Estimating the Demand for In-situ Groundwater for Climate Resilience: The Case of the Mississippi River Alluvial Aquifer in Arkansas[1]

Kent F. Kovacs[2], Shelby Rider[3]

Abstract

A drier and hotter climate diminishes the natural recharge of underground aquifers, which leads to a greater decline in the water table, lower agricultural profits, and reduced property values. The empirical magnitude of the climate change effect on land and groundwater values is what we measure in this paper. Eastern Arkansas overlays the Mississippi River Alluvial Aquifer, and we use the hedonic framework in this region to study how land prices and the agricultural demand for groundwater responds to climatic change. An inch decrease in expected rainfall during the growing season due to climate change decreases the per acre value of irrigated farmland with an average 120 feet saturated thickness by $170 to $180.

Keywords: groundwater value, climatic change, sustainability

JEL codes: Q15, Q25, Q20

---

[1] The findings and conclusions in this manuscript are those of the authors and should not be construed to represent any official USDA or U.S. government determination or policy.

[2] USDA-Economic Research Service, Resource and Rural Economics Division

[3] University of Arkansas, Department of Agriculture and Agribusiness

1. Introduction

Groundwater systems are connected to climate change and variability both through natural recharge and through changes in the use of groundwater. Those impacts depend on human choices such as changes in land use. Since groundwater is a common source of high-quality fresh water, there is frequent development of the resource which can easily scale to meet local needs without a major need for infrastructure (Giordano 2009). Throughout the world, groundwater supplies a third of freshwater for domestic use, more than a third for agriculture use, and nearly a third for industrial use (Doll 2012). In periods low or absent rainfall, the groundwater will naturally replenish the baseflow of waterbodies such as streams and wetlands. While certainly crucial to natural and human systems, there is general lack of studies on the relationship between climate, groundwater, and its monetary value that restricts how well the Intergovernmental Panel on Climate Change (IPCC) can assess human impacts related to climate change. The value of in-situ groundwater is difficult to measure because there is no market for the resource, and this complicates the evaluation of climate impacts on groundwater value. We examine how agricultural property value change with climate using the relationship between agricultural land values and saturated thickness in the Lower Mississippi River Basin in Arkansas, USA.

Decision makers seeking to understand the value of land through the underlying groundwater resource face uncertainties in the hydrologic, economic, and institutional aspects of groundwater management. There is uncertainty in the problem of predicting the consequence of the future climate. The challenge stems from the difficult evaluation of groundwater benefits in the future and irreversible nature of groundwater management impacts. A central distinction in groundwater value is between extractive value, which occur from the extraction of groundwater and use, and in situ values that occur by keeping the water in the aquifer. Examples of in situ value include values associated with subsidence, buffer values, recreational values, ecological values, and existence values.

Groundwater problems receive ever greater attention because greater withdrawals cause problem like destruction of wildlife, habitat, subsidence, and saltwater intrusion. In addition, groundwater is important as a buffer, or emergency supply, and this has become more widely acknowledged. The importance of this value was evident in California during the drought in the early 1990s and the 2010s, when the surface water demand greatly exceeded the supply available. The use of effluent to restore groundwater is frequent in the southern region of California. The aquifer is a converted into an adaptively managed storage receptacle, and the supply of the groundwater is replenished by surface water imports, treated effluents, and flood flows. Over a relatively short period, the water travels through the material of the aquifer and then provides a buffer against surface water shortages.

We make several contributions to the literature on climate and groundwater. First, we provide empirical evidence for the change in agricultural land value as overdraft intensifies due to the heating and drying beyond the current levels. Second, we estimate a non-marginal WTP for groundwater using the revealed preference hedonic property value method. Using the consumer surplus from the uncompensated demand, the loss in property value from a decrease in average precipitation is $160 and $202 depending on the severity of the climate change, assuming that the current saturated thickness is between 100 to 120 feet.

2. Theoretical model

Suppose M identical agricultural landowners, and parcels of land overlie a portion of the aquifer area. The profit of the landowners is given by $\boldsymbol{\pi} = (\boldsymbol{p}, \boldsymbol{h})$ where p is the pumping rate and h is the height of water table. The water table height (or saturated thickness) is the distance between water level and the bottom of the aquifer. We assume an open access regime with profit maximizing landowner ignoring the effects of their pumping on the water table. All users pump at the same rate with open access, and the height of the water table is the same for all landowners. The water table height changes over time as

$$\dot{h}(t) = RE - Mp(h(t))$$

where RE is natural recharge and $Mp(h(t))$ is aggregate pumping. If aggregate pumping exceeds the recharge, there is a water table decline and the pumping rate falls. When the pumping rate and recharge are equal, then there is a steady state. The price of a parcel of land is equal to the present discounted value of the stream of profits.

$$V = \int_0^\infty \pi(p(s), h(s))\, e^{-\delta s} ds,$$

with a discount rate δ and the time frame includes the declining water table and the steady state. Climatic change diminishes the natural recharge and leads to a greater decline in the water table. Our expectation is that lower profits accrue to the agricultural landowners, and the price of the parcel of land falls. We test this hypothesis with the empirical setting of agricultural landowners in the Arkansas Delta to examine whether declines in the natural recharge of an aquifer due to a drier and hotter climate affect the value of land.

3. Data

Arkansas is the largest user of the Mississippi River Valley Alluvial (MRVA), which is the third most used aquifer in the USA (Konikow, 2013). Much of the region has experienced declines in groundwater levels to half of those before settlement (Clark et al., 2013). County land records for Arkansas are the basis for agricultural land sale information (DataScout LLC 2020). The 4,071 agricultural land transactions occur from 1993 to 2019 for parcels greater than 10 acres in size. We remove transactions where the total assessed value exceeds the land assessed value and where the price per acre is greater than the 95th percentile or below the 5th percentile. We use a geographic information system to link a parcel identification number to a spatial coordinate for each property. Daily gridded climate data merged to the parcels come from the PRISM to understand how the climate affects the parcel sale (Table 1). Average growing season precipitation is for the past ten years and for the previous thirty years. Also, we use the average number of degree days between 10 and 32 °C in the past thirty years, and the average number of degree days when heat harms crop growth (i.e. above 32 °C) in the past thirty years (Schlenker et al. 2005).

The calculation of the saturated thickness is the difference between the depth to the bottom of aquifer from the US Geologic Survey (USGS) and the three-year rolling average depth to the saturated region of the aquifer from the Arkansas Department of Agriculture, Division of Natural Resources. Figure 1 shows the saturated thickness largely declined over the time frame of the analysis, but some sub-regions have seen a recovery. Lateral hydro-conductivity for the alluvial aquifer depends on the slug tests by the USGS for forty-two wells. We use irrigation well dummy variables for parcels that have a well on property, within a quarter mile of the property, and within a half mile of the property. The presence of an irrigation well comes from the

Arkansas water well construction commission (WWCC), and the information on the well includes the location coordinates, pumping capacity, and designated use.

Additional control variables for the first-stage hedonic analysis include proximity to streams or rivers from the National Hydrology Dataset or proximity to on-farm reservoirs or tail-water recovery systems (West and Kovacs 2018). Soil characteristics such as the root available water storage, the soil organic matter, and percentage of the parcel land with a soil pH less the 5.3 come from the on-line SSURGO soil survey with the USDA Natural Resources Conservation Service. Urban influence controls include ArcGIS network analyst derived commute times to towns with greater than 5,000 in population and greater than 40,000 in population.

The estimation of in-situ value of groundwater with the inverse demand equation uses survey responses from farm landowners. A 2016 questionnaire through a phone survey had more than 100 questions, and 199 producers completed the survey in full for a response rate of 32%. There were 182 survey responses from farm landowners in the Arkansas Delta used for estimation of the demand equation. The features of the farm that enter as explanatory variables in the demand equation include the climatic variables, the number of irrigated acres, and socioeconomic characteristics such as income and education (Table 2). The climatic variables from the hedonic equation are matched to survey responses based on the county.

4. Empirical model

The hedonic price function has the specification in Eq. 1. The natural log of the price per acre of parcel *i* sold during period *t* is $\ln P_{it}$, and the saturated thickness of the MRVA aquifer is S_{it}.

$$\begin{aligned}\ln P_{it} = {} & \beta_{0j} + \beta_{1j} S_{it} + \beta_{2j} S_{it}^2 + \beta_{3j} S_{it}^3 + \beta_{4j} W_{it} + \boldsymbol{\eta}_j^{'} \mathbf{z_{it}} + \mathbf{v}_j^{'} \mathbf{x_i} + \tau + \theta_{c,t,q} \\ & + W_{it}(\beta_{5j} S_{it} + \beta_{6j} S_{it}^2 + \beta_{7j} S_{it}^3 + \beta_{8j} H_i + \beta_{9j} R_{it} + \beta_{10j} PR_{it}) + \varepsilon_{it}\end{aligned}. \tag{1}$$

We avoid bias in the OLS estimation of a log-linear model by using a generalized linear model with the average of the dependent variable transformed rather than all observations of the dependent variable (Sampson et al. 2019). Using the Box-Cox functional form to examine the appropriate functional form for the hedonic model, we find the log of price provides the best fit statistically (Cropper et al. 1988; Kuminoff et al. 2010). A cubic form for saturated thickness provides flexibility in the examination of the non-linear marginal value of the groundwater stock. The dummy variable W_{it} takes on the value of one if there is an irrigation well on the parcel *i* in period *t*. The vector $\mathbf{z_{it}}$ comprises climatic and other time-varying characteristics (e.g. precipitation, number of degree days, proximity to on-farm reservoirs), and time invariant characteristics are in the vector $\mathbf{x_i}$ (e.g. commute time to population centers). Spatial fixed effects from no controls to county subdivision controls, τ, account for unobserved heterogeneity in land prices that do not vary over time. All specifications have critical groundwater area (CWA) by year by quarter dummies, $\theta_{c,t,q}$, to control for commodity price movements and water management rule changes that could affect CWAs differently over time (ADA 2021).

The price per acre of a parcel may be affected differently by the explanatory variables in Eq. 1 if a well is present on the parcel. We examine this through interaction variables between W_{it} and climatic features such as precipitation (PR_{it}), aquifer features (S_{it} and lateral hydro-conductivity H_i), and irrigation infrastructure like reservoirs (R_{it}). The subscript *j* on β, $\boldsymbol{\eta}$, and $\mathbf{v}$ indicate that these coefficients, which determine the shape of hedonic price function, are estimated for several land markets. Coefficient estimates from several land markets are necessary to properly estimate the demand equation for in-situ groundwater (Zhang et al. 2015). We classify four different agricultural land markets with the Mid-South Land Values and Lease

Trend Reports (ASFMRA 2021). We account for heteroscedasticity from spatially correlated errors by allowing for intragroup correlation using counties for the clusters.

The implicit price of saturated thickness specific in each land market comes from the derivative of the hedonic price equation with respect to saturated thickness, and the second stage analysis uses the implicit prices associated with agricultural parcels that have a well on the property. The demand function for saturated thickness with the implicit price for the dependent variable is

$$\begin{aligned} p_{SAT} = \alpha_0 + \alpha_1 \text{SATTHICK} + \alpha_2 \text{LMKT1} + \alpha_3 \text{LMKT2} + \alpha_4 \text{LMKT3} + \\ + \alpha_5 \text{PRECIP\_10} + \alpha_6 \text{PRECIP\_30} + \alpha_7 \text{DHARM\_30} + \alpha_8 \text{ACRES} + \\ + \alpha_9 \text{INC} + \alpha_{10} \text{INC\_NA} + \alpha_{11} \text{EDU} + \mu. \end{aligned} \tag{3}$$

SATTHICK is the saturated thickness estimate associated with each survey respondent's farm, and LMKT1, LMKT2, LMKT3 are land market dummies corresponding to the agricultural land market. PRECIP_10 and PRECIP_30 are measures of precipitation in the past 10 and 30 years, respectively, and DHARM_30 is the average number of degree days that heat harms crop growth over the past 30 years. A negative coefficient on PRECIP_10 (α_5) or PRECIP_30 (α_6) implies that producers who receive greater rainfall have a lower shadow price of groundwater. A positive coefficient on DHARM_30 implies that producers who experience a greater number of high temperature degree days have a higher shadow price of groundwater. ACRES is the acres of cultivated land on the farm; INC and INC_NA represent the household income and a dummy if income not reported; EDU is an index for the years of education attained; μ is an error term, and the vector α are preference parameters to estimate.

We use a set of instruments inspired by the literature of residential sorting (Klaiber and Kuminoff, 2014) and land market/demand shifter interaction terms (Bartik 1987). An index for the average level of saturated thickness in a county, SI, is a sorting instrument which takes a value of one for a county with lowest saturated thickness, a value of two in the county with the second lowest saturated thickness, and so on. The land market dummies (LMKT2 and LMKT3) interacted with the percentage of farmland in cotton are valid instruments under the assumption that the hedonic function varies across land market but unobserved tastes do not. The percentage of farmland in cotton proxies as a natural recharge demand shifter in LMKT2 and LMKT3 because cotton is principally grown in a region with more natural recharge.

5. Results and Discussion

The hedonic model on the left (Table 3) has spatial controls for 23 counties in the study area, and the column on the right has the estimates for a hedonic model using spatial controls for 235 county subdivisions defined by the US Census Bureau. The coefficients on the saturated thickness variables interacted with well on parcel are significant. The presence of a well means that a parcel of land increases in value as groundwater abundance rises. Based on the cubic relationship between land value and saturated thickness, the land value increases at a decreasing rate with greater saturated thickness, and the land value is largely unaffected by saturated thickness after the thickness is 160 feet or greater. The complete set of coefficient estimates for the first stage hedonic model are shown in Table A1.

The growing season precipitation has a positive influence on the land value, and the thirty-year average of precipitation has a greater influence on land value than the ten-year average of precipitation. An average increase in degree days over 32 Celsius over the last thirty years decreases land value for the hedonic model. Climatic variables interacted with the dummy for well on a parcel are also statistically significant. Parcels with a well sold for more if the precipitation in the past thirty years was higher because buyers presumably have a lower cost of irrigation. Also, parcels with a well and a greater number of degree days over 32 Celsius over the last thirty years have lower agricultural land value since the greater heat stress on the crop lowers the crop productivity or increases the irrigation costs. Other variables in the hedonic model, though not our main interest, have significant coefficients. Very acidic soils (pH less than 5.3) can harm crops, although rice prefers slightly acidic soil, and this lowers the land values. An increase in commute time to a city with more than 40,000 people lower the agricultural land value but greater commute time to a city with more than 5,000 people has not effect.

The implicit prices from equation (2) are the dependent variable in equation (3) for the estimation of the saturated thickness demand parameters. We assign a value of zero to observations with a negative implicit price in the baseline model for the second stage (Netusil et al. 2010; Day et al. 2007). Estimation of IV Model 1 and IV Model 2 is through a two-step instrumental variable (IV) generalized method of moments (GMM) estimator with a saturated thickness sorting index (SI) used for instrumental variables in IV Model 1 and additional demand shifter IVs (LMKT2_PCTCOT and LMKT3_PCTCOT) used in IV Model 2 (Table 4).

The negative coefficient on SATTHICK across all models indicates that landowners' WTP for saturated thickness decreases as aquifer conditions improve. Instrumenting for the endogenous quantity variable suggests that the slope of the demand function is either -0.183 or more negative, given the positive bias expected even in IV estimation (Nevo and Rosen 2012). Weak instruments can lead to even more bias in the coefficients than OLS (Stock et al. 2002). The first stage F-statistic is greater than 200 for IV Model 1 and greater than 816 for IV Model 2, suggesting that the instruments are sufficiently strong. Another concern is that the IVs are correlated with the error term, but the Hansen J statistic for GMM estimation is not significant in either model.

Several of the covariates in equation (3) are statistically significant, providing evidence that farmers living in areas with higher average precipitation (PRECIP_10 and PRECIP_30) are willing to pay less for saturated thickness. Farmers living in areas with more degree days over 32 Celsius over the last thirty years (DHARM_30) have a stronger preference for saturated thickness. These coefficient signs match expectations as farmers have preferences for precipitation rather than costly irrigation inputs, and the number of degree days over 32 Celsius increases the crop need for groundwater resources for irrigation. The number of years of education a farmer has (EDU) is significant and negative indicating that education makes farmers less willing to pay for groundwater.

The welfare implications of a decrease in average precipitation from 0.5 inches to 2 inches due to climate change are shown in Table 5. The value of agricultural land declines in a drier climate because the value of groundwater lost to overdraft is greater. A twenty-foot decline in saturated thickness leads to lower property values of $148 per acre if the initial saturated thickness is 120 feet (Table A2). A decrease in average precipitation by 0.5 inches would decrease the per acre value of land by $160 for the 10-year average and $165 for the 30-year average, respectively. If the 10-year average precipitation falls a further half inch, the value of the agricultural land would decrease by $171 per acre. The value of land falls by $189 per acre if the average precipitation declines by 2 inches. Slightly greater decreases in the value of land occur when using the thirty-year average for precipitation.

6. Conclusion

Empirical measurement of the in-situ value of groundwater in response to climate change is a challenge because in-situ groundwater is a non-market good. One approach available to the practitioner is the second-stage hedonic analysis to estimate an inverse demand for natural capital. Shifters of the demand equation include measures of precipitation and heat because those influence farmer's management of their natural resources. Our empirical analysis of groundwater in the Arkansas Delta provides evidence for losses of agricultural property value as the level of precipitation declines due to climate change. Groundwater overdraft is a chronic challenge for agricultural and urban communities alike as populations increase, agriculture intensifies, and the climate changes. Proper groundwater management requires comparing private benefits of agricultural producers versus the conservation of natural resources.

Policy interventions are often created with the aim of increasing groundwater as illustrated by the recent development of California's Sustainable Groundwater Management Act (Kiparsky et al. 2017). However, estimation of a non-marginal change in the value of groundwater through the use a groundwater demand curve is a challenge since landowners choose how much groundwater to purchase and the price paid for the groundwater simultaneously. We contribute to the hedonic literature on groundwater using a two decade of panel dataset of agricultural land sales to determine the welfare implications associated with a non-marginal increase in saturated thickness. We predict that farm landowners in Arkansas will lose $160 to $202 in property value per acre in the next thirty years as saturated thickness declines faster due to a drier climate.

Our application to groundwater shows that precipitation can have a vital role in systems with interacting natural capital stocks. Our approach could be extended to include a greater array of climate measures (e.g. growing degree days, heat stress) and natural capital (e.g. water and soil quality). Policy makers and natural resource managers may use the empirically measured relationship among the groundwater and climatic indicators to assess tradeoffs with scarce budgets.

References

American Society of Farm Managers and Rural Appraisers (ASFMRA). 2021 Mid-South Land Values and Lease Report. Jonesboro AR, February 2021. https://www.glaubfm.com/blog/2021-mid-south-land-values-report-now-available

Arkansas Department of Agriculture (ADA), Natural Resources Division. *2020 Arkansas Groundwater Protection and Management Report*. Little Rock AR, May 2021.

Bartik, T. 1987. The estimation of demand parameters in hedonic price models. Journal of Political Economy 95(1): 81-88.

Clark, B.R., Westerman, D.A., Fugitt, D.T. 2013. Enhancements to the Mississippi embayment regional aquifer study (MERAS) groundwater-flow model and simulations of sustainable water-level scenarios. The U.S. Geological Survey Scientific Investigations Report 2013–5161, 29p.

Cropper, M.L., Deck, L.B., McConnell, K.E. 1988. On the choice of functional form for hedonic price functions. Review of Economics and Statistics 70: 668–675.

DataScout, LLC. 2020: County Land Record for Eastern Arkansas. DataScout, LLC. Data Archive, received 5 June 2020, http://datascoutllc.com/.

Day, B., Bateman, I., Lake, I. 2007. Beyond implicit prices: recovering theoretically consistent and transferable values for noise avoidance from a hedonic property price model. Environmental and Resource Economics 37(1): 211-232.

Döll, P. et al. 2012. Impact of water withdrawals from groundwater and surface water on continental water storage variations. Journal of Geodynamics 59: 143–156.

Giordano, M. 2009. Global groundwater? Issues and solutions. Annual Review of Environment and Resources **34**: 153–178.

Kiparsky, M., Milman, A., Owen, D., Fisher, A. 2017. The importance of institutional design for distributed local-level governance of groundwater: The case of California's Sustainable Groundwater Management Act. Water 9(10): 755.

Klaiber, H., Kuminoff, N. 2014. Equilibrium sorting models of land use and residential choice. The Oxford handbook of land economics 352-379.

Konikow, L.F. 2013. Groundwater depletion in the United States (1900−2008): U.S. Geological Survey Scientific Investigations Report 2013−5079, 63 p.

Kuminoff, N. V., Parmeter, C. F., Pope, J. C. 2010. Which hedonic models can we trust to recover the marginal willingness to pay for environmental amenities? Journal of Environmental Economics and Management 60(3): 145-160.

Netusil, N. R., Chattopadhyay, S., Kovacs, K. F. 2010. Estimating the demand for tree canopy: a second-stage hedonic price analysis in Portland, Oregon. Land Economics 86(2): 281-293.

Nevo, A., Rosen, A. M. 2012. Identification with imperfect instruments. Review of Economics and Statistics 94(3): 659-671.

Sampson, G.S., Hendricks, N.P., Taylor, M.R. 2019. Land market valuation of groundwater. Resource and Energy Economics 58: 101120.

Schlenker, W., Hanemann, W.M., Fisher, A.C. 2005. Will US agriculture really benefit from global warming? Accounting for irrigation in the hedonic approach. American Economic Review 95: 395–406.

Stock, J. H., J. H. Wright, and M. Yogo. 2002. A survey of weak instruments and weak identification in generalized method of moments. *Journal of Business & Economic Statistics* 20: 518–529.

West, G., Kovacs, K. 2018. Tracking the Growth of On-site Irrigation Infrastructure in the Arkansas Delta. Arkansas Bulletin of Water Research: A Publication of the Arkansas Water Resources Center. https://agcomm.uark.edu/awrc/publications/bulletin/Issue-2018-Kovacs-and-West-Growth-of-onsite-irrigation-infrastructure-in-Arkansas-delta.pdf

Zhang, C., Boyle, K. J., Kuminoff, N. V. 2015. Partial identification of amenity demand functions. Journal of Environmental Economics and Management 71: 180-197.

Table 1. Variable summary statistics for the first stage hedonic equation

Variable	Well on parcel (n=890)		No well on parcel (n=3,811)	
	Mean	Std. Dev.	Mean	Std. Dev.
Price per acre ($/acre)	3,146.5	2,165.2	2,689.9	2,473.1
Growing season precipitation: ten-year average (inches)	26.2	6.9	24.2	6.7
Growing season precipitation: thirty-year average (inches)	24.5	4.9	23.2	5.2
Degree days between 10 and 32 Celsius: thirty-year average (degrees*days)	2,414.2	315.2	2,427.2	378.6
Degree days over 32 Celsius: thirty-year average (degrees*days)	0.25	0.42	0.3	0.3
Well within quarter mile (Binary)	--		0.5	0.5
Well within half mile (Binary)	--		1.0	0.2
Saturated thickness (ft)	119.5	57.8	119.1	54.1
Hydraulic Conductivity (ft/day)	141.1	92.4	142.0	94.7
Intermittent stream within quarter mile (Binary)	0.6	0.5	0.6	0.5
Reservoir within half mile (Binary)	0.01	0.1	0.01	0.1
Root zone available water storage (inches)	10.2	1.6	10.3	1.7
Soil organic matter (kg per square meter)	1.50	0.4	1.49	0.4
Acidic soils (percent of land pH<5.3)	3.1	12.5	3.5	13.6
Commute time to 5,000 population (minutes)	26.3	11.7	27.2	12.6
Commute time to 40,000 population (minutes)	50.1	25.5	54.6	29.5

Table 2. Definitions and summary statistics of the farm operation characteristics for the second stage groundwater inverse demand equation

Variable	Definition	Sample Mean	Sample standard deviation	2017 Census of Agriculture Mean
SATTHICK	Saturated thickness (feet)	84.01	38.25	
Demand shifters				
LMKT1	=1 if respondent live in the land market one	0.14	0.35	
LMKT2	=1 if respondent live in the land market two	0.39	0.49	
LMKT3	=1 if respondent live in the land market three	0.16	0.36	
PRECIP_10	Growing season (April to October) precipitation: ten year average (inches)	27.21	2.42	
PRECIP_30	Growing season (April to October) precipitation: thirty year average (inches)	26.52	2.51	
DHARM_30	Degree days over 32 Celsius: thirty-year average (degrees*days)	0.23	0.32	
ACRES	Acres irrigated	2,308	2,716	1459.1
INC	Household income in 2015 from all sources ($ thousands)	104.9	105.5	152.2
INC_NA	=1 if household income not reported	0.23	0.42	
EDU	=1 if no formal education and =8 if beyond Master's degree	4.95	1.55	
Excluded instruments				
SI	Index of the average saturated thickness for a county. =1 for the lowest saturated thickness, =2 for the next lowest saturated thickness, and so forth.	12.31	6.99	
LMKT2_PCTCOT	LMKT2*Percentage of irrigated cropland in cotton	1.27	7.77	
LMKT3_PCTCOT	LMKT3*Percentage of irrigated cropland in cotton	0.86	7.58	

Note: GMM Instruments include all the demand shifters and excluded instruments.

Table 3. Coefficient estimates for the first stage hedonic model

	County spatial fixed effect	County subdivision fixed effects
Well on parcel interacted with saturated thickness	0.0128[c]	0.026[b]
	(0.005)	(0.008)
Well on parcel interacted with square of saturated thickness	-9.85E-05[c]	-1.63E-04[b]
	(5.81E-05)	(6.74E-05)
Well on parcel interacted with cube of saturated thickness	2.38E-07	3.49E-07[b]
	(1.94E-07)	(1.82E-07)
Acidic soils	-5.29E-04	-1.25E-03[c]
	(9.92E-04)	(1.61E-03)
Growing season precipitation: ten year average	1.10E-03[b]	3.17E-03[b]
	(6.95E-04)	(6.62E-04)
Growing season precipitation: thirty year average	1.64E-03[b]	3.84E-03[b]
	(6.16E-04)	(6.49E-04)
Degree days over 32 Celsius: thirty year average	-0.03[b]	-0.041[b]
	(0.006)	(0.004)
Commute time to 40,000 population	-0.007[b]	-0.0129[a]
	(0.003)	(0.003)
Other variables interacted with well on parcel		
Growing season precipitation: thirty year average	5.94E-04[a]	7.35E-04[a]
	(2.21E-04)	(2.62E-04)
Degree days over 32 Celsius: thirty year average	-2.45E-03[a]	-4.01E-03[a]
	(1.31E-04)	(2.89E-04)
Spatial fixed effects (#)	23	235
BIC	85,400	84,879

Number of observations: 4,701. Standard errors clustered at counties in parentheses. All models have controls for groundwater region by year by quarter dummy variables. [a] $p<0.01$. [b] $p < 0.05$. [c] $p < 0.1$.

Table 4. Coefficient estimates for GMM estimation of the second stage groundwater inverse demand equation

Variable	IV Model 1	IV Model 2
SATTHICK	-0.242^a (0.027)	-0.183^a (0.016)
LMKT1	19.1^a (6.82)	12.11 (9.31)
LMKT2	16.18^a (2.16)	17.82^a (3.83)
LMKT3	21.38^a (2.32)	19.72^a (3.41)
PRECIP_10	-2.11^a (0.081)	-2.25^a (0.113)
PRECIP_30	-3.47^a (0.012)	-3.22^a (0.013)
DHARM_30	3.11 (1.011)	4.56 (0.921)
ACRES	0.001 (0.0004)	-0.0003 (0.001)
INC	0.004 (0.005)	0.008 (0.006)
INC_NA	-1.26 (3.03)	0.636 (3.17)
EDU	-1.57^a (0.443)	-1.99^a (0.445)
Constant	68.62^a (19.91)	59.73^a (15.70)
Instruments	SI	SI; LMKT2_PCTCOT; LMKT3_PCTCOT
R^2	0.34	0.37
First stage F-statistic (p-value)	201.2^a (0.00)	816.40^a (0.00)
Overidentification Hansen J (p-value)	0.55 (0.29)	2.26 (0.41)

Robust standard errors clustered at counties in parentheses. ^{a} $p<0.01$. ^{b} $p < 0.05$. ^{c} $p < 0.1$. The negative implicit prices from the first stage are adjusted to zero.

Table 5. Change in the value per acre of agricultural land for a twenty-foot decline in saturated thickness for alternative changes in the 10 and 30-year average precipitation based on the inverse demand equation for groundwater

Change in average precipitation (inches)	Loss of agricultural land value from a twenty-foot decline in saturated thickness	
	10-year average	30-year average
-0.5	-160	-165
-1	-171	-180
-1.5	-181	-192
-2	-189	-202

We assume that the initial saturated thickness is 120 feet. The first stage is the cubic specification for saturated thickness and county subdivision fixed effects while the second stage is the linear specification for inverse groundwater demand.

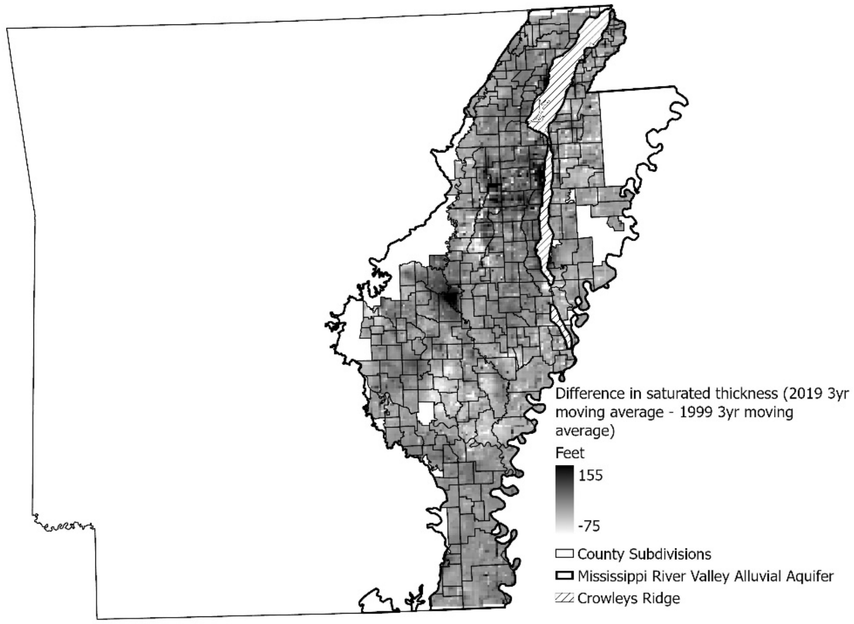

Figure 1. Change in saturated thickness between the three year moving average for 1999 and the three year moving average for 2019

Appendix

Tables A1 has the full set of coefficient estimates for the first-stage hedonic model. Table A2 indicates the per acre property value benefit from changes in saturated thickness using second stage welfare measures.

Table A1. Coefficient estimates for the first stage hedonic model

	No spatial fixed effects	County spatial fixed effect	County subdivision fixed effects
Saturated thickness	-6.06E-03	-4.13E-03	2.99E-03
	(5.63E-03)	(5.89E-03)	(8.25E-03)
Square of saturated thickness	3.47E-05	2.68E-05	-2.16E-05
	(4.33E-05)	(4.37E-05)	(6.11E-05)
Cube of saturated thickness	-4.73E-08	-4.45E-08	4.38E-08
	(9.98E-08)	(9.83E-08)	(1.34E-07)
Root zone available water storage	0.019	0.013	0.012
	(0.013)	(0.013)	(0.010)
Soil organic matter	0.009	0.047	0.0532
	(0.049)	(0.054)	(0.047)
Acidic soils	1.16E-04	-5.52E-04	-1.89E-03[c]
	(7.94E-04)	(9.37E-04)	(1.04E-03)
Degree days between 10 and 32 Celsius: five year average	1.08E-04	1.05E-04	1.17E-04
	(8.00E-05)	(1.30E-04)	(1.17E-04)
Commute time to 5,000 population	-8.67E-04	-2.73E-03	-1.59E-03
	(2.78E-03)	(3.88E-03)	(7.35E-03)
Well on parcel	-0.715[a]	-0.747[a]	-0.972[a]
	(0.227)	(0.269)	(0.305)
Well within quarter mile	-0.101[b]	-0.115[b]	-0.133[a]
	(0.044)	(0.050)	(0.051)
Well within half mile	0.189[b]	0.201[b]	0.213
	(0.090)	(0.097)	(0.132)
Reservoir within half mile	0.057	0.038	0.021
	(0.199)	(0.180)	(0.110)
Intermittent stream within quarter mile	0.046	0.053	0.058
	(0.041)	(0.048)	(0.048)

Other variables interacted with well on parcel			
Hydraulic Conductivity	4.06E-04[c]	4.09E-04[c]	4.79E-04[c]
	(2.20E-04)	(2.37E-04)	(2.91E-04)
Reservoir within half mile	0.335[b]	0.325[c]	0.332[b]
	(0.145)	(0.134)	(0.187)
Implicit price if well on parcel			
80 feet	1.47 (3.46)	4.58 (3.35)	8.96[b] (3.92)
110 feet (average)	-0.88 (2.38)	0.62 (2.23)	-3.28 (3.42)
Spatial fixed effects (#)	0	23	235
BIC	85,498	85,400	84,879
Number of observations	4,701	4,701	4,701

Standard errors clustered at counties in parentheses. All models have controls for groundwater region by year by quarter dummy variables. [a] $p<0.01$. [b] $p < 0.05$. [c] $p < 0.1$. ^ Rice parcels include any parcel with rice in the last five years.

Table A2. Per acre property value benefit from changes in saturated thickness using second stage welfare measures

Change in saturated thickness (feet)	Baseline (No change in average precipitation)
20 to 40	362 ± 304
60 to 80	255 ± 281
100 to 120	148 ± 257
140 to 160	41 ± 233

95% confidence intervals shown beside each estimate of the per acre property value benefit. The first stage is the cubic specification for saturated thickness and township fixed effects while the second stage is the IV Model 2 for the inverse groundwater demand.