*) d\boldsymbol{z}.$$

We specified algebraic functions for *f*(.), *g*(.) and *h*(.), then estimated the coefficients of those functions by regressing observed values of the aquifer level change at the county level on observed values of ***p*** and ***z***. The estimated functions then allow us to predict changes in aquifer level due to changes in prices, **p**, and weather variables, ***z***.

***What data did we use to estimate these relationships?***

We used county-level variables for 183 counties over the HPA for 1985, 1990, 1995, 2000 and 2005, giving us 915 observations. County-level crop, fertilizer and chemicals prices were obtained from an earlier study by Garcia Suarez, et al

(2019). Water price was estimated based on a relationship given by Mieno and Brozović (2016) between dynamic cost of lifting and the fractions of fuel types, their prices and the county average well depth-to-water. The county average well depth-to-water was derived from well depth reports on the USGS NWIS database (United States Geological Survey, 2017). Finally, we obtained county-level fraction of surface area irrigated and water applied per acre irrigated based on data reported by Maupin et al. (2014).

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Richard K. Perrin
Jim Roberts Professor
Department of Agricultural Economics
University of Nebraska-Lincoln
rperrin@unl.edu
Phone: (402) 472-9818

Lilyan E. Fulginiti
Roy Frederick Professor
Department of Agricultural Economics
University of Nebraska-Lincoln
lfulginiti@unl.edu
Phone: (402) 472-0651

Felipe Silva
Assistant Professor
Department of Agricultural Sciences
Clemson University
fdsilva@clemson.edu
864-656-5764

Karina Schoengold
Associate Professor
Department of Agricultural Economics
University of Nebraska-Lincoln
kschoengold2@unl.edu
402-472-2304