Estimating use-based groundwater premiums in Kansas using hedonic price analysis

by

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Abstract

Declining aquifer levels in the Western US are increasing competition among water users, especially between competing uses. Yet, institutional constraints and intentional sources of friction in the water market may prevent users with greater marginal benefits from capturing the increasingly scarce resource. In Kansas water rights are appropriated for a specific use and changing the use requires approval from both local and state regulatory agencies. Assuming that the value of a water right is indicative of the expected returns, I would expect that there would be a use-based premium associated with the type of water right. In this paper, I use a hedonic model to test for evidence of this disparity in water right premiums across uses with agricultural land market sales.

To estimate the hedonic model, I construct a dataset combining land sale records from the Property Valuation Division (PVD) of the Kansas Department of Revenue, hydrologic data on the characteristics of the aquifer below parcels, and information on the water rights associated with transacted parcels. I find that on average another 100 feet of saturated thickness has a premium of $1,241/acre for livestock parcels, 68% higher than dryland. In comparison irrigation parcels have a premium of $2,145/acre on average, 191% higher than the average dryland premium. To investigate this difference further I plot the marginal effect of additional saturated thickness across its range and find evidence that buyers of livestock water rights are more sensitive to differences in saturated thickness at lower levels of the aquifer, before peaking around 150-200ft and then declining.

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Introduction

Water is an increasingly scarce resource that agricultural production relies on. As aquifers deplete, resource managers must balance competing uses and how best to distribute the increasingly scarce, valuable resource. Aquifer depletion is one of the primary concerns when looking at water use in Kansas. The goal of ensuring that the aquifer remains usable for the future is a top priority, especially when considering its importance for agriculture.

The High Plains aquifer includes the Ogallala Aquifer, the Equus Beds Aquifer, and the Great Bend Prairie Aquifer in Kansas. It is the primary source of water for Western Kansas, with much of the water used for irrigation (Whittemore et al., n.d.). However, the levels of the aquifer are decreasing and leading to less available water to pump. Since predevelopment, the High Plains Aquifer has decreased more than 150 feet in Kansas and Texas. In 2015 research found that without changes to water use, "70% of the aquifer in Kansas will be depleted within 50 years." Estimated useable lifetime of groundwater is 50 years or less (Stover & Buchanan, 2017).

Within the land market, water is often bought and sold along with the land. Using a hedonic price model allows for the valuation of groundwater through land transaction data, as the water is often attached to the land when sold. Previous papers have valued groundwater in Kansas using hedonic price models with land transaction data (Edwards et al., 2025; Sampson et al., 2019). Rosen (1974) defines hedonic prices as the implicit prices of attributes that are observed from differentiated products. Sampson et al. (2019) found that irrigated land within the High Plains region of Kansas is valued 53% higher than non-irrigated land. Another important aspect of groundwater valuation is water right characteristics such as seniority. Groundwater access rights have a land value premium of 71% (Edwards et al., 2025).

Hedonic price analysis has been used in states outside of Kansas to value both groundwater and surface water. The average capitalization of groundwater in the San Joaquin Valley is estimated as $3,723/acre-foot of surface water using a small sample of repeat sales of agricultural land (Buck et al., 2014). In Treasure Valley, Oregon, the estimated marginal value of water for irrigation is $9/acre-foot, with the soil capability class identified as having a strong influence (Faux & Perry, 1999). Previous papers focus on valuing water use, whether surface water or groundwater, focusing on irrigation only. This paper includes an updated value for irrigation water rights in Kansas but also includes the addition of valuing groundwater for livestock production.

I use a hedonic model to value groundwater, differentiating the water use by the type of water right is attached to the land. Comparing the value of groundwater based on the water rights attached to the land can help to present friction in the water market. Previous papers have found that there are differences in the value of water based on the use of water. Frictions in surface water markets in California has shown that there is a willingness-to-pay gap between farmers and cities of $2500/acre-foot (Ferguson 2025).

In this paper I calculate the value of groundwater in Kansas by using land transaction data. Using a hedonic price model, I use land values to estimate the value of another acre-foot of water available. Then looking for frictions in the value of water that is used for either livestock or irrigation. I find that the premium for an irrigation parcel is $2,145/acre and $1,241/acre for livestock parcels. The marginal effects show that another 100ft of saturated thickness increase the price of livestock parcels by 20.2% compared to 17.82% for irrigation parcels.

The first contribution of this paper is calculating the value of groundwater in Kansas. This has previously been completed; however, this paper provides updated numbers with data

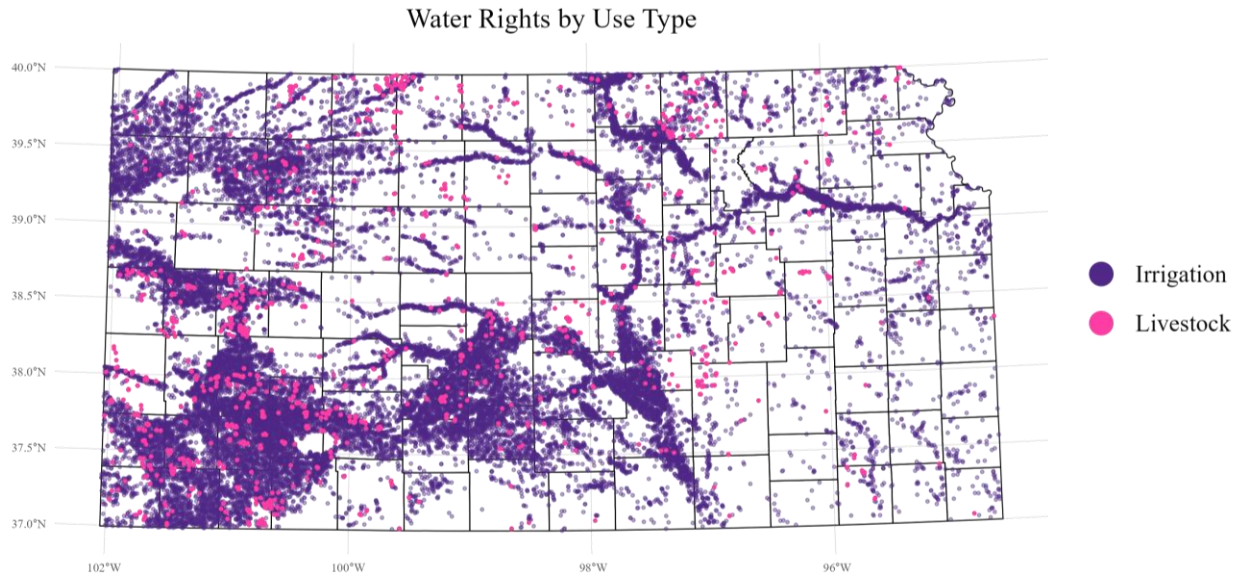
from beyond 2015. The valuation is focused on using land sales that are tied to irrigated farmland and land for livestock use. I will identify what the land is used for based on the water right associated with the land. The second contribution of this paper is looking for friction in the market in Kansas by analyzing if livestock producers value water differently than irrigators. I use the value of groundwater that I calculated to compare how groundwater that is used for irrigation and water that is used for livestock is valued differently.

Background

Water Rights in Kansas

Within Kansas, producers must obtain water rights to pump water from the High Plains Aquifer. While there are myriad approved beneficial uses of water in the state, the two that are most relevant for the agricultural sector are irrigation and stockwater. Farmers with crops in Kansas can either use irrigated farming or dryland farming based on whether they have an irrigation water right. Irrigation provides row crop farmers with the option to plant a greater variety of crops to plant, enables greater yields, and decreases yield variability (Deb et al., 2022). As a result, and as evidence by prior literature, irrigated land conveys a significant land value premium reflective of these production benefits (Sampson et al., 2019). Comparatively little work has focused on the value of livestock water rights, although the motivation for their value is similarly straightforward given its straightforward role as an input. Animal welfare regulations place strict limits on the quantity of water that must be provided per livestock unit, such that water availability provides a binding constraint on the total quantity of animals an operation may produce (*Kan. Admin. Regs. § 5-3-22 - Maximum Reasonable Quantity of Water for Livestock and Poultry*, n.d.).

Figure 1: Locations of Stockwater and Irrigation Water Rights in Kansas



Data Source: Kansas Geological Survey, WIMAS

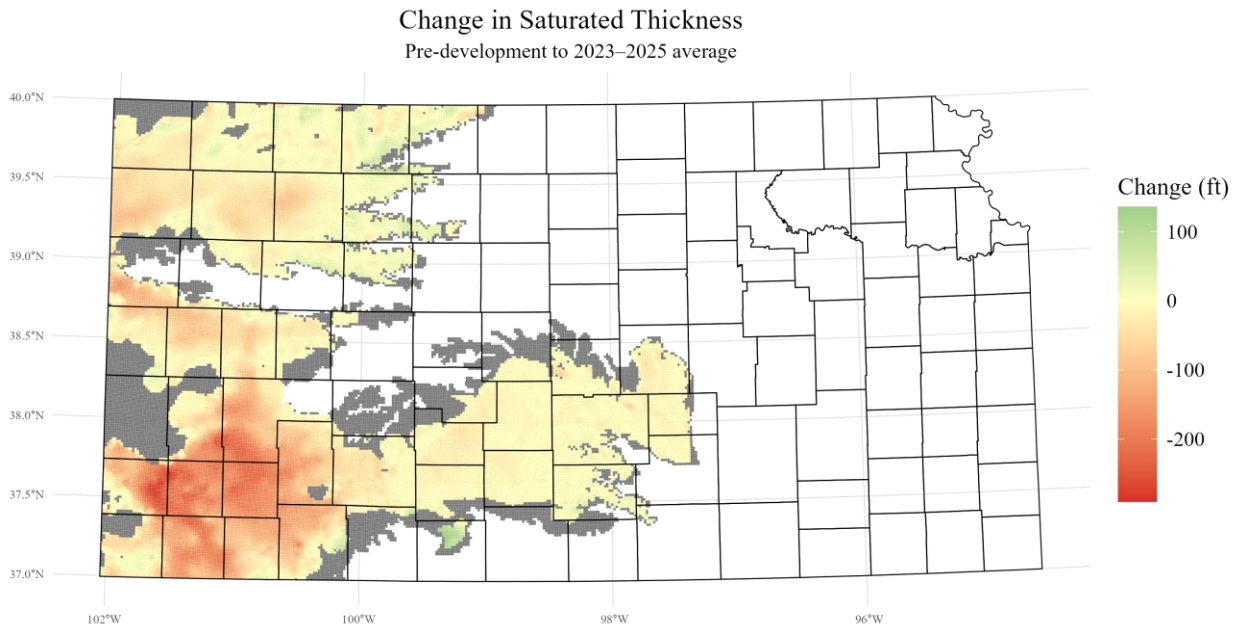
The Kansas Water Appropriations Act of 1945 established that "all water within the state of Kansas is hereby dedicated to the use of the people of the state, subject to the control and regulation of the state in the manner herein prescribed" (Griggs, 2021). This act established the use of water rights in the state of Kansas. The water rights assigned after 1945 are appropriated water rights, while the water rights that were grandfathered in pre-1945 are vested water rights. Water users must apply for water rights and must be approved for the use of groundwater and surface water. The Chief Engineer of the Division of Water Resources (DWR) is the office that is primarily in charge of laws relating to the use of water (Griggs, 2021). The Water Appropriations Act continues to be a center point for policy relating to water in Kansas. Following the Water Appropriations Act, Groundwater Management Districts (GMDs) were established in 1972 by the Kansas Legislature, after the need was recognized for special districts for groundwater in the state (*82a-1020*, n.d.). There are five groundwater management districts in the state that are located within Western and Central Kansas. The existence of these districts is

important to note as there are regulation differences between GMDs. These districts are the basis of HB 2279 as they are creating reports and helping to manage water in the most critical areas of the state. Policies such as this, further impact differences in water use regulations within the GMDs.

Aquifer depletion is one of the primary concerns when looking at water use in Kansas. The goal of ensuring that the aquifer remains usable for the future is a top priority, especially when considering its importance for agriculture. The aquifer has depleted significantly over time, as seen in figure 2. While portions of the aquifer have increased the saturated thickness, this is not true throughout. Another important aspect of the aquifer is the recharge rate. Aquifer recharge rates differ across the state. In the Western third of the state, recharge rates are much lower than those in the Eastern portion of the state. Recharge is defined as the movement of water back into the aquifer. There are several factors that impact the rate of recharge, such as climate, soil and geography, vegetation and land use, topography, and depth to groundwater. There are models that can predict the rate of recharge; however, it can be difficult to directly calculate the recharge rates in the field. When considering ways to reduce aquifer depletion, using the recharge rate when enacting policies and constructing action plans is necessary (Sophocleous & Buchanan, 2003). These recharge and depletion rates were key factors in determining the areas of concern in the annual reports that the districts must provide yearly after the enactment of HB 2279.

Figure 2: Change in Saturated Thickness from Pre-Development to the 2023-2025 Average

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Data Source: Kansas Geological Survey

Livestock Industry in Kansas

The livestock industry in Kansas accounts for 65% of agricultural sales per year (USDA NASS, 2024). This analysis focuses exclusively on the portion of the state overlying the High Plains Aquifer as the primary objective is to estimate how differences in groundwater access and abundance affect land values. This restriction does not severely limit my ability to estimate livestock specific effects of groundwater access and abundance because many of the large livestock operations are located within Western Kansas. Given that an operation is only required to possess a livestock water right if they have over 1,000 head, many of the operations that meet this requirement are located in the Southwestern portion of Kansas where the industry is concentr.

Livestock farms in Kansas are only required to have livestock water right if they operate with 1,000 head of livestock or more. If an operation has under 1,000 head, they only need a domestic water right which do not have the same reporting requirements as irrigation and stockwater rights. Such smaller livestock operations are excluded from my analyses due to the resulting lack of information on which domestic water rights serve livestock purpose. As such, my results should be interpreted as the effects of groundwater access and abundance on land values to larger livestock operations having 1,000 head or more.

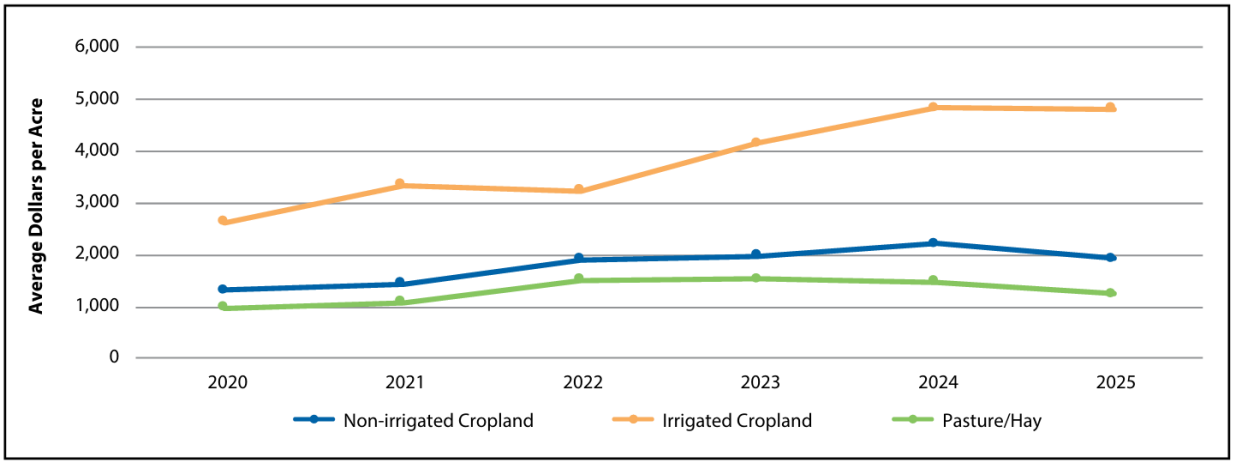
Land Values in Kansas

I source farmland transactions from the Property Valuation Division of Kansas. This dataset includes the sale price for the parcel of land. However, farmland values are a widely tracked datapoint that extension services publish yearly, including Kansas State Extension. The yearly published farmland values can help understand the bigger picture, while ethe farmland transaction data helps to understand individual transactions. Figure 1 below shows the price per acre of various farmland including non-irrigated cropland, irrigated cropland, and pasture/hay. This is important to understand overall land values trends; however, it does not show the impact of individual attributes on land values. Figure 1 below specifically shows the land values for southwest Kansas, showing the differences in prices for types of land (Reid & Hughes, 2026).

In addition to land values information, the Kansas Department of Agriculture (KDA) publishes a feedlot appraisal guide that outlines how county appraisers are to value feedlots that 1) has feed yard capacity over 1,000 head, 2) licensed with the KDA Division of Animal Health, and 3) feed pens are permanent with some type of feed mill or at least minimal feed handling processing capabilities. This report outlines the factors that go into pricing and selling a feedyard, such as capacity, structural improvements, feeding pens and alleys, corral and working

facility, and feed processing (Feedlot Appraisal Guide, 2026). However, the appraisal guide does not consider the access to water. Access to water is an especially important concern in western Kansas as without guaranteed access to groundwater, operations would struggle.

Figure 3: Land Values in Southwestern Kansas



Source: Farmland Values Report, 2026

Theoretical model and empirical approach

I assume buyers of agricultural land are forward-thinking, such that the price they are willing to pay is a function of the expected rents from a parcel of land. Ricardian theory of land rent demonstrates how farmland values capitalize the expected net returns from a parcel's use, so variations in land prices reveal how buyers value different characteristics such as distance to town, water rights, saturated thickness, and climate associated with the parcel (Mendelsohn et al., 1994; Schlenker & Roberts, 2005). I adapt the theoretical framework of Bahrami et al. (Bahrami et al., 2025) to illustrate how use-specific water rights affect the expected returns for a parcel and consequently allow me to recover use-specific estimates of water right premiums.

To illustrate how my empirical approach estimates water right premiums by use, I focus on three uses defined by the presence and type of an accompanying water right. The superscripts D, I, and L are used indicate if a parcel does not have an associated water right, has an irrigation water right, or has a livestock water right, respectively. I start with the simplest case, where a representative parcel i has no associated water right. I expect the price observed for parcel i would reflect the capitalized value of dryland production is defined as:

Equation 1: Value of Dryland Parcel

$$V_i^D = \int_{t=0}^{\infty} e^{-rt}\, \pi_t^D(X_i, \varphi_{it}) dt,$$

where $\pi_t^D(X_i, \varphi_{it})$ is the annual rent from dryland production given the time invariant attributes of the parcel, X_i, and saturated thickness φ_{it}. I include saturated thickness because local dryland parcels might benefit from colocation over the aquifer. Equation 1 states that in the absence of a water right, the price observed for parcel i captures the time-discounted expected returns to dryland production in perpetuity.

I now consider the case when parcel i has an accompanying irrigation water right with characteristics W_i^I, including the seniority date and authorized quantity. I assume the growing condition attributes of parcel i, defined by X_i, and saturated thickness underlying the parcel, φ_{it}, remain otherwise unchanged. The value of irrigated production on parcel i given the presence of accompanying irrigation water right W_i^I is defined as:

Equation 2: Value of Irrigated Parcel

$$V_i^I = \int_{t=0}^{\infty} e^{-rt}\, \pi_t^I(X_i, W_i^I, \varphi_{it})dt.$$

In equation 2, the value of irrigated parcel i is defined as the discounted expected returns to irrigated production given the production characteristics X_i, saturated thickness φ_{it}, and an irrigation water right with characteristics W_i^I. The premium attributable to parcel i having the irrigation water right W_i^I can be expressed as the difference between the value of irrigated and dryland production holding production characteristics X_i and saturated thickness φ_{it} constant:

Equation 3: Irrigated Premium

$$V_i^I(X_i, W_i^I, \varphi_{it}) - V_i^D(X_i, \varphi_{it}).$$

The hedonic model of valuation and my empirical approach relies on exactly this type of comparison to estimate the value of irrigation.

Finally, I consider the case when parcel i has an associated livestock water right, W_i^I. The value of livestock production is expressed as:

Equation 4: Value of Livestock Parcel

$$V_i^L = \int_{t=0}^{\infty} e^{-rt}\, \pi_t^L(X_i, W_i^L, \varphi_{it})dt,$$

where $\pi_t^L(X_i, W_i^L, \varphi_{it})$ is defined as the rents generated from livestock production on parcel i given land characteristics X_i, saturated thickness φ_{it}, and livestock water right W_i^L. The analogous expression for the livestock water right premium is as follows:

Equation 5: Livestock Premium

$$V_i^I(X_i, W_i^L, \varphi_{it}) - V_i^D(X_i, \varphi_{it}).$$

In the next two sections, I describe the data and empirical approach I employ to estimate the premiums expressed in equations 3 and 5.

Data

The data for this analysis comes from several different sources. The data was merged in R and Stata to create a dataset of the transaction prices and land characteristics specific to each individual parcel. The included attributes were chosen to address the main drivers of agricultural land values outlined in my literature review and to enable estimation of the premiums attributable to groundwater access and abundance. I find that land sales for dryland and irrigation have no major grouping trend in terms of what years the sales occurred. For livestock parcels there are two larger groups, however, they are not all within the same year (See Appendix for figures).

Land Sales

The dataset constructed for this research is comprised of parcel-level transaction data from the Property Valuation Division (PVD) of the Kansas Department of Revenue and contains sales data for every agricultural land sale containing 40 or more acres (Tsoodle et al., 2006)[1]. The PVD data includes information on the total sale amount, date of sale, dollar value of improvements to the land, acreage of the land that is dryland or irrigated, among other relevant characteristics. I limit my analysis to the portions of Kansas overlying the High Plains Aquifer to ensure my empirical approach is consistent with the theoretical model outlined above. To address outliers whose price may be driven by context-specific factors or erroneous data, I drop all observations above the 99th percentile for the value of total improvements or with total improvement less than zero. For similar reasons, I also drop all observations with a price per acre

[1] More details are available in Tsoodle et al. (2006).

less than \$5 or above the 99th percentile. In doing so, I ensure my analysis relies on differences in sale price between comparable parcels within the same market.

In addition to these considerations for extreme values, I also take advantage of a variable in the dataset indicating the validity of the sale and restrict the sales in my analyses to "arm's length transactions." This restriction ensures the remaining sales were sold on the open market and not privately. For example, a land sale between family members is not a valid sale and would therefore be dropped from the dataset. After these restrictions, the resulting dataset I employ in the subsequent analyses contains data from 144,863 transactions at the parcel level. I then link these transaction data to geospatial parcel boundaries from Regrid to enable the spatial joins described next.

Table 1: Summary Statistics

	N	Mean	SD	Min	Max
Real price per acre	144,863	11,879.18	24,377.1	5.010197	257,652.4
Saturated thickness (100s of ft)	144,863	1.24	0.92	0.00	5.73
Log real value of improvements	144,863	3.31	4.89	0.00	12.94
Distance to town with 10,000 population (mi)	144,863	36.82	26.75	0.20	114.66
Distance to town with 1,000 population (mi)	144,863	10.05	6.13	0.00	40.58
Distance to town with 40,000 population (mi)	144,863	142.19	39.59	15.43	192.18
Degree days 10--32°C	144,863	18,455.58	2,290.28	11,316.32	27,389.15
Degree days above 32°C	144,863	71.95	49.15	1.97	486.55
Precipitation (mm)	144,863	461.68	131.65	153.35	1,017.06
Available water capacity	144,863	0.16	0.02	0.12	0.20
Saturated hydraulic conductivity	144,863	25.23	8.99	4.90	38.97
Clay (%)	144,863	0.02	0.02	0.00	0.06
Sand (%)	144,863	0.03	0.03	0.00	0.16
Loam (%)	144,863	0.14	0.06	0.00	0.31
Silt (%)	144,863	0.00	0.00	0.00	0.00
Total acres	144,863	149.03	117.70	0.05	850.10
Cropland (%)	142,493	71.96	39.63	0.00	2,786.89
Native grass (%)	144,294	28.46	38.65	0.00	965.00
Tame grass (%)	142,486	0.20	4.06	0.00	100.00
Vested water right	144,863	0.13	0.34	0.00	1.00

Water right priority year	144,863	1,118.92	973.89	0.00	2,016.00
Authorized Quantity	144,863	1.47e+06	1.73e+06	0.00	3.52e+06

Water Rights

Water right information is publicly available through the Water Information Management System (WIMAS), jointly managed by the Kansas Department of Agriculture Division of Water Resources (KDA-DWR) and the Kansas Geological Survey (KGS) (Wilson et al., n.d.). I join the water right data to my dataset of transactions by intersecting the parcel boundaries with authorized places of use for both irrigation water rights and stockwater rights. The characteristics I use from WIMAS are the authorized quantity, priority year, the water right code, and whether the water right is vested. This includes information such as the type of water right, where the water right is located, and the amount of water used. In addition to information on the type of water right associated with a parcel, WIMAS includes specific information to control for "paper water," or the allocated groundwater amount that each right can pump annually. This accounts for situations where parcels have similar quantities of groundwater, meaning they have similar saturated thickness, but differ in their ability to utilize the resource due to differences in allocations.

Saturated Thickness

Year-specific estimates of saturated thickness are provided by KGS in raster format and are attached by taking the mean value within each parcel boundary for a given year. Saturated thickness is the distance from the water table to the base of the aquifer (*Aquifers and Groundwater U.S. Geological Survey*, 2018). The data provided by KGS interpolates the aquifer depth based on data from monitoring wells. In some instances where the aquifer is shallow, the resulting saturated thickness numbers are negative. I removed parcels with negative saturated

thickness values from my dataset such that the dataset used in my analyses relies on parcels with saturated thickness greater than or equal to zero[2].

Weather and Soil

To control for the effect of local climate and growing conditions on land values, I obtain data on weather data and soil from PRISM and SSURGO, respectively (PRISM Climate Group, 2026; Soil Survey Staff). The market price of agricultural land depends greatly on the climate and soil of the region where the land is located, as it is directly related to the land's long-term productivity (Borland & Snyder, 1975). The weather data was downloaded from PRISM at the county level and includes the total precipitation measured in millimeters during the growing season, the number of days where the temperature is between 10 and 32 degrees Celsius, and the number of days over 32 degrees Celsius. Massetti et al. (2016) finds that degree days and temperature are nearly perfect substitutes in controlling for the effects of climates on land values.

The soils data I employ is drawn from the Soil Survey Geographic Database (SSURGO) provided by the USDA Natural Resource Conservation Service. The soil data from SSURGO is time invariant and is included to control for parcel-specific differences in soils that benefit agricultural productivity or hydrologic conditions. The specific soil characteristics included in my analyses includes soil characteristics for each parcel such as amount of sand, silt, loam, or clay present. This also includes information such as slope of the soil, saturated hydraulic conductivity, and available water capacity. Miranowski and Hammes (1984) find that various

[2] Removing negative saturated thickness values dropped 4,869 observations from the sample.

soil characteristics have a marginal value ranging from $12/acre to $31/acre capitalized into farmland values in Iowa.

Proximity to population centers

I control for the effect of development pressure on land values by including the distance from towns of various sizes. Previous research has shown that the proximity to urban areas causes higher prices of agricultural land, as rather than the land only representing the streams of future rents for agriculture, but also the potential development benefits (Guiling et al., 2009; Huang et al., 2006; Isgin & Forster, 2006; Shi et al., 1997). I create three measures of proximity to population centers using the geospatial boundaries associated with transactions and census data on the population of towns (U.S. Census Bureau, 2023). More specifically, I calculate the straight-line distance from the centroid of each parcel and the centroid of the nearest towns with a population of at least 1,000, 10,000, and 40,000 people.

Empirical Analysis

I use a hedonic price method to determine the value of groundwater across users as it allows for the implicit values of a good to be calculated (Rosen, 1974). Hedonic models are commonly employed in the resource economics literature for valuing resources which are bundled together with heterogenous land assets (Buck et al., 2014; Chay & Greenstone, 2005; Crouter, 1987; Edwards et al., 2025; Faux & Perry, 1999; Huang et al., 2006; Sampson et al., 2019). In this instance, it allows us to calculate the effect of marginal changes in biophysical water resource availability or access rights on the value of agricultural land, holding all other characteristics equal. I examine how the right to access water for stockwater and irrigation uses, a marginal change in the saturated thickness below a parcel with access, and a marginal change in the authorized quantity for the associated right affect the price of a parcel. To estimate these target effects, I specify the following regression equation:

Equation 6: Hedonic Land Value Model

$$\boldsymbol{y_{it} = \beta_0 + \beta_1 \varphi_{it} + \beta_2 \varphi_{it}^2 + \Omega' w_i + \Psi' w_i(\varphi_{it}) + \Theta' w_i(\varphi_{it}^2) + \Lambda' z_{it} + \Upsilon' x_i + \beta_3 h_{it} + \lambda_{gt} + \varepsilon_{it}}$$

where y_{it} is the natural log of the real price per acre of parcel i in year t, φ_{it} and φ_{it}^2 are saturated thickness and, and w_i is a vector of three indicator variable indicating whether it is a dryland parcel or there is a stockwater or irrigation water right associated with the parcel, The vector x_i contains the time invariant features of parcels including the water right characteristics, distance to town, and soil characteristics, and the vector z_{it} includes the year-specific temperature and precipitation variables. The total improvements for each parcel are represented by h_{it}. Total improvements are included because of the previously discussed importance of improvements to livestock land values, as well as the differences in improvements between

livestock and irrigation parcels. Finally, λ_{gt} represents the GMD by year fixed effects included in my preferred model specification.

I specify the model in equation 6 using semi-log functional form as the sales data are strictly positive and exhibit an exponential distribution, as seen in Summary Table 1. In addition, the semi-log functional form allows the resulting estimates to be interpreted as percentage changes. I estimate equation 6 using a GLM regression, with a log link and clustered at the county level.

Results and Discussion

Main results

I find that the premium for irrigation parcels is higher than those for livestock parcels. Irrigation parcels have an associated premium of $2,145/acre. Whereas, for livestock parcels there is a $1,241/acre premium associated with an increase of 100 feet of saturated thickness. I find that the marginal effect of increased saturated thickness is higher for livestock parcels compared to irrigation parcels. Livestock producers are much more sensitive to changes in the level of the aquifer. While the marginal effect for livestock is larger than for irrigation, the premium per acre is higher for irrigation than it is for livestock.

The results from my regression are presented in Table 2. The results are consistent with expectations that land values increase with increased saturated thickness. However, this is at a diminishing rate. At a level of zero saturated thickness, the predicted price for dryland is higher than both livestock and irrigation, which is in line with expectations. The marginal effect of another 100 feet of saturated thickness is associated with a 7.14% higher price for dryland. For irrigation another 100 feet of saturated thickness is expected to increase the price of irrigated parcels by 17.82% and by 20.2% for livestock parcels.

Table 2: Full Regression Results Table with Regard to ln(Price/Acre)

	(1) No Quadratic Saturated Thickness	(2) No GMD Variable	(3) Quadratic Term with Fixed Effects	(4) GMD by Year FE
Irrigation	-0.002	-0.033**	0.003	-0.027**
	(0.014)	(0.015)	(0.014)	(0.012)
Livestock	0.040	-0.011	-0.022	-0.036
	(0.065)	(0.096)	(0.074)	(0.084)
Saturated thickness (100s of ft)	-0.003	0.021*	0.015	0.020*

	(0.005)	(0.011)	(0.016)	(0.012)
Irrigation x Saturated thickness	0.004	0.048***	0.014	0.038***
	(0.007)	(0.014)	(0.011)	(0.011)
Livestock x Saturated thickness	-0.012	0.055	0.043	0.085
	(0.033)	(0.091)	(0.070)	(0.082)
Saturated Thickness^2		-0.005*	-0.006*	-0.005*
		(0.003)	(0.003)	(0.003)
Irrigation x Saturated Thickness^2		-0.011***	-0.004	-0.009***
		(0.003)	(0.002)	(0.002)
Livestock x Saturated Thickness^2		-0.019	-0.012	-0.025
		(0.018)	(0.014)	(0.017)
ln (value of improvements)	0.006***	0.006***	0.006***	0.006***
	(0.001)	(0.001)	(0.001)	(0.001)
Distance to town with 10,000 population (mi)	-0.001	-0.001**	-0.001*	-0.001
	(0.000)	(0.000)	(0.001)	(0.000)
Distance to town with 1,000 population (mi)	0.001	0.001	-0.001*	0.000
	(0.001)	(0.001)	(0.001)	(0.001)
Distance to town with 40,000 population (mi)	0.000	0.000	0.001**	0.000
Vested water right	-0.010	-0.015	0.008	-0.003
	(0.015)	(0.015)	(0.013)	(0.012)
Water right priority year	0.000	0.000*	0.000	0.000
	(0.000)	(0.000)	(0.000)	(0.000)
Authorized Quantity	0.000	0.000	0.000	-0.000
	(0.000)	(0.000)	(0.000)	(0.000)
Constant	2.110***	2.104***	1.861***	2.360***
	(0.280)	(0.289)	(0.242)	(0.321)
Observations	142481	142481	106173	142481

Standard errors in parentheses
* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

As seen in Table 2 several other factors aside from water and aquifer characteristics are significant predictors of price. These factors have the expected sign given prior literature which include similar regressors. Total improvements to a property are expected to have a positive impact on the land value. Land that is closer to more urban areas is associated with higher land

values. I expect better soil composition for farming to have higher land values, as they can lead to better yields for crops or are more advantageous soil compositions for livestock production. If soil variables were not accounted for, this would leave concern for omitted variable bias as soil characteristics are a major consideration for agricultural land.

The characteristics of the water right attached to the parcel were also considered in this analysis to account for "paper water." However, the three included measures outside of the type of water right – vested, priority year, and authorized acre-feet – how little effect on the sale price of the land. This could be due to producers being more concerned about the physically available water underneath a parcel. It could also come from the assumption that there are no additional monetary benefits from having a vested water right if they believe water rights will be cut uniformly rather than based on seniority. The type of water right a parcel has does have an effect on the price of the land. Both lead to higher prices, with a livestock water right being more valuable in comparison to an irrigation water right.

To ensure that the results were not based on baseline differences in the parcels, I used coarsened exact matching to match irrigation and livestock parcels by similar characteristics, and then reran the regression to ensure the results did not change. The figures showing the love plot for dryland/irrigation, dryland/livestock, and livestock/irrigation as well as the regression table and marginal effects graph are shown in the appendix. The regression results from my preferred model specification using the matched do not differ significantly from my findings with the unmatched sample. The estimated premiums are similar in magnitude and the signs for my

regressors of interest are unchanged.

Figure 4: Predicted Price/Acre

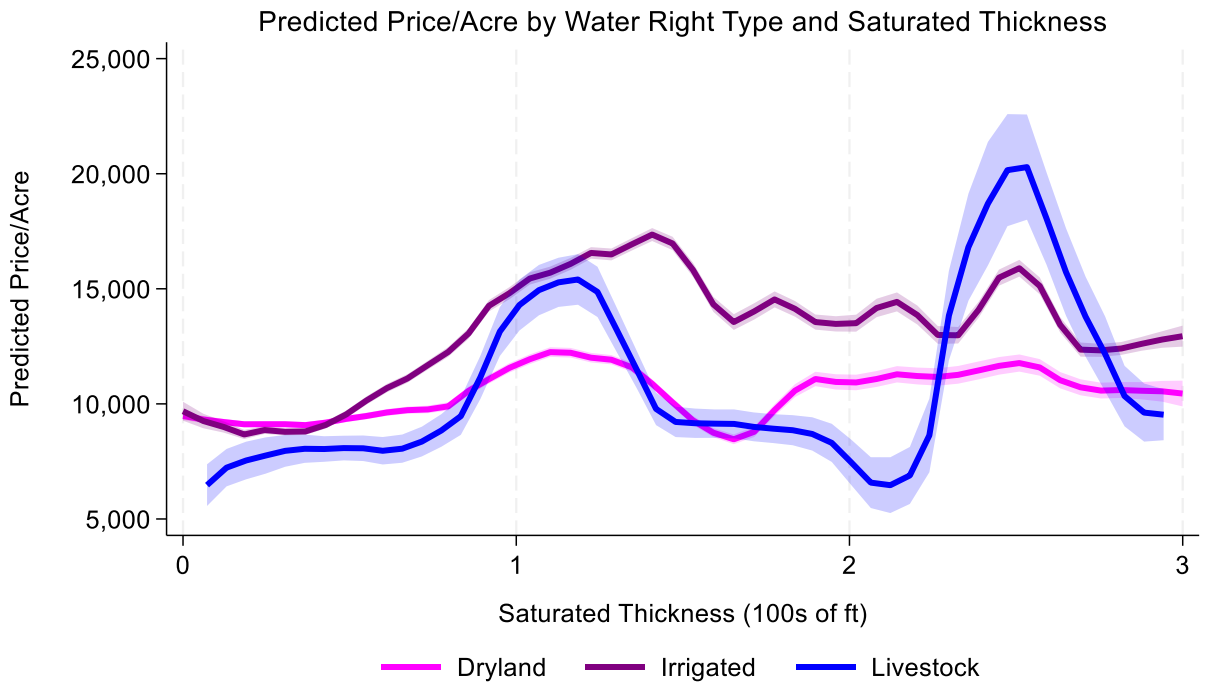
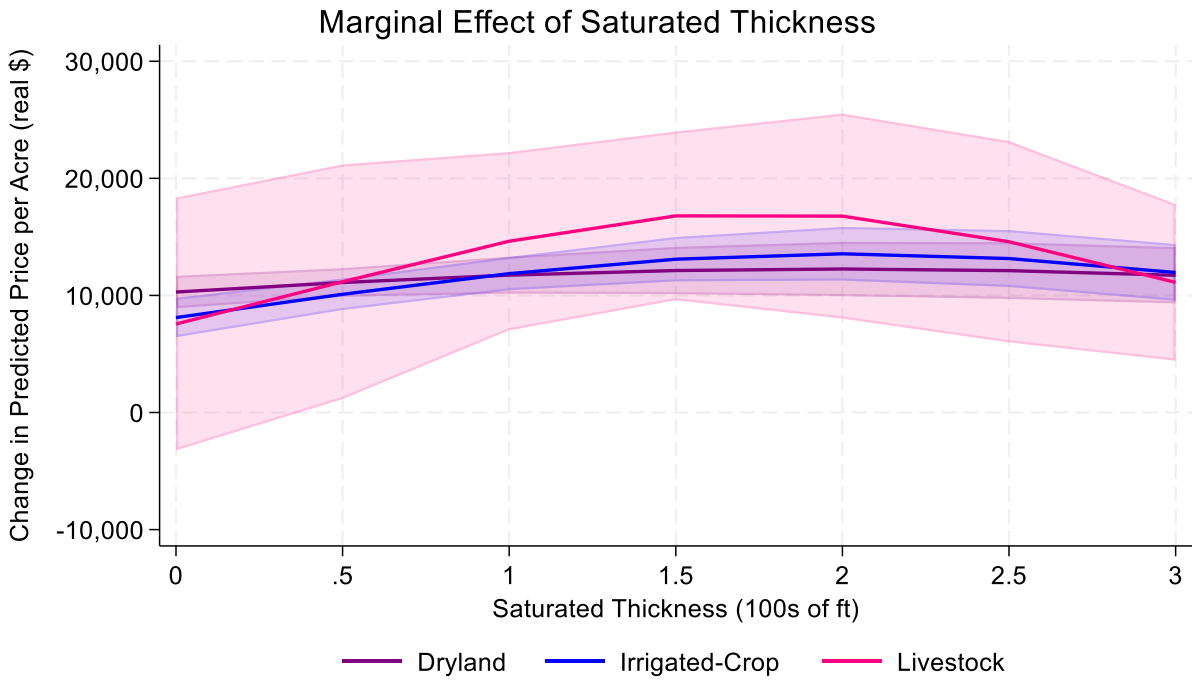


Figure 4 above shows the predicted prices for the different water right types at different levels of saturated thickness (in 100s of feet). It shows that livestock producers are much more sensitive to changes in saturated thickness in comparison to both irrigation and dryland sales, which are much smoother and more consistent. While both the irrigation and dryland predicted prices follow similar trends, just at different levels, the livestock price varies significantly. Some of this variation comes from the fact that there are much fewer livestock observations compared to irrigation and dryland. The predicted prices for livestock are much more dependent on each individual sale.

Figure 5 below shows the marginal effect of saturated thickness at various levels. Dryland barely responds to changes in the aquifer, which would be expected as there is not a water right currently on the land. For both irrigated and livestock parcels, the marginal effect curve is

concave and rises steeply at lower levels of saturated thickness before leveling off, once they hit their peak. At lower levels of the aquifer, dryland parcels are expected to sell at higher prices than irrigated or livestock prices. This is expected as it represents the fact that even if there is a water right on the parcel, there is no usable water beneath the parcel. The land market capitalizes saturated thickness availability primarily in the median levels of saturated thickness rather than at extremely high or extremely low levels of groundwater.

Figure 5: Marginal Effect of Saturated Thickness



Robustness

As stated in my literature review, the best way to check the true value of changes in saturated thickness is to use repeat sales. Restricting the sample to only include repeat sales enables inclusion of parcel level fixed effects that would address time invariant variation my current model does not observe. While this model would be the best way to demonstrate changes in value, restricting my sample to only include repeat sales hinders precise estimation of water

right premiums. Nevertheless, I estimate the same model set on a sample restricted to repeat sales and present the results in Table 3. The results in Table 3 indicate another 100 feet of saturated thickness leads to a 12.98% increase in the price of irrigated parcels and an 11.07% increase in livestock parcels. However, as expected, the repeated sales results are based on small number of observations. For example, there are only 54 livestock parcels with repeat sales, so the price/acre heavily depends on these parcels.

Table 3: Repeat Sales Results with Regard to ln(Price/Acre)

	No Quadratic Saturated Thickness	No GMD Variable	Quadratic Term with Fixed Effects	GMD by Year FE
Irrigation	0.007	-0.018	-0.013	-0.012
	(0.019)	(0.019)	(0.019)	(0.020)
Livestock	0.034	0.061	0.072	0.069
	(0.072)	(0.121)	(0.119)	(0.108)
Saturated thickness (100s of ft)	0.000	0.021**	0.015	0.015
	(0.005)	(0.009)	(0.012)	(0.012)
Irrigation x Saturated thickness	0.008	0.041**	0.039**	0.035**
	(0.005)	(0.018)	(0.017)	(0.015)
Livestock x Saturated thickness	-0.006	-0.080	-0.087	-0.071
	(0.046)	(0.217)	(0.214)	(0.197)
Saturated Thickness^2		-0.005	-0.004	-0.004
		(0.003)	(0.003)	(0.003)
Irrigation x Saturated Thickness^2		-0.009**	-0.008**	-0.007**
		(0.004)	(0.004)	(0.003)
Livestock x Saturated Thickness^2		0.029	0.030	0.021
		(0.071)	(0.071)	(0.065)
ln (value of improvements)	0.006***	0.006***	0.006***	0.006***
	(0.001)	(0.001)	(0.001)	(0.001)
Distance to town with 10,000 population (mi)	0.000	-0.000	-0.000	0.000
	(0.000)	(0.000)	(0.000)	(0.000)
Distance to town with 1,000 population (mi)	0.001	0.000	0.000	0.000
	(0.001)	(0.001)	(0.001)	(0.001)
Distance to town with 40,000 population (mi)	-0.000	-0.000	-0.000	-0.000

	(0.000)	(0.000)	(0.000)	(0.000)
Vested water right	0.029	0.023	0.028	0.028
	(0.028)	(0.028)	(0.026)	(0.026)
Water right priority year	0.000	0.000	0.000	0.000
	(0.000)	(0.000)	(0.000)	(0.000)
Authorized Quantity	0.000	0.000	0.000	0.000
	(0.000)	(0.000)	(0.000)	(0.000)
Constant	2.021***	2.090***	2.042***	2.252***
	(0.310)	(0.294)	(0.306)	(0.330)
Observations	22840	22840	22840	22840

Standard errors in parentheses
* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Table 4 below includes regression results leaving out authorized quantity and saturated thickness, respectively, to address any collinearity concerns. With saturated thickness removed, authorized quantity has a positive linear term and a negative squared term, keeping the same concave pattern. With authorized quantity removed, the irrigated saturated thickness terms are similar to the main estimates, so this demonstrates that collinearity with authorized quantity is not driving the result.

Table 4: Results Leaving out Authorized Quantity and Saturated Thickness with Regard to ln(Price/Acre)

	(1)		(2)
	Authorized Quantity		Saturated Thickness
Irrigation	0.009	Irrigation	-0.029*
	(0.014)		(0.015)
Livestock	0.021	Livestock	-0.004
	(0.048)		(0.098)
Authorized Quantity	0.000*	Saturated thickness (100s of ft)	0.012
	(0.000)		(0.013)
		Irrigation x Saturated thickness	0.045***
Irrigation x Authorized Quantity	-0.000*		(0.013)
	(0.000)		
		Livestock x Saturated	0.049

		thickness	
Livestock x Authorized Quantity	-0.000		(0.091)
	(0.000)		
		Saturated Thickness^2	-0.004
Authorized Quantity^2	-0.000*		(0.003)
	(0.000)		
Irrigation x Authorized Quantity^2	0.000	Irrigation x Saturated Thicknesss^2	-0.011***
	(0.000)		(0.003)
Livestock x Authorized Quantity^2	-0.000	Livestock x Saturated Thickness^2	-0.018
	(0.000)		(0.018)
ln (value of improvements)	0.006***	ln (value of improvements)	0.006***
	(0.001)		(0.001)
Distance to town with 10,000 population (mi)	-0.001	Distance to town with 10,000 population (mi)	-0.001
	(0.000)		(0.000)
Distance to town with 1,000 population (mi)	0.001	Distance to town with 1,000 population (mi)	0.001
	(0.001)		(0.001)
Distance to town with 40,000 population (mi)	0.000	Distance to town with 40,000 population (mi)	0.000
	(0.000)		(0.000)
Vested water right	-0.009	Vested water right	-0.011
	(0.016)		(0.014)
Water right priority year	0.000	Water right priority year	0.000
	(0.000)		(0.000)
Constant	2.109***	Constant	2.117***
	(0.285)		(0.278)
Observations	142481		142481

Standard errors in parentheses
* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Since I ran my model at the parcel level, rather than the transaction level, Table 5 shows the results excluding the validity code "includes additional parcels." Dropping sales with this validity code drops sales from 142,481 to 55,338. While the initial sample size included 1,197 livestock parcels, with this restriction it dropped to 270 livestock parcels. The irrigated saturated thickness term is nearly unchanged from the main results to these results. The control variables

are also in line with what is expected, with vested water rights positive and distance to large towns negative.

Table 5: Results without Validity Code "Includes Additional Parcels" with Regard to ln(Price/Acre)

	(1) No Quadratic Saturated Thickness	(2) No GMD Variable	(3) Quadratic Term with Fixed Effects	(4) GMD by Year FE
Irrigation	-0.013	-0.025*	-0.032**	-0.026**
	(0.010)	(0.014)	(0.013)	(0.010)
Livestock	0.057**	0.091**	0.076**	0.054
	(0.029)	(0.042)	(0.034)	(0.036)
Saturated thickness (100s of ft)	0.003	-0.002	-0.005	0.001
	(0.005)	(0.010)	(0.009)	(0.008)
Irrigation x Saturated thickness	0.013**	0.033**	0.045***	0.037***
	(0.005)	(0.014)	(0.013)	(0.011)
Livestock x Saturated thickness	-0.035*	-0.118**	-0.076*	-0.010
	(0.020)	(0.053)	(0.042)	(0.050)
Saturated Thickness^2		0.001	0.002	0.001
		(0.003)	(0.002)	(0.002)
Irrigation x Saturated Thickness^2		-0.007**	-0.009***	-0.008***
		(0.003)	(0.003)	(0.003)
Livestock x Saturated Thickness^2		0.026*	0.014	-0.006
		(0.015)	(0.012)	(0.015)
ln (value of improvements)	0.012***	0.012***	0.012***	0.012***
	(0.001)	(0.001)	(0.001)	(0.001)
Distance to town with 10,000	-0.000	-0.000	-0.000	-0.000*

population (mi)				
	(0.000)	(0.000)	(0.000)	(0.000)
Distance to town with 1,000 population (mi)	-0.000	-0.001	-0.000	-0.001
	(0.001)	(0.001)	(0.001)	(0.001)
Distance to town with 40,000 population (mi)	-0.001**	-0.000	-0.001**	-0.001***
	(0.000)	(0.000)	(0.000)	(0.000)
Vested water right	0.027**	0.023*	0.027**	0.029***
	(0.012)	(0.013)	(0.012)	(0.010)
Water right priority year	-0.000	-0.000	-0.000	-0.000**
	(0.000)	(0.000)	(0.000)	(0.000)
Authorized Quantity	-0.000*	-0.000*	-0.000*	-0.000***
	(0.000)	(0.000)	(0.000)	(0.000)
Constant	2.080***	2.382***	2.071***	2.308***
	(0.216)	(0.300)	(0.214)	(0.249)
Observations	55338	55338	55338	55338

Standard errors in parentheses
* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Conclusion

This paper estimates how groundwater availability is capitalized into agricultural land values in Kansas, specifically for livestock and irrigation use. Using parcel-level sales from 1985 to 2024, I estimate a hedonic model that allows the value of saturated thickness to differ across dryland, irrigated land, and livestock use. I find that land prices rise with increasing saturated thickness at a decreasing rate, consistent with the concept of diminishing marginal returns. I find that the premium for irrigation parcels is $2,145/acre and the livestock premium it is $1,241/acre. The marginal effect of 17.82% for irrigation parcels and 20.2% for livestock parcels.

Understanding how water availability is capitalized into agricultural land values can help producers make decisions for farm operations, as land is often a farms largest asset. In addition, my results can help inform policy makers contemplating curtailments in their decisions over which water rights to cut. As the aquifer continues to decline, allocating the remaining scare water resources will involve increasingly difficult trade-offs, not only in Kansas but across the country. Estimates of the value of water across competing uses, such as those presented here for irrigation and livestock water rights, can help inform decisionmakers as they try to balance competing water demands.

Subsequent investigations could improve upon the work in this thesis by focusing on how the value of improvements is incorporated into the hedonic model. I include the appraised value of total improvements to account for important the difference in infrastructure on parcels. This is especially important for parcels with livestock water rights given the large investments needed for pens, barns, and other infrastructure. In comparison, there are few improvements of similar magnitude for dryland and irrigated parcels. One potential extension of this work to address such

differences would be to use a matching approach that ensures comparisons are made between irrigation and livestock water rights with similarly valued improvements.

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Appendix

Table 6: Full Regression Results Table

	(1) No Quadratic Saturated Thickness	(2) No GMD Variable	(3) Quadratic Term with Fixed Effects	(4) GMD by Year FE
Log real price per acre				
Log real value of improvements	0.006***	0.006***	0.006***	0.006***
	(0.001)	(0.001)	(0.001)	(0.001)
Distance to town with 10,000 population (mi)	-0.001	-0.001**	-0.001*	-0.001
	(0.000)	(0.000)	(0.001)	(0.000)
Distance to town with 1,000 population (mi)	0.001	0.001	-0.001*	0.000
	(0.001)	(0.001)	(0.001)	(0.001)
Distance to town with 40,000 population (mi)	0.000	0.000	0.001**	0.000
	(0.000)	(0.000)	(0.000)	(0.000)
Degree days 10--32°C	-0.000	-0.000	0.000	-0.000
	(0.000)	(0.000)	(0.000)	(0.000)
Degree days above 32°C	-0.000*	-0.000**	-0.001**	0.000
	(0.000)	(0.000)	(0.000)	(0.000)
Precipitation (mm)	-0.000	-0.000	-0.000	0.000
	(0.000)	(0.000)	(0.000)	(0.000)
Available water capacity	-0.212	-0.109	0.189	-0.170
	(0.911)	(0.822)	(0.245)	(0.914)
Saturated hydraulic conductivity	0.002	0.002*	0.000*	0.002*
	(0.002)	(0.001)	(0.000)	(0.001)
Clay (%)	0.789**	0.660**	-0.023	0.671**
	(0.325)	(0.261)	(0.035)	(0.300)

Sand (%)	-0.105	-0.229	0.001	-0.299
	(0.251)	(0.251)	(0.035)	(0.252)
Loam (%)	-0.264***	-0.260***	0.017	-0.226**
	(0.089)	(0.097)	(0.021)	(0.100)
Total acres	-0.000***	-0.000***	-0.000***	-0.000***
	(0.000)	(0.000)	(0.000)	(0.000)
Cropland (%)	-0.000	-0.000	0.000	-0.000
	(0.000)	(0.000)	(0.000)	(0.000)
Native grass (%)	0.000	0.000	0.000	0.000
	(0.000)	(0.000)	(0.000)	(0.000)
Tame grass (%)	0.001***	0.001***	0.001**	0.001***
	(0.000)	(0.000)	(0.000)	(0.000)
Vested water right	-0.010	-0.015	0.008	-0.003
	(0.015)	(0.015)	(0.013)	(0.012)
Water right priority year	0.000	0.000*	0.000	0.000
	(0.000)	(0.000)	(0.000)	(0.000)
Authorized Quantity	0.000	0.000	0.000	-0.000
	(0.000)	(0.000)	(0.000)	(0.000)
Irrigated-Crop	-0.002	-0.033**	0.003	-0.027**
	(0.014)	(0.015)	(0.014)	(0.012)
Livestock	0.040	-0.011	-0.022	-0.036
	(0.065)	(0.096)	(0.074)	(0.084)
Saturated thickness (100s of ft)	-0.003	0.021*	0.015	0.020*
	(0.005)	(0.011)	(0.016)	(0.012)
Irrigated-Crop # Saturated thickness (100s of ft)	0.004	0.048***	0.014	0.038***
	(0.007)	(0.014)	(0.011)	(0.011)
Livestock # Saturated thickness (100s of ft)	-0.012	0.055	0.043	0.085
	(0.033)	(0.091)	(0.070)	(0.082)
Groundwater Management	-0.019		-0.035	-0.238**

District=1				
	(0.026)		(0.031)	(0.113)
Groundwater Management District=2	0.079***		0.020	0.124***
	(0.024)		(0.021)	(0.039)
Groundwater Management District=3	0.018		-0.047	-0.233
	(0.025)		(0.047)	(0.217)
Groundwater Management District=4	0.015		-0.006	-0.060
	(0.015)		(0.021)	(0.110)
Groundwater Management District=5	0.022		0.067**	-0.062
	(0.017)		(0.029)	(0.151)
Saturated thickness (100s of ft) # Saturated thickness (100s of ft)		-0.005*	-0.006*	-0.005*
		(0.003)	(0.003)	(0.003)
Irrigated-Crop # Saturated thickness (100s of ft) # Saturated thickness (100s of ft)		-0.011***	-0.004	-0.009***
		(0.003)	(0.002)	(0.002)
Livestock # Saturated thickness (100s of ft) # Saturated thickness (100s of ft)		-0.019	-0.012	-0.025
		(0.018)	(0.014)	(0.017)
Constant	2.110***	2.104***	1.861***	2.360***
	(0.280)	(0.289)	(0.242)	(0.321)
Observations	142481	142481	106173	142481
R^2				

Standard errors in parentheses
* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Figure 6: Number of Livestock Sales by Year

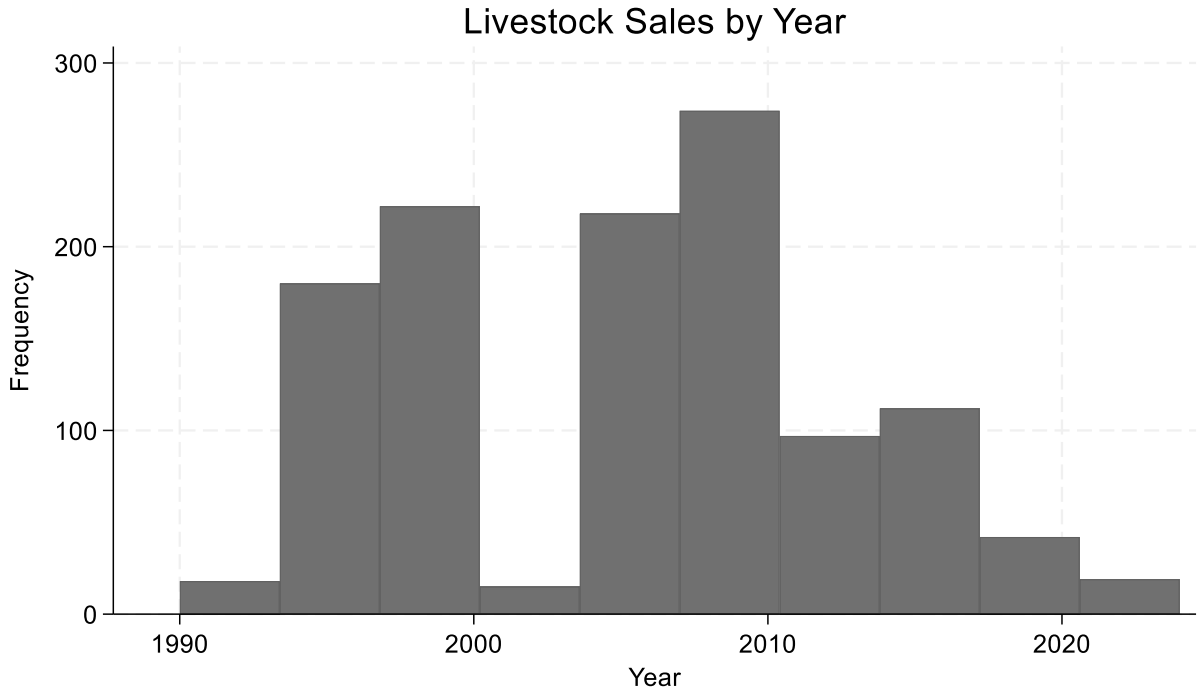


Figure 7: Number of Irrigation Sales by Year

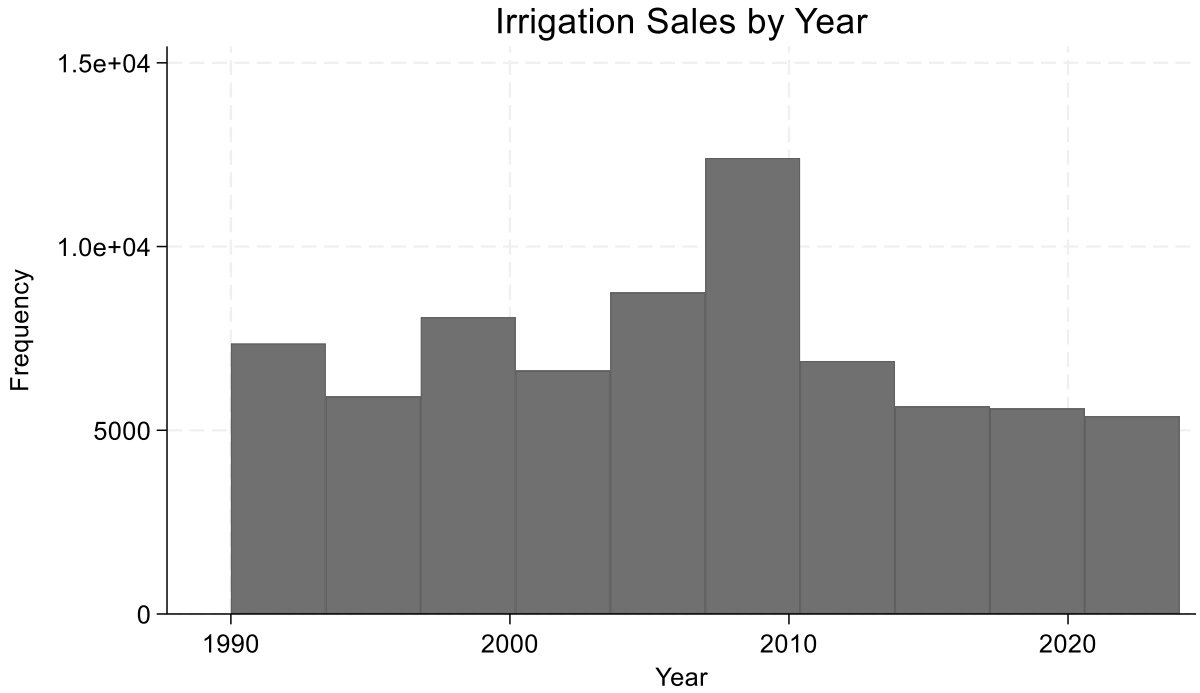


Figure 8: Number of Dryland Sales by Year

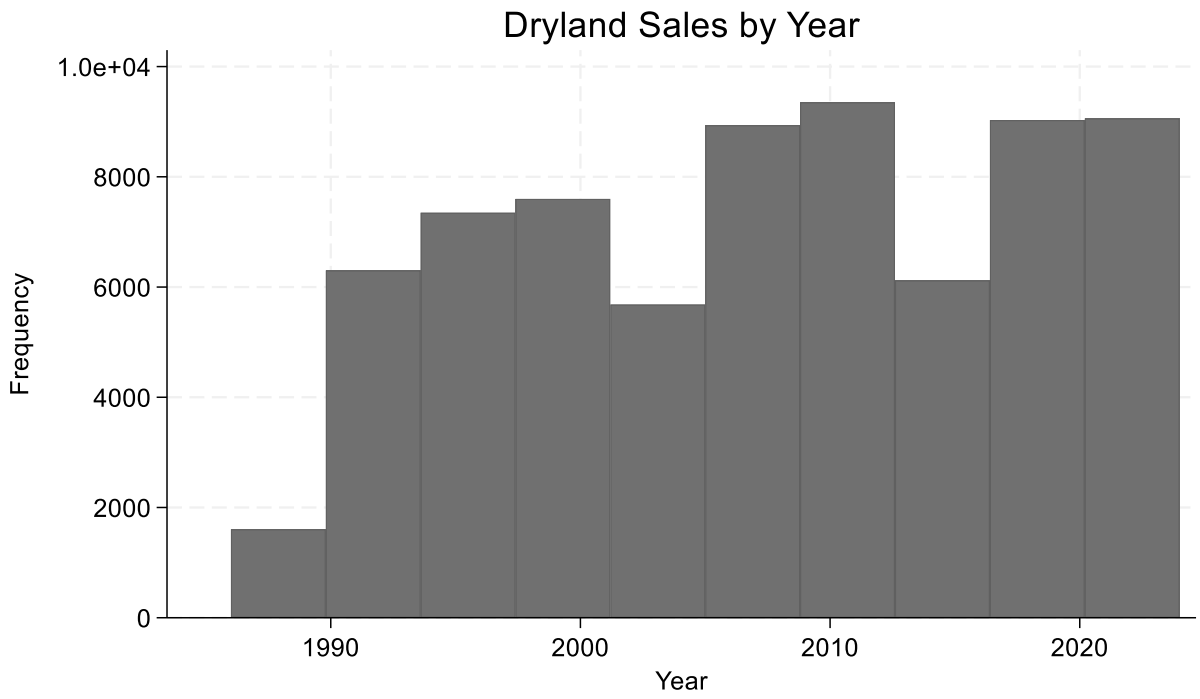


Figure 9: Map of GMD Locations

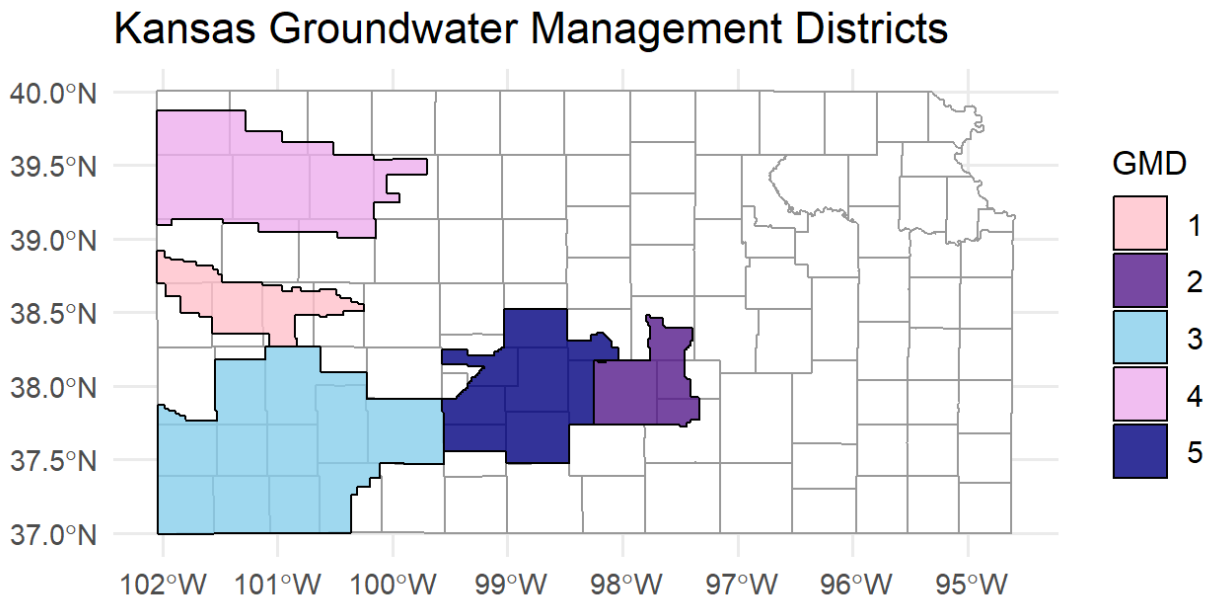


Figure 10: Love Plot for Irrigated and Livestock Matched Data

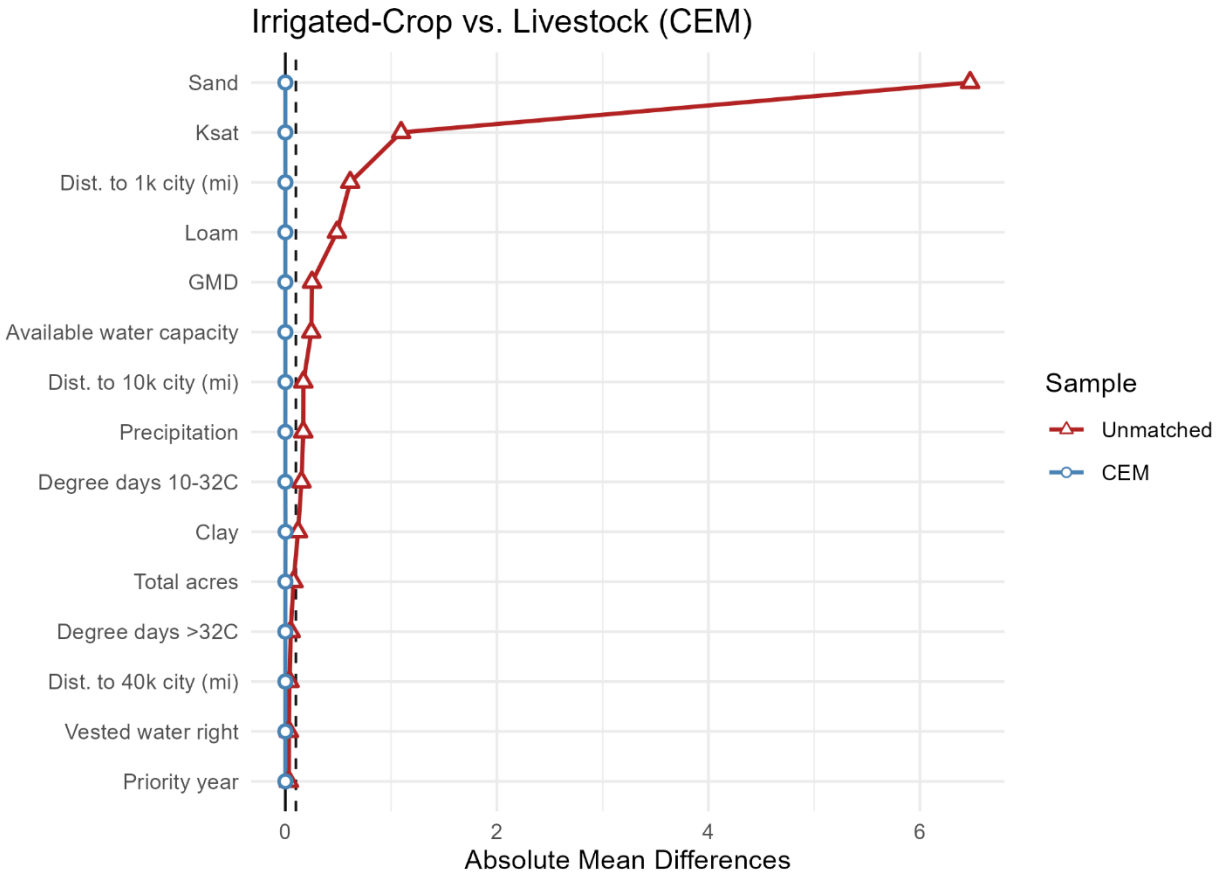


Figure 11: Love Plot for Dryland and Livestock Matched Data

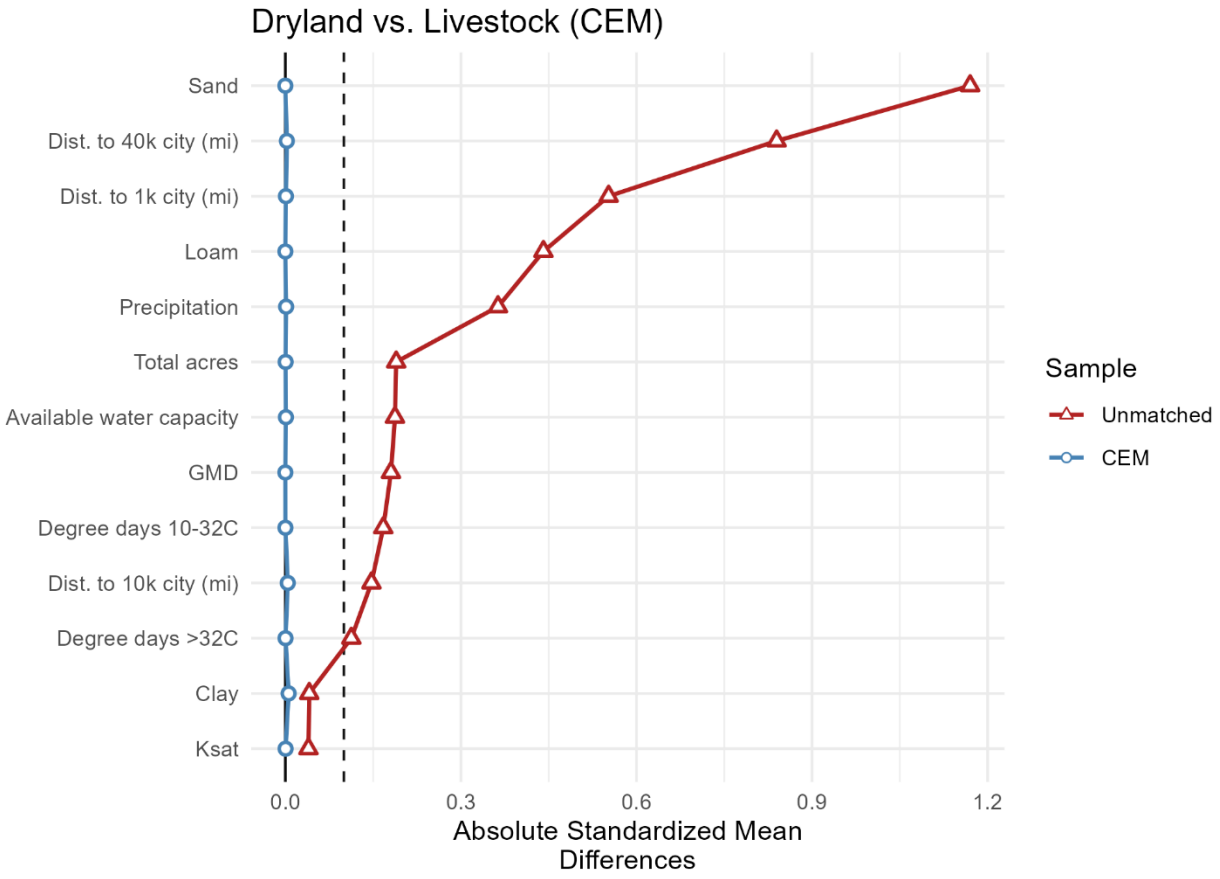


Figure 12: Love Plot for Irrigated and Dryland Matched Data

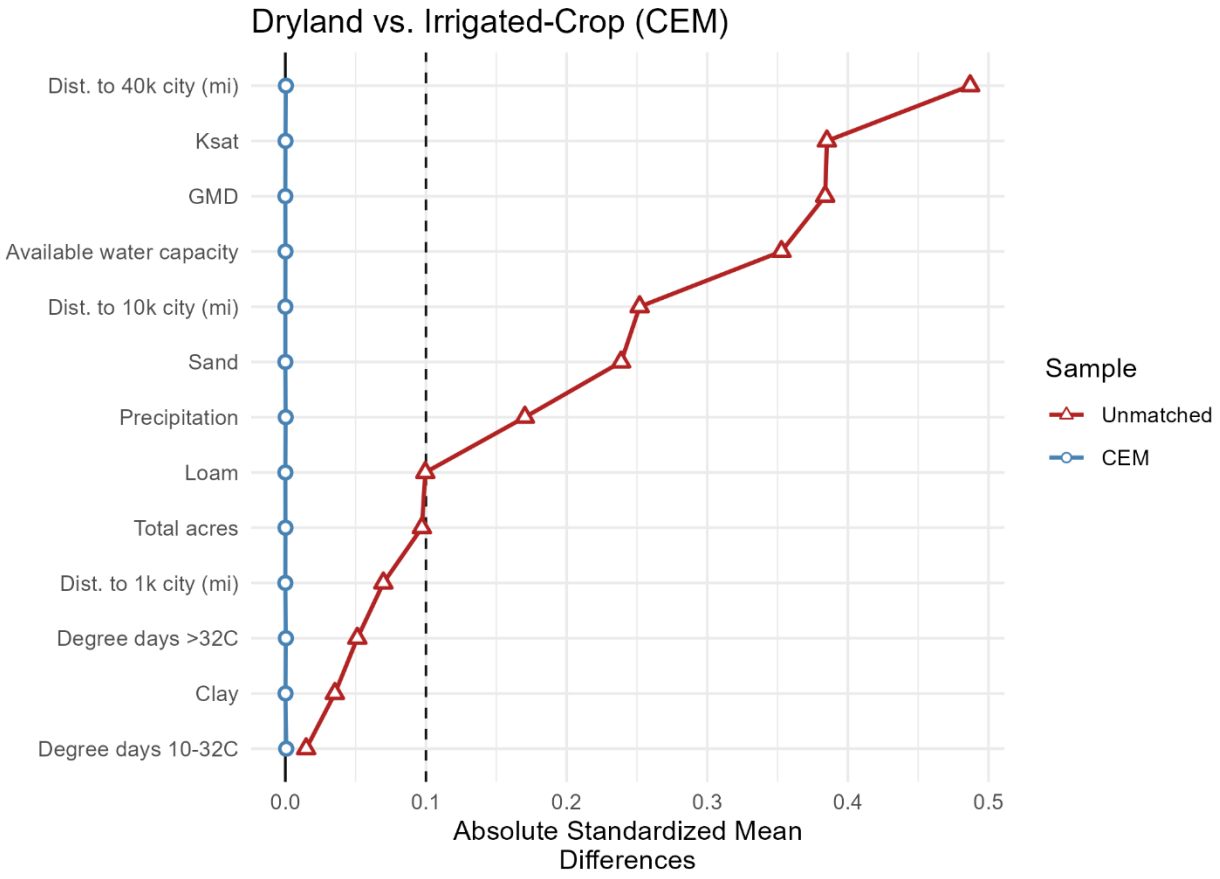


Table 7: Regression Results with Matched Data

ln(total improvements)	0.005
	(0.001)
Distance to town over 10k	-0.000
	(0.000)
Distance to town over 1k	0.001
	(0.001)
Distance to town over 40k	0.001
	(0.000)
Degree days between 10 and 32C	0.000
	(0.000)
Degree days over 32C	-0.001

	(0.001)
Precipitation	-0.000
	(0.000)
awc	0.117
	(0.259)
ksat	0.000
	(0.000)
clay	0.045
	(0.087)
sand	-0.022
	(0.038)
loam	0.032
	(0.030)
Total acres	-0.000
	(0.000)
Percent crop	-0.000
	(0.000)
Percent natural grass acres	-0.000
	(0.000)
Percent tame grass acres	0.000
	(0.001)
Vested Water Right	0.029
	(0.011)
Priority year	-0.000
	(0.000)
Authorized Quantity	-0.000
	(0.000)
Irrigation	-0.009
	(0.007)
Livestock	-0.031
	(0.061)
Saturated Thickness	0.046
	(0.021)
$Saturated\ Thickness^2$	-0.011
	(0.004)

Irrigation × saturated thickness	-0.005
	(0.006)
Livestock × saturated thickness	0.029
	(0.055)
Irrigation × $Saturated\ Thickness^2$	0.001
	(0.001)
Livestock × $Saturated\ Thickness^2$	-0.007
	(0.011)
Num.Obs.	86700
AIC	361921.1
BIC	363607.8
RMSE	1.13
FE: Year by GMD	X

Figure 13: Matched Data Marginal Effects

