The Economic Benefits to Agricultural Producers of Water Right Retirement in Kansas

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Abstract

We measure the economic benefits to agricultural producers of a water right retirement program in southwest Kansas. A dichotomous choice contingent valuation survey method is used to estimate a marginal willingness to pay function that accounts for both market and non-market values from groundwater stocks. We then simulate baseline and policy scenarios using a physical groundwater model that describes groundwater stock levels over space and time. Under the baseline scenario, the benefits from groundwater stocks in the study region decline in value by $5.5 million dollars over 15 years. The water right retirement program (the Upper Arkansas River Basin Conservation Reserve Enhancement Program) leads to groundwater benefits that are $1.2 million higher than in the baseline after 15 years. Using ecosystem service valuation methods to value the benefits from natural capital stocks such as groundwater can inform policy design and provide insight into the sustainability of resource and environmental systems.

Keywords: non-market valuation, natural capital, ecosystem services, groundwater, conservation policy.

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1 Introduction

Many rural economies depend on the use of natural capital, including forests, land, and water resources. Improving livelihoods while ensuring the ability of future generations to maintain standards of living requires an understanding of the value of physical, human, and natural capital (Arrow et al. 2012), and how it is affected by public policies. For example, groundwater stocks provide a valuable input for agricultural production but are often depleted over time (Fenichel et al. 2016). The common property nature of groundwater aquifers suggests that this depletion is unlikely to be optimal from society’s perspective (Hardin 1968; Brozović et al. 2010). This has led to surging interest in managing groundwater systems. Specific groundwater management policies include well spacing requirements (Stephenson 1996), restricted water use (Drysdale and Hendricks 2018), and fees for pumping groundwater (Smith 2018).

Recently, programs that provide incentives for agricultural producers to alter practices have become increasingly common. For example, according to the USDA Farm Service Agency, the Conservation Reserve Program has allocated approximately $1.8 billion per year to programs that offer incentives for agricultural producers to (at least temporarily) retire land. Programs such as the Conservation Reserve Enhancement Program (CREP) (Monger et al. 2018) have included incentive payments to reduce groundwater use by retiring irrigated land and water rights. Similarly, in the San Luis Valley of Colorado, tax revenue from groundwater pumping fees has funded the retirement of irrigated acres (Smith et al. 2017). Despite the increasing prevalence of incentive-based land and water retirement programs (and their associated costs), surprisingly little is known about the value of the benefits they generate for agricultural producers and society.

To fill this gap, we estimate the benefits of a CREP program that retires groundwater rights in southwest Kansas and leaves more water in the ground for future use. Since 2008, the program cost exceeds $45 million. To calculate the benefits of CREP, we estimate agricultural producers’ marginal willingness to pay (mWTP) for additional groundwater, considering both market and non-market values. Using a dichotomous choice contingent
valuation question (Johnston et al. 2017a), we generate a function that describes how the mWTP for additional groundwater stock varies with current stock levels in a producer’s vicinity, measured by well capacity\(^1\). This groundwater stock benefit function is then linked to a model of the physical groundwater system and used to describe the depreciation of the stock that occurs in the absence of policy\(^2\). The linked model is used to estimate the benefits from the increase in groundwater stock that occurs after 15, 30, and 50 years of CREP in the study region in southwest Kansas.

We find that, without the retirement policy, the benefits from groundwater stocks in the study region decline by $5.5 million over 15 years. Retiring the wells enrolled in CREP for 15 years results in groundwater stocks that average 3.9 feet higher than in the no-policy baseline (or 13% of baseline depletion), with impacts concentrated in the vicinity of retired wells. The predicted changes in groundwater stocks across the 5,074 wells of the study region means that 15 years of retirement under the CREP program increases the benefits derived from the stock by $1.2 million, or 22% of baseline depreciation.

This analysis contributes to the economics literature on ecosystem service and natural capital valuation (Polasky et al. 2019), integrated modeling (Bateman et al. 2016), and policy evaluation. While significant improvements have been made towards conceptualizing natural capital and its role for sustainability, even its biggest advocates recognize that its “Achilles Heel is the determination of the shadow prices” (Smulders 2012). Fenichel and Abbott (2014) make substantial progress in operationalizing the valuation of natural capital, though they do not capture asset values derived from non-market flows of ecosystem services. We demonstrate that the tools of ecosystem service valuation, including stated preference methods, can provide a productive path towards measuring natural capital shadow values while accounting for spatial heterogeneity in stocks (Addicott and Fenichel 2019; De Valck et al. 2018) and WTP (Schaafsma et al. 2013). This is particularly true for environmental and natural resource goods for which markets are thin or do not

\(^1\)Well capacity describes the maximum rate at which water can flow through a well (e.g., in gallons per minute) and depends on the saturated thickness (water stock) of the aquifer around a well.

\(^2\)The predicted losses in natural asset value should be subtracted from conventional measures of economic activity to describe a net economic product (Barbier 2014).
exist (Fenichel and Hashida 2019).

The role of integrated models has become increasingly important for water resource management and planning (Harou et al. 2009). For example, Hrozencik et al. (2017) link agricultural producer optimization decisions to a model of a groundwater system to estimate the economic impacts of alternative groundwater conservation policies. Others have linked economic decision models with groundwater models (Guilfoos et al. 2013; Mulligan et al. 2014; Guilfoos et al. 2016) to evaluate the benefits and costs of conservation policies. Hydro-economic models have also informed analysis of policies in coupled surface and groundwater systems (Kuwayama and Brozović 2013). Despite the increase in prevalence of integrated modeling, relatively few studies have linked non-market values with models of physical systems. A prominent exception to this is Bateman et al. (2016), who link a model of climate change to land use and water quality. The benefits of water quality are valued through a travel cost model that allows for estimation of climate change impacts on recreation benefits through the mechanisms modeled in the physical system. Bateman et al. (2006) describe an integrated modeling approach for valuing the impacts of Europe’s Water Framework Directive in a river basin in Britain, focusing on costs to agricultural producers and benefits to recreationalists. They propose stated preference methods as a potentially useful way to value both use and non-use benefits of water quality improvements. Bateman et al. (2013) use integrated modeling to examine the impacts of land use change. Non-market values are estimated using meta-analysis methods. Nelson et al. (2009) describe the use of the modeling tool, Integrated Valuation of Ecosystem Services and Tradeoffs (InVEST), to examine tradeoffs among multiple ecosystem services from alternative land use scenarios.

Often, economists estimate the total willingness to pay for a discrete change in environmental service provision, as described by physical scientists. For example, Loomis et al. (2000) ask households if they are willing to pay for a bundle of services from river restoration in Colorado. While useful in determining the value of the specific change considered, this does not allow for evaluation of alternative policies and counterfactual
scenarios that would lead to varying levels of ecosystem service provision over time.

Others have modeled policy impacts on ecosystem service flows, but do not attempt to measure the value of those flows and what they mean for society’s natural capital. For example, Claassen et al. (2016) model the impact of crop insurance on flows of nitrate, erosion, and carbon sequestration. Similarly, Lawler et al. (2014) examine the impact of land-use change in the US and policy interventions on a range of ecosystem service flows such as habitat provision. Fezzi and Bateman (2011) use a model of land use to predict changes in nitrogen surpluses available for leaching.

Since marginal values of ecosystem services are not likely constant over all levels of provision, it can be beneficial to estimate how the marginal value depends on the level of the service. For example, Poe and Bishop (1999) show that the incremental willingness to pay for water quality improvements depends on a respondent’s current levels of water quality.

In some cases, valuing ecosystem service flows may provide an incomplete picture of a natural system’s capacity to continue to support human well-being. This is particularly true in contexts of rapid environmental change or stock-dependent ecosystem service flows. For example, measuring the value produced by a groundwater management policy by examining extracted groundwater values ignores the impact on groundwater stocks. A similar argument can be made for valuing fish policies by focusing on fish harvested from a fish stock. Less trivially, measuring the benefit of policy-induced improvements in water quality may not capture expected changes to an aquatic system’s capacity to produce water quality in the face of background environmental change. Therefore, a benefit exists to linking valuation functions to models of natural capital and accounting for the environmental system’s role in sustaining ecosystem service flows. This can be achieved by valuing and projecting changes in ecosystem service flows or by directly valuing natural capital stocks. As an example, Loomis and González-Cabán (1998) value the willingness to pay for additional spotted owl habitat. In this case the stock of habitat provides the flow of benefits from protected owl populations.
Finally, we use non-market valuation methods to estimate the benefits of groundwater because evidence is emerging that producers value groundwater beyond its impact on agricultural profit over time (Lauer et al. 2018). Consistent with this, producers across the Ogallala region of the US say that they value water for more than its contribution to agricultural profit. Table 1 presents a summary of the extent to which producers agree with several reasons to support water conservation. Notably, producers agree most strongly that water conservation is important because it benefits future generations (including children and grandchildren) in the area. Agricultural profitability is the third-most agreed-upon reason for conserving water. Many producers also agree that groundwater conservation provides benefits to their community and to the environment (generating hunting and fishing benefits), suggesting that non-market values such as bequest, altruism, and recreation are important components of groundwater stock values. Therefore, it is feasible that the benefits from groundwater stocks exceed the market value they produce.

The existence of non-market values could explain support for conservation policies (Shepler et al. 2019) despite costs to agricultural producers (Hrozencik et al. 2017). There is evidence that groundwater stocks can contribute to local economy-wide outcomes (Hornbeck and Keskin 2015) and allow producers to bequest value to future generations. There may also be environmental benefits from improved water quality (Lichtenberg and Zimmerman 1999), surface water flows, and habitat.

Our approach uses a contingent valuation method to measure both the profit and non-market values of groundwater stocks to agricultural producers. We allow the marginal value of water availability to differ based on current levels and link this valuation function to an aquifer model. This permits valuation of policy impacts or counterfactual scenario analysis that aids in policy design. The estimated policy benefits can be used to evaluate policy efficiency.

The remainder of this paper is organized as follows. In the next section, we provide an overview of the empirical context used for this study. Then, in Section 3, we describe the
modeling framework and components, how they are parameterized, and how we value
the benefits of a water right retirement program. Section 4 presents the model results,
including the estimated mWTP function, baseline decline in benefits from groundwater,
and the increase in value provided by the well retirement program. We discuss results in
Section 5 and Section 6 concludes.

2 Study Area

Irrigated land retirement programs have become an increasingly popular tool for water
conservation (Monger et al. 2018). In this analysis, we focus on the Conservation Re-
serve Enhancement Program (CREP) in the Upper Arkansas River Basin (UARB) located
in southwest Kansas (see Figure 1 for the location of this basin). Agriculture plays a
large role in the economy of the region, and groundwater from the High Plains Aquifer
provides the main source of water for irrigation. Common irrigated crops include corn,
wheat, sorghum, soy, and alfalfa. The region has experienced a large decline in satu-
rated thickness since the middle of the 20th century, and as a result has been identified
as a high-priority conservation area. The Kansas Geological Survey defines saturated
thickness as the vertical height of an aquifer in which pore spaces are filled with wa-
ter (http://www.kgs.ku.edu/HighPlains/atlas/atpst.htm.). Figure 1 shows considerable
heterogeneity in the decline of aquifer levels over time across the High Plains Aquifer,
and that the UARB has experienced a substantial reduction in saturated thickness. The
average decrease in saturated thickness in the study area is 105 feet (32 meters) of decline
since 1935, or 1.3 feet (0.4 meters) per year.

To slow aquifer decline in the basin, the UARB CREP pays producers an annual rental
rate for 15 years in exchange for the permanent retirement of a water right. Accord-
ing to the Kansas Geological Survey, per-acre annual rental payments as of 2016 ranged
from $153 to $193, depending on location and irrigation technology. CREP also offers
upfront bonus payments and cost shares for plugging wells and establishing specific dry-
land management practices. During the 15 years of payments, producers cannot use the
land for agricultural production but after the payments end, dryland production can resume. To be eligible, producers must have used at least half of their water right in three of the five previous years and at least 51% of the irrigated land must be within the program area.

The cost of retirement incentives is shared between the federal government and local institutions, including the state government. As of September, 2017, the program had cost $45.5 million with $33.5 million coming from federal sources\(^3\). The program has enrolled 18,659 acres and retired 37,999 acre-feet of water rights. While program costs are readily apparent, the benefits are less clear.

The first two objectives of the program are to enroll 28,950 acres of land and to retire 45,135 acre-feet of water. This reduction in water use is meant to reduce the rate of decline of the aquifer, increase stream flows in the Arkansas River, decrease salinity, protect recreation in connected surface water bodies, and increase aquifer recharge while increasing wildlife habitat. Estimating benefits of the program that derive from additional groundwater availability, therefore, requires a model of how well retirement affects groundwater stocks. Then, the economic benefits of higher water levels must be estimated, accounting for the non-market benefits generated from higher water levels.

3 Modeling Framework and Parameterization

To value the benefits of the UARB CREP program to agricultural producers, we develop a model that links baseline and policy groundwater pumping to physical outcomes and economic values. We focus on the main channel through which producers in the Ogallala region experience changes in groundwater stocks. This occurs through changes in well capacity, or the flow of water that a well can sustain, often expressed in gallons per minute (GPM). Groundwater stocks can be measured in terms of the well capacity they allow. Higher well capacities can generate both market (agricultural profit) and non-market

(bequest, altruistic, option, recreation) values.

Figure 2 describes the model components used for this valuation exercise. We model the components within the dashed frame in the figure. Each policy scenario, including a baseline, involves groundwater pumping that influences groundwater stocks and well capacity. Spatially explicit well capacities produce a flow of values to beneficiaries in every time period moving forward (outside the frame of this analysis). Instead of valuing these flows, we provide an estimate of the value of the benefits from the groundwater stock, which captures the expected present value of the flow of ecosystem services over time. We now describe each model component and its parameterization using data from the UARB in Kansas. We also describe the simulations used to value the benefits of the CREP program in the UARB.

3.1 Valuation of Natural Capital

Agricultural producers experience changes in groundwater stocks (i.e., saturated thickness) through changes in well capacity. Therefore, the stock variable that we value is well capacity in the vicinity of a given well. If agricultural profit were the only value of groundwater, we could value these stocks using profit functions (Guilfoos et al. 2016) or through the Ricardian or hedonic method (Torell et al. 1990). Since groundwater generates both market and non-market values, and because an individual’s value from well capacity could depend in part on neighboring well capacities, we employ a dichotomous choice contingent valuation method (CVM) survey question that asks producers their willingness to pay for a discrete increase in well capacities at all wells in the area.

3.1.1 Theoretical Model

To examine changes in the benefits from groundwater stocks in the study region, we describe well-level mWTP for additional capacity in an area. See Table A1 in the appendix for a summary of model variables, functions, and parameters. Assume that well \( i \) generates indirect utility for a producer in year \( t \) equal to \( u(y_i(x_{it}), x_{it}) + \delta m_i \) where \( x_{it} \) is the
well capacity in the vicinity of well \( i \) in year \( t \) and \( m_i \) is exogenous nonagricultural income earned by the operator of well \( i \). \( y_i(x_{it}) \) is the groundwater used in period \( t \). In addition to this use value, capacity also contributes directly to utility in period \( t \). \( \delta \) is the constant marginal utility of income. This indirect utility function assumes that producers make water decisions over time as a function of the well capacity in each year. Therefore, there is no choice variable in the indirect utility function. Given a discount rate of \( r \), the present value of this indirect utility flow as of year \( \tau \) can be expressed as

\[
V(x_{i\tau}, m_i) = \sum_{t=\tau}^{T} \frac{u(y_i(x_{it}), x_{it}) + \delta m_i}{(1 + r)^{t-\tau}}
\]  

(1)

with

\[
x_{it+1} = g(y(x_t), x_t)
\]  

(2)

The path of \( x_{it} \) evolves over time according to groundwater pumping, \( y(x_t) \), and groundwater levels across the aquifer, \( (x_t) \), and the producer at well \( i \) has a belief about this trajectory. An accurate understanding of this biophysical relationship is important for using stated preference methods to value environmental goods and services (\(?\)). Agricultural producers have substantial experience with well capacity and its changes over time. They also know what well capacity means for farm profitability generally. Therefore, they likely have a clear understanding of how well capacity translates into market and many non-market (bequest, option, etc.) values over time.

The marginal utility benefit of a small increase in well capacity can be expressed as \( \frac{dV}{dx_{i\tau}} \). Following Nordhaus (2014), we normalize this derivative by the marginal utility of income to convert the marginal benefit into a mWTP (or shadow value) for increased capacity in dollar terms. To calculate the total value of a change in well capacity, we integrate this derivative between two capacities. The increase in value at one well from a
change in well capacity from \( c_0 \) to \( c_1 \) is

\[
\Delta V = \int_{c_0}^{c_1} \frac{1}{\delta} \frac{dV}{dx_{i\tau}} dx_{it}
\]

(3)

In Figure 3, the area below the demand curve between \( c_0 \) and \( c_1 \) is a graphical representation of this change in welfare from the increase in well capacity (Mäler et al. 2008). This approach calculates the change in welfare from a change in capital stock, accounting for the change in resource shadow price over different levels of the natural resource (Fenichel and Hashida 2019). Alternatively, this represents the value lost from natural capital depreciation as well capacity falls from \( c_1 \) to \( c_0 \). The height of the mWTP curve describes an individual’s marginal willingness to pay for an instantaneous change in capacity at a given level of \( x_{i\tau} \).

To obtain an estimate of the monetary value of changes in capacity across \( N \) wells in year \( \tau \), we define the change in capacity in the vicinity of well \( i \) as the difference between \( x_{1i\tau} \) and \( x_{0i\tau} \). Then, we sum \( \Delta V \) across \( N \) wells to obtain

\[
\Delta PV(x^0_{i\tau}, x^1_{i\tau}) = \sum_{i=1}^{N} \int_{x_{0i\tau}}^{x_{1i\tau}} \frac{1}{\delta} \frac{dV}{dx_{i\tau}} dx_{it}
\]

(4)

\( x^0_{\tau} \) represents a vector of current area well capacities, \( (x^0_{1\tau}, x^0_{2\tau}, ..., x^0_{N\tau}) \). \( x^1_{\tau} \) represents a vector of new well capacities across all areas. The economic benefits produced by a policy that leads to a change in well capacities from \( x^0_{\tau} \) to \( x^1_{\tau} \) is \( \Delta PV(x^0_{i\tau}, x^1_{i\tau}) \) because it reflects the change in present value of the flows of benefits into the future, summed across all individuals and years.

### 3.1.2 Empirical Model

To empirically estimate the marginal willingness to pay function described above, we approximate it by eliciting a monetary amount that producers would pay for the discrete change from \( x^0_{i\tau} \) to \( x^1_{i\tau} \), defined as \( \Delta x_{i\tau} \) and we examine how this WTP depends on \( x^0_{i\tau} \).

Consider an increase in well capacity in the vicinity of well \( i \) from \( x^0_{i\tau} \) to \( x^1_{i\tau} \) at an
annuitized annual cost of \( A_t^{an} \), which has the same present value as a 1-time payment of \( A \) in \( t = \tau \). Indirect utility for the producer at well \( i \) from this costly increase is

\[
V(x_i^1, m_i - A_t^{an})
\]

The willingness to pay \( (\Delta WTP_i^{an}) \) for the discrete increase in well capacity is the level of \( A_t^{an} \) that equates

\[
V(x_i^0, m_i) = V(x_i^1, m_i - \Delta WTP_i^{an})
\]

where the present value of \( \Delta WTP_i^{an} \) is the maximum willingness to pay, \( \Delta WTP_i \), for the increase in capacity, conditional on \( x_i^0 \). We approximate \( \frac{1}{\delta} \frac{dV}{dx} \) with \( \frac{\Delta WTP_i}{\Delta x_i} \approx mWTP_i \).

To produce an estimable model using cross-sectional data, we assume that the present value change in willingness to pay for producer \( i \) is \( \Delta WTP_i \) (time subscripts have been suppressed and values are for individuals in a survey year), which depends on observed well capacity in a producer’s vicinity, \( x_i \), climate conditions, \( z_i \), and a random term, \( \varepsilon_i \), that is distributed with mean 0 and standard deviation \( \sigma \). Assuming that \( \Delta WTP_i \) is log-linear, we can express it as

\[
\ln(\Delta WTP_i) = \beta_0 + \beta_1 x_i + \beta_2 z_i + \varepsilon_i
\]

The probability that producer \( i \) prefers the higher well capacity at an immediate cost of \( A_i \) is:

\[
\text{prob}(pref \ x_i^1) = \text{prob}(\varepsilon_i < \beta_0 + \beta_1 x_i + \beta_2 z_i - \ln(A_i))
\]

Further, we normalize by \( \sigma \) and assume that \( \frac{\varepsilon_i}{\sigma} \) is distributed extreme value so that:

\[
\text{prob}(pref \ x_i^1) = \frac{1}{1 + e^{\tilde{\beta} \ln(A_i)}}
\]

where \( \tilde{\beta} = \frac{\beta}{\sigma} \). Noting that \( \tilde{\delta} = \frac{1}{\sigma} \), we can divide each parameter by \( -\tilde{\delta} \) to recover the struc-
tural parameter and produce a predicted median marginal willingness to pay, conditional on well capacity, equal to:

$$\hat{\Delta WTP}_i = e^{\hat{\beta}_0 + \hat{\beta}_1 x_i + \hat{\beta}_2 z_i}$$ (10)

where hats indicate an estimated structural parameter or variable. Using the estimated parameters, we predict median $\Delta WTP$ for well capacity over a range of capacities and divide by the discrete change in capacity to produce a predicted approximate mWTP. This empirical mWTP function approximates the dollar-valued analytical mWTP function and can be used to value groundwater depletion and management policies.

### 3.1.3 Parameterizing the mWTP Model

We parameterize the demand model using a dichotomous choice contingent valuation (CVM) question (Johnston et al. 2017a) that was asked to producers in 227 counties across 6 states in the Ogallala region of the US\(^4\). The survey was originally intended to value well capacity across the region and we use the estimated demand curves to value differences in groundwater stocks that result from the CREP policy in the UARB.

In January of 2018, a survey was sent to 8,000 randomly selected producers across the study area. Postcard reminders were sent in February and a second survey was sent to those who had not responded by the end of February. Completed surveys were received by 1,226 producers. Of the surveys sent, 430 were either non-deliverable (142) or ineligible (retired, deceased, etc.) (288). Excluding these, the response rate was 16.19%. Using only survey respondents who operated at least one high capacity (> 200 GPM) well, we are left with a sample size of 532 producers. Table 2 provides summary statistics for the variables used to estimate equation 9, which allow us to parameterize the mWTP function in equation 10. The variables for the mWTP model are averaged across the 532 survey respondents.

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\(^4\)Colorado, Nebraska, Kansas, Oklahoma, Texas, and New Mexico; while the Ogallala also covers part of Wyoming and South Dakota, the survey did not include producers in those states.
The CVM question asked producers if they support a project to add 100 (or 200) GPM to well capacities to each well in their area at a cost of $X per well, where $X$ included 500, 1000, 1500, 3000, and 5000 (exact question wording provided in Appendix A). This cost represents the $A_i$ for the wells described in the empirical model. Whether a producer supports the project is the binary dependent variable for estimating the model described in equation 9. Overall, 24% of respondents supported the project, with support generally decreasing as the project cost increases.

We generate mWTP functions at the well level but we asked producers if their mWTP, potentially averaged across multiple wells, exceeds the project cost. In theory, aggregating mWTP in this way leads to a biased estimate of mWTP if a respondent has a large degree of heterogeneity in relevant well capacities and a nonlinear mWTP function. As variation in well capacity for a respondent goes to zero, this bias is eliminated. Since we examine mWTP for capacity in an area, it is likely that a producer operating multiple wells in a given area experiences minimal variation in this capacity (see Appendix B for an example showing this bias for a producer with 2 wells and log-linear mWTP).

To assign a capacity to each well, we use information from survey responses that indicated the number of wells operated in 100 GPM bins, including < 200, 200 – 300, 400 – 500, etc. up to > 1200. For each respondent, we create an average well capacity by assigning each well the midpoint of the selected bin and averaging. We do not consider wells with capacity below 200 GPM and for wells above 1200 GPM, we set the capacity to 1250 GPM. Well capacity at each well serves as a proxy for well capacity in the area of each respondent. Because we do not have more spatially detailed information on respondent location, we do not know neighboring wells’ exact capacities. Averaging at the county level would likely introduce additional measurement error into the area well capacity because of within-county spatial variation. The reported average capacity allows us to examine how the mWTP for capacity varies with current capacity.

The survey provides information on the county of residence for each respondent, and includes respondents in the UARB counties. Since we do not know the exact location of
respondents, we use county average climate data in the year of the survey to estimate mWTP functions that depend on well capacity and climate. Climate data come from the Oregon State PRISM dataset\textsuperscript{5}, and include 30 year normals for temperature and precipitation.

We use county average climate variables to estimate well capacity demand curves with intercepts that depend on average temperature and precipitation. Holding climate fixed at historical levels for each well, we predict median mWTP for additional capacity at well capacities between 200 and 1250 GPM. Dividing these predictions by the additional GPM presented in the survey produces well-level empirical mWTP functions whose levels depend on current area well capacity.

3.2 MODFLOW and Well Capacities for Simulation

The hydrology of the groundwater system is modeled with the use of the Kansas Geological Survey’s (KGS’s) MODFLOW model of the Ogallala Aquifer region in southwest Kansas (Liu et al. 2010). MODFLOW (Harbaugh 2005) is a physically-based, spatially-distributed groundwater flow model that simulates spatially- and temporally-dependent groundwater hydraulic head by solving a groundwater flow equation using finite difference methods. Hydraulic head minus the bottom of the aquifer height is the aquifer’s saturated thickness. The model domain of MODFLOW is discretized into blocks laterally and vertically, referred to as grid cells. Each cell has uniform properties (e.g., hydraulic conductivity, specific storage, and specific yield). Groundwater head can be simulated for each grid cell in each time step of the model.

The KGS MODFLOW model used for this analysis includes 14 counties\textsuperscript{6} covering 100 by 150 miles using 1 mile by 1 mile grid cells. There are 17,711 wells in the modeled region, of which 5,074 are in the CREP-eligible region.

The model simulates pumping under policy and baseline scenarios using historical

\textsuperscript{5}http://www.prism.oregonstate.edu/
\textsuperscript{6}Hamilton, Kearny, Finney, Hodgeman, Gray, Ford, Stanton, Grant, Haskell, Meade, Clark, Morton, Stevens, and Seward
pumping data from the Kansas Geological Survey’s Water Information Management and Analysis System (WIMAS) dataset. If a grid cell contains multiple wells, pumping is summed across those wells to determine extraction in the MODFLOW model. Also, annual pumping is distributed evenly throughout the days of the agricultural season. The model historic baseline runs from 1997 to 2007, generating initial head levels and pumping rates for the simulation period, beginning in 2008 (initial year of CREP policy). The simulation uses 11-year cycles of historic weather and pumping corresponding to baseline weather and pumping, and can be run for an arbitrary number of periods. We consider time horizons of 15, 30, and 50 years of the CREP policy.

Model output includes head levels and saturated thickness at each well in the model in each model period. We consider modeled saturated thickness at the beginning of each year to determine well capacity at each well. To convert saturated thickness to well capacity at well \(i\) in year \(t\), we model a well’s reported pump rate as a function of preseason saturated thickness (Haacker et al. 2016) using data on capacity from the WIMAS dataset from 1996-2016. Given this, well capacity at well \(i\) in year \(t\) is:

\[
x_{it} = d_i + fs_{it} + \gamma_{ct} + \varepsilon_{it}
\]

where \(d_i\) is a well fixed effect, \(\gamma_{ct}\) is a county-year fixed effect and \(f\) is the marginal effect of a change in saturated thickness on well capacity. \(\varepsilon_{it}\) is a random error term.

To predict changes in well capacity over time, we use a well’s pumping rate in 2008 to initialize well capacity, and calculate well capacity in year \(\tau\) as \(x_{i\tau} = x_{i0} + f \times \Delta s_{i\tau}\) where \(\Delta s_{i\tau}\) is the change in saturated thickness between year \(0\) and year \(\tau\).

In approximately half of the cases (\(n = 2,497\)), wells do not report a pump rate in 2008. In this case, we use the most recent reported well capacity, updated to 2008 using saturated thickness changes, as the initial capacity (\(n = 1,545\)). If no pump rate for well \(i\) is available in the WIMAS data (\(n = 952\)), we predict well capacity using an average of capacity at all wells within 1 mile of the well.

Therefore, each well in the model has a unique starting well capacity and mWTP in-
tercept, despite a common mWTP slope. In order to assign the relevant capacity to each well for use in the simulation, we turn to the wording of the CVM question (see Appendix A for exact wording). Specifically, respondents were asked a WTP for a change in well capacity on average in their area. Therefore, the valuation at a given point in time does not depend on a single well’s capacity. We consider changes in value using average well capacities within a 1 mile radius of each well in the CREP area. For reference, a section in the Public Land Survey System is 1 square mile; therefore, we define the area to be the size of 4 sections (2 miles by 2 miles).

We now have well-level demand curves for well capacity and a model to produce well-specific estimates of capacity over time for all wells in the study area. This provides the necessary information to value changes in well capacity in an area over time under no-policy and policy scenarios.

### 3.3 Estimating The Benefits of Well Retirement

To estimate the benefit of well retirement, we first simulate a baseline scenario for $T$ years in which all wells continue to pump according to historic levels. We then note the change in well capacities between year 0 and year $T$ under scenario $j$ and create well capacity in the area of each well, $x_{iT}^{jk}$, using average capacity within 1 mile of a well. $k$ is the indicator for starting ($k = 0$) or ending ($k = 1$) capacity. Integrating the estimated mWTP function at each well from $x_{i0}^0$ to $x_{iT}^b$ produces the estimated baseline depreciation in groundwater benefits at each well. Summing these values across wells provides the baseline estimate of lost natural capital value.

We simulate the CREP program by setting pumping to zero at all enrolled wells in the study area ($n = 173$) and use MODFLOW to estimate well capacity at all wells after $T$ years of the program. This produces policy-scenario estimates of pumping capacity for all wells in the region in year $T$. Integrating demand functions from $x_{i0}^0$ to $x_{iT}^C$ produces the decrease in benefits from the groundwater stock at each well with the CREP program in place. Summing across individuals provides an estimate of the total loss in
natural capital value with CREP. Since CREP reduces groundwater use across the region, $x_{iT}^{IC} > x_{iT}^{IB}$ for most wells. The benefit of the water right retirement program derives from the value of the additional well capacity after $T$ years relative to the no-policy baseline. Therefore, policy impacts are estimated as the difference in difference over time across policy scenarios.

For the policy simulations, we examine the additional value of well capacity after 15, 30, and 50 years at all wells, including those enrolled in CREP. We include capacities at retired wells for 2 reasons. First, water at retired wells is available to be used by society and thus has value as a natural capital stock. Next, if well operators at active (non-CREP-enrolled) wells anticipate slower declines in well capacity than in the baseline, the mWTP function would shift up to capture the additional value. Therefore, allowing all wells to continue pumping after $T$ years means that the changes in capacity moving forward more closely resemble changes in the baseline scenario, just from higher starting values.

Our estimates may overstate groundwater values if the water at retired wells is not usable by active wells in the near future. On the other hand, we may understate values if part of the additional water at CREP wells is capitalized into the value of water at the wells that remain active. Future work should investigate the capitalization effects of neighbor well retirement on the value of water at active wells.

We choose 15 years as a minimum time for valuation because CREP pays producers over a period of up to 15 years. Therefore, at a minimum, we value the benefits created during the time in which society is paying to retire wells. We also explore how the benefits change as CREP wells remain inactive for longer periods of time because CREP enrollment in the UARB prohibits irrigation indefinitely.

Given this, we calculate the value of the water at all wells after 15, 30, and 50 years of water right retirement as $\Delta PV^C$ and compare this to $\Delta PV^b$ to quantify the increase in natural capital value that occurs because of the CREP policy.
4 Results

Here, we present results for the contingent valuation exercise, the well capacity model, and the estimated benefits of CREP.

4.1 Marginal Willingness to Pay for Well Capacity

Table 3 presents the coefficient estimates from equation 9. Consistent with theoretical expectations, the negative coefficient on the project cost means that respondents are less likely to support the program if it is more expensive. The negative coefficient on capacity means that the mWTP for well capacity declines as well capacity is higher. This is also consistent with theoretical expectations (and the example provided in Figure 3) because additional well capacities above a certain level provide no immediate gains, at least in terms of profitability and the economic viability of irrigated agriculture. At low well capacities, additional well capacity can provide immediate benefits.

Figure 4 presents the mWTP function using average temperature and precipitation in Finney County (part of the UARB) and demonstrates that the mWTP for additional capacity grows quickly as the well capacity falls below 500 GPM. This is consistent with Hrozencik et al. (2017), who find that profitability at groundwater wells in eastern Colorado begins to fall quickly below 500 GPM, particularly on sandy soils. Above this level, additional well capacity adds little to profitability, leading to a low shadow value of capacity. While wells that currently pump at greater than 500 GPM would benefit from extra water in the future (because it would delay depletion to levels that reduce profitability), this benefit is diminished because of discounting.

4.2 Predicting Capacity Changes

Table 4 presents the parameter estimates used to predict changes in well capacity from changes in saturated thickness that occur at each well (equation 11). The positive coefficient means that falling saturated thickness causes producers to have lower well capac-
It implies that losing a foot of saturated thickness is associated with a 3.6 GPM decrease in well capacity. Taken together with the mWTP functions presented above, this confirms that lower aquifer levels correspond to lower groundwater stock values.

### 4.3 Baseline Depreciation

We first present results from baseline model simulations that assume no water right retirement program. Relevant output includes predicted declines in saturated thickness, well capacity, and total value of groundwater. Table 5 shows the (average) decline in saturated thickness that occurs over 15, 30, and 50 years in the baseline scenario across the study area. The average declines in saturated thickness lead to drops in well capacity that average 81, 165, and 258 GPM respectively. Coupling these changes in well capacity with the results of the WTP model means that the CREP region experiences a decrease in natural capital value of $5.5 million, $17.4 million, and $48.2 million in current value over the 15, 30, and 50 years of simulation. The value increases nonlinearly over time as more wells fall to low capacity levels where the mWTP is high. Figure 5 also presents these costs values in present value, assuming a 5% discount rate. This decrease suggests that economic sustainability requires investment in non-resource capitals to maintain standards of living in the area. Since the groundwater stock is a common property resource, this drop in natural capital value is not likely socially optimal.

### 4.4 CREP Policy Impacts

To examine the economic benefits of CREP to agricultural producers in the UARB region of Kansas, we now demonstrate how well retirement affects saturated thickness and well capacity declines over time, and how this affects the value of natural capital depreciation in the region.

Table 6 shows the average increase in saturated thickness and well capacity across the region after 15, 30, and 50 years of well retirement, relative to the baseline scenario. Notably, the difference in decline averaged across the region is small. After 15 years,
saturated thickness is predicted to be less than 4 feet higher on average, producing an average increase in well capacity of 11 GPM. The increase in well capacity across the region is valued at $1.2 million, or 22% of baseline depreciation. Comparing this total increase in benefits after 15 years to the program’s cost ($45 million) suggests that the program cost is difficult to justify only on the total economic benefit that accrues to agricultural producers during the program period. After 30 and 50 years, the program benefits, in current value, are $3.7 and $13.5 million, respectively, or 21% and 28% of baseline depreciation.

Examining the present value (PV) of benefits suggests that retiring wells for a longer time period increases benefits. After 15 years, the PV of benefits is just $585,000. The present value benefit rises to $1.2 million after 50 years, which illustrates the additional benefits associated with permanent retirement relative to shorter run programs.

To explore the heterogeneity in impacts, Figure 5 presents a map of the additional well capacity in each well’s area after 15 years because of the CREP policy. The impacts of well retirement are quite local, with a median change in area well capacity of 6 GPM after 15 years. For the 623 wells within 1 mile of a retired well, well capacity changes from 15 years of CREP can be larger. Within 1 mile, the average change in capacity after 15 years is 32 GPM (from a 9-foot increase in saturated thickness), valued at an average benefit of $770 per well (see Table 6). When compared to the region-wide average of $240, it becomes clear that CREP benefits disproportionately reach nearby wells, with most wells experiencing small direct benefits. To demonstrate this more completely, Figure 6 shows a map of the spatially-explicit increase in value created by the CREP program. The wells with economically meaningful increases in value are those either directly impacted by nearby enrolled wells or indirectly impacted through wells in the area that have a nearby enrolled well.

Since some retired wells are located close to the border of the Arkansas River Basin, we also expand the analysis to include all wells in the KGS MODFLOW model. The results of this analysis are presented in Appendix C and demonstrate that benefits increase slightly but do not substantially change model conclusions.

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\(^7\)CREP programs in other regions have allowed irrigated production to continue after payments cease.
5 Discussion

We have demonstrated a process for linking a stated preference valuation function with the output of a model of a physical system to facilitate policy evaluation. We find that the impacts of land retirement on groundwater stocks is relatively small and concentrated at the wells within a close distance of retired wells. Our results suggest that 15 years of CREP retirement increases groundwater stock values by a total of $1.2 million after 15 years, climbing to $13.5 million (in current value) after 50 years. While this includes market and non-market values to agricultural producers in the basin, it does not account for non-market values to other segments of society in- or outside the area. The median change in groundwater stock at a well in the policy region is 2.7 ft (or 6 GPM), suggesting that most wells experience minimal changes in stocks. Wells within 1 mile of a retired well, however, see increases of an average of 9 ft (32 GPM) of saturated thickness. Therefore, while program benefits are small on average, they may be large for some producers. The small number of producers with large changes in groundwater availability suggests that the benefits to communities as a whole are likely to be small.

Comparing this to a program cost of $45.5 million suggests that the program cannot be justified only by considering market and non-market values to agricultural producers that receive small increases in groundwater stock and well capacity. Interestingly, the benefit is more similar in magnitude to the non-federal portion of the program cost. While producers often support voluntary programs that compensate them for changes in management, their economic justification may require benefits beyond those considered in this study.

In the context studied here, the non-market benefits created by CREP that accrue to non-producers would have to exceed $42 million after 15 years to justify the program on a benefit-cost basis (even before discounting). Given 2012 Census estimates of population in the Kansas CREP counties of 119,284, this requires a benefit of $355 per person. After discounting, this exceeds the estimated benefits per well that include the market and non-market benefits of groundwater. To provide context, Colby (1990) suggest that
existence, bequest, and option values from unique recreation sites are in the range of $40 to $80 dollars per person (or $77 to $154 in 2018 dollars). Therefore, even if the program successfully conserves valuable habitat, the economic development and recreation benefits would likely have to exceed $24 million, or $200 per person to justify the cost of the CREP program from a benefit-cost perspective. These benefits may also accrue to households outside the study region, which could diminish the per-household benefit needed to justify the CREP program.

In addition to these household benefits, the program may also be justified as a way for states to remain in compliance with interstate compact agreements regarding surface water flows. Yet, the local nature of changes in groundwater stocks that occur because of well retirement underscores the importance of spatial targeting when surface water flows are a priority. In many cases, spatial targeting may increase program costs as eligible areas become smaller. This is exacerbated by higher soil productivity on land near surface water bodies. This variation in soil quality has led to spatially differentiated payments in specific CREP programs (Monger et al. 2018) but in many cases (including the UARB in Kansas), the higher payments do not appear to compensate for higher profitability. The spatially explicit nature of policy impacts in agricultural groundwater suggests that future policy evaluation must consider the spatial impacts of retirement policies on specific program objectives. To the extent that non-producers benefit from these program objectives, analyses should consider the benefits that accrue to society as a whole, including producers, regulators, and non-agricultural households and firms.

Given the relatively small benefits to agricultural producers compared to program costs, if broader social goals justify the use of this CREP program, federal initiatives are likely necessary. Since the costs exceed the benefits to producers, we would not expect them to impose and fund this type of program locally.

To place our WTP estimates in the literature and to examine the role of non-market values to agricultural producers, we compare our results to those from Brozovic and Islam (2010), who estimate the value of well capacity using hedonic methods. They find
that an additional GPM increases land sales prices by $0.18 per acre or $23.40 per GPM across 130 acres (the typical number of irrigated acres per well). Our results suggest that well retirement leads to average increases in current groundwater value at each well equal to $22, $37, and $95 per additional GPM after 15, 30, and 50 years of well retirement (dividing row 5 by row 2 in Table 6). These values for additional capacity appear to be the same order of magnitude as hedonic estimates, though they increase with time as more wells fall into lower well capacity ranges where the marginal benefit of additional capacity becomes larger. Since the value of additional well capacity in the shorter term (when well capacities are more similar to the ranges described in Brozovic and Islam (2010)) is similar to hedonic estimates, we take this as evidence that the non-market benefits of groundwater may be relatively small. Despite agreement seen in Table 1 that non-profit motivations could justify water conservation, producers do not appear willing to pay much to generate these benefits.

Our results require a few caveats that provide lessons for efforts to value natural capital stocks in the future. First, before a complete program evaluation can be undertaken, non-producer values must be estimated. This could be done through a benefit transfer exercise or through other non-market valuation methods. It would also be a useful exercise to value the non-market services of groundwater stocks directly because valuing the stock, which is an input into the service that produces value, requires survey respondents to accurately link stocks to non-market services and their value (Johnston et al. 2017b). It could be that producers are comfortable making the link between groundwater stocks, profit, and some non-market values such as bequest, but are less certain about how capacity generates other benefits such as recreation and habitat values.

Next, the additional water available at CREP-enrolled wells could become partially capitalized into the value of water at neighboring wells in ways that our valuation function does not capture. This highlights the need for future research that assesses potential changes in how resource stocks change over time, how producers update beliefs about these changes, and how this influences stock values.
Our dichotomous choice survey question asked producers if they support a government program that would be financed through taxation. Tax aversion and skepticism of government programs could cause producers who would pay for additional water to nevertheless decline to support this specific program. Respondents may also be concerned about where the water for aquifer recharge would come from. While traditional methods of testing for protest responses may alleviate this concern, future survey work should consider the social context and the potential for protesting efforts to improve natural capital stocks such as groundwater.

Finally, our estimated demand curves include both rival and non-rival values, making aggregation challenging. This means that well capacity values may vary across space in a way we cannot capture here. For example, well capacity that is close to a river may produce more value to society than capacity at a well that is farther away because the closer well has a bigger impact on surface water flows. In that case, the non-rival component of well capacity may be large for the well that is close to the river, even if they both produce similar market values. Some of this heterogeneity in value could be estimated with more detailed information on the location of wells, at least relative to surface water bodies. This suggests that future work should prioritize the isolation of resource attributes that provide private rival values versus those that produce public and non-rival benefits. This will facilitate accurate aggregation of both types of values created through resource management.

6 Conclusion

As land retirement programs become a more common method to implement conservation policies in agri-environmental systems, researchers must develop methods that can estimate their effectiveness and value to society. We demonstrate the use of stated preference methods to value a natural capital stock and how it is impacted by the Conservation Reserve Enhancement Program in southwest Kansas. The relatively small benefits generated suggest that other policies may be more cost effective at achieving groundwater
conservation goals.

The valuation framework we present here provides an instructive example of linking economic valuation functions with a physical model of natural capital. This method facilitates the valuation of program impacts when ecosystem service flows depend on the state of a resource stock. It can be especially useful when tradeoffs exist between collecting ecosystem service value and maintaining natural resource productive capabilities over time. Therefore, valuing natural capital offers a complementary approach to valuing the flows of ecosystem services provided by the earth’s natural systems.
References


Appendix A: CVM Survey Information

The following information was provided to survey respondents prior to eliciting support for a project that would increase well capacities (emphasis added):

Suppose that, to address groundwater depletion, your state is considering a one-time charge of $[XX] per irrigation well that would be charged to all producers that use groundwater for irrigation in your area. This charge would be included in your 2018 local property taxes and would finance an aquifer recharge program that would provide a 1-time increase in water in the aquifer, leading to an average of [YY] gallons per minute in additional well capacity in your area within 2 years.
8 Appendix B: Bias from Aggregating Value at Wells with Heterogeneous Capacity

Suppose a producer operates two wells with well capacities $x_1$ and $x_2$. The well level mWTP function is $mWTP(x_i)$ where the function is constant across wells but well capacity differs. To estimate a mWTP for each well, we would like to know if

$$mWTP(x_i) > A_i \quad i = 1, 2$$

Given that the CVM question is administered to the producer, we only know if the sum of $mWTP(x_i)$ exceeds $2A_i$, i.e.,

$$\frac{(mWTP(x_1) + mWTP(x_2))/2}{2} > A_i$$

This implies that

$$\ln\left(\frac{(mWTP(x_1) + mWTP(x_2))/2}{2}\right) > \ln(A_i)$$

The challenge is that we elicit a single mWTP from each producer which is based on the mWTP averaged across wells. This means we estimate if

$$\ln\left(\frac{(mWTP(\bar{x}) + mWTP(\bar{x}))/2}{2}\right) > \ln(A_i)$$

or

$$\ln(mWTP(\bar{x})) > \ln(A_i)$$

The left-hand side of equation 16 is the mWTP of the average well capacity, which differs from the average mWTP on the left-hand side of 14 as long as the mWTP function is nonlinear. In general, the predicted mWTP differs from the true well-level mWTP. The direction of the bias depends on the curvature of the mWTP function. If the function is concave (convex) then the estimated function over (under)-predicts the true mWTP at the well level. Given a convex functional form as in our empirical context (log linear), estimates understate the true well-level mWTP.

If, however, $x_1 = x_2 = \bar{x}$, then the bias disappears as the left-hand sides of equations 16 and 14 become equivalent. Therefore, if a producer’s well are located in a single area, and the same area average well capacity applies to both wells, then this aggregation bias approaches 0.
Figures 5 and 6 demonstrate that many enrolled wells are located on the border of the Arkansas River Basin. This suggests that benefits could accrue to wells outside the Arkansas River Basin. While surface water connections may be minimal across basin boundaries, this is not necessarily the case for groundwater. Therefore, we also investigate the benefits to all wells in the KGS MODFLOW model, presented in the map in Figure A1.

Figure A1 indeed suggests that some wells, particularly to the southwest of the Arkansas River Basin, experience increases in well capacity from the program. Therefore, we repeat the analysis for the region presented in Figure A1 and present results in Table A2. While the value of benefits increases when including more wells, the increase is not large, with most wells in the region beyond the MODFLOW model experiencing no additional saturated thickness and well capacity. This leads to current value increases of $1.5, $4.7, and $18.4 million after 15, 30, and 50 years of retirement respectively, compared to $1.2, $3.7, and $13.5 million when only considering the Arkansas River Basin.
Table 1: Summary of responses to reasons for conservation support

<table>
<thead>
<tr>
<th>Reason</th>
<th>(1) Mean</th>
<th>(2) St. Dev.</th>
<th>(3) Top score</th>
<th>(4) Strongly agree</th>
</tr>
</thead>
<tbody>
<tr>
<td>Future generations in area</td>
<td>4.113</td>
<td>0.71</td>
<td>0.77</td>
<td>0.28</td>
</tr>
<tr>
<td>Children and grandchildren</td>
<td>4.111</td>
<td>0.72</td>
<td>0.78</td>
<td>0.29</td>
</tr>
<tr>
<td>Ag remains profitable for me</td>
<td>3.960</td>
<td>0.79</td>
<td>0.67</td>
<td>0.22</td>
</tr>
<tr>
<td>Ag remains profitable for community</td>
<td>3.902</td>
<td>0.80</td>
<td>0.63</td>
<td>0.19</td>
</tr>
<tr>
<td>Jobs in community</td>
<td>3.823</td>
<td>0.81</td>
<td>0.56</td>
<td>0.17</td>
</tr>
<tr>
<td>Future drought more frequent</td>
<td>3.771</td>
<td>0.83</td>
<td>0.56</td>
<td>0.16</td>
</tr>
<tr>
<td>Compact compliance</td>
<td>3.397</td>
<td>0.98</td>
<td>0.36</td>
<td>0.11</td>
</tr>
<tr>
<td>Future higher prices</td>
<td>3.302</td>
<td>0.99</td>
<td>0.36</td>
<td>0.10</td>
</tr>
<tr>
<td>Hunt and fish</td>
<td>3.174</td>
<td>1.01</td>
<td>0.28</td>
<td>0.07</td>
</tr>
</tbody>
</table>

Note: The response categories are ordered from the highest mean Likert-scale response to lowest (column 1). Column 3 indicates the frequency with which a particular category received the highest Likert-scale response relative to the other categories. Since there are frequently ties for the highest response, column 3 sums to considerably more than one. Column 4 provides the frequency with which respondents indicated that they agree strongly (score of 5) that the category is a reason for supporting groundwater conservation.

Table 2: Summary Statistics for mWTP Model

<table>
<thead>
<tr>
<th>Model</th>
<th>Variable</th>
<th>Mean</th>
</tr>
</thead>
<tbody>
<tr>
<td>mWTP</td>
<td>Well capacity (GPM)</td>
<td>648.910</td>
</tr>
<tr>
<td>mWTP</td>
<td>Temperature 30-year normal (degrees C)</td>
<td>22.890</td>
</tr>
<tr>
<td>mWTP</td>
<td>Precipitation 30-year normal (mm)</td>
<td>77.562</td>
</tr>
<tr>
<td>Simulation</td>
<td>Initial well capacity (GPM)</td>
<td>655.569</td>
</tr>
<tr>
<td>Simulation</td>
<td>Saturated thickness (ft)</td>
<td>126.076</td>
</tr>
</tbody>
</table>
Table 3: Coefficient Estimates from Logit Model

<table>
<thead>
<tr>
<th>Dependent variable:</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Support</td>
<td></td>
</tr>
<tr>
<td>Log well capacity</td>
<td>−0.591** (0.283)</td>
</tr>
<tr>
<td>Log mean temperature</td>
<td>4.747*** (1.618)</td>
</tr>
<tr>
<td>Log mean precipitation</td>
<td>−2.130*** (0.613)</td>
</tr>
<tr>
<td>Log project cost</td>
<td>−0.439*** (0.134)</td>
</tr>
<tr>
<td>Constant</td>
<td>0.608 (5.902)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Observations</th>
<th>532</th>
</tr>
</thead>
<tbody>
<tr>
<td>Log Likelihood</td>
<td>−267.616</td>
</tr>
<tr>
<td>Akaike Inf. Crit.</td>
<td>545.232</td>
</tr>
</tbody>
</table>

Note: *p<0.1; **p<0.05; ***p<0.01

Table 4: Impact of Saturated Thickness on Well Capacity

<table>
<thead>
<tr>
<th>Dependent variable:</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Well capacity</td>
<td></td>
</tr>
<tr>
<td>Saturated thickness</td>
<td>3.584** (1.593)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Observations</th>
<th>76,266</th>
</tr>
</thead>
<tbody>
<tr>
<td>R²</td>
<td>0.006</td>
</tr>
<tr>
<td>Adjusted R²</td>
<td>−0.118</td>
</tr>
<tr>
<td>F Statistic</td>
<td>0.818 (df = 464; 67815)</td>
</tr>
</tbody>
</table>

Note: Model includes controls for well and county-year fixed effects *p<0.1; **p<0.05; ***p<0.01
### Table 5: Baseline Change in Groundwater and Value

<table>
<thead>
<tr>
<th>Variable</th>
<th>15 years</th>
<th>30 years</th>
<th>50 years</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 Saturated thickness (ft)</td>
<td>-28.933</td>
<td>-59.611</td>
<td>-98.543</td>
</tr>
<tr>
<td>2 Well capacity (GPM)</td>
<td>-81.323</td>
<td>-164.564</td>
<td>-258.277</td>
</tr>
<tr>
<td>3 Value ($)</td>
<td>-5,482,229</td>
<td>-17,447,124</td>
<td>-48,207,468</td>
</tr>
<tr>
<td>4 Present value ($)</td>
<td>-2,637,046</td>
<td>-4,036,871</td>
<td>-4,203,871</td>
</tr>
<tr>
<td>5 Value per well ($)</td>
<td>-1,080,455</td>
<td>-3,438,534</td>
<td>-9,500,881</td>
</tr>
<tr>
<td>6 Present value per well ($)</td>
<td>-519.717</td>
<td>-795.599</td>
<td>-828.512</td>
</tr>
</tbody>
</table>

### Table 6: Well Retirement Policy Benefits

<table>
<thead>
<tr>
<th>Wells</th>
<th>Variable</th>
<th>15 years</th>
<th>30 years</th>
<th>50 years</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 All wells</td>
<td>Saturated thickness (ft)</td>
<td>3.862</td>
<td>7.470</td>
<td>12.679</td>
</tr>
<tr>
<td>2 All wells</td>
<td>Well capacity (GPM)</td>
<td>10.778</td>
<td>19.548</td>
<td>27.617</td>
</tr>
<tr>
<td>3 All wells</td>
<td>Value ($)</td>
<td>1,215,256</td>
<td>3,708,376</td>
<td>13,535,172</td>
</tr>
<tr>
<td>4 All wells</td>
<td>Present value ($)</td>
<td>584,559</td>
<td>858,034</td>
<td>1,180,317</td>
</tr>
<tr>
<td>5 All wells</td>
<td>Value per well ($)</td>
<td>239,507</td>
<td>730,858</td>
<td>2,667,555</td>
</tr>
<tr>
<td>6 All wells</td>
<td>Present value per well ($)</td>
<td>115,207</td>
<td>169,104</td>
<td>232,621</td>
</tr>
<tr>
<td>7 Within 1 mile</td>
<td>Saturated thickness (ft)</td>
<td>9.335</td>
<td>18.455</td>
<td>32.726</td>
</tr>
<tr>
<td>8 Within 1 mile</td>
<td>Well capacity (GPM)</td>
<td>31.916</td>
<td>57.017</td>
<td>80.239</td>
</tr>
<tr>
<td>9 Within 1 mile</td>
<td>Value ($)</td>
<td>479,589</td>
<td>1,843,511</td>
<td>5,279,023</td>
</tr>
<tr>
<td>10 Within 1 mile</td>
<td>Present value ($)</td>
<td>230,690.9</td>
<td>426,546.8</td>
<td>460,350.5</td>
</tr>
<tr>
<td>11 Within 1 mile</td>
<td>Value per well ($)</td>
<td>769.807</td>
<td>2,959.086</td>
<td>8,473.552</td>
</tr>
<tr>
<td>12 Within 1 mile</td>
<td>Present value per well ($)</td>
<td>370.290</td>
<td>684.666</td>
<td>738.925</td>
</tr>
</tbody>
</table>

Note: All wells represents the aggregation across the entire study area. Within 1 mile represents the impacts only on wells that are within 1 mile of a well participating in CREP.
<table>
<thead>
<tr>
<th>Variable, Function, or Parameter</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>$x_{it}$</td>
<td>Area well capacity for well i in year t</td>
</tr>
<tr>
<td>$m_i$</td>
<td>Annual income for well i</td>
</tr>
<tr>
<td>$V(x_{it}, m_i)$</td>
<td>Present value indirect utility</td>
</tr>
<tr>
<td>$r$</td>
<td>Discount rate</td>
</tr>
<tr>
<td>$\delta$</td>
<td>Marginal utility of income</td>
</tr>
<tr>
<td>$x_t$</td>
<td>Vector of all area well capacities in year t</td>
</tr>
<tr>
<td>$g(x_t)$</td>
<td>Function describing new well capacity</td>
</tr>
<tr>
<td>$\frac{dV}{dx}$</td>
<td>Resource shadow value</td>
</tr>
<tr>
<td>$\Delta V$</td>
<td>Increase in value from a change in capacity</td>
</tr>
<tr>
<td>$\Delta PV$</td>
<td>Sum of $\Delta V$ across all wells</td>
</tr>
<tr>
<td>$x_{it}^0$</td>
<td>Well capacity used for lower bound of integral</td>
</tr>
<tr>
<td>$x_{it}^1$</td>
<td>Well capacity used for upper bound of integral</td>
</tr>
<tr>
<td>$A_{it}^{an}$</td>
<td>Annual cost of increasing well capacity</td>
</tr>
<tr>
<td>$\Delta WTP_{i}^{an}$</td>
<td>Annual WTP for an increase in well capacity</td>
</tr>
<tr>
<td>$\Delta WTP$</td>
<td>Present value WTP for an increase in well capacity</td>
</tr>
<tr>
<td>$mWTP$</td>
<td>Marginal willingness to pay for well capacity</td>
</tr>
<tr>
<td>$y_{it}$</td>
<td>Pumping from well I in year t (acre-ft)</td>
</tr>
<tr>
<td>$s_{it}$</td>
<td>Saturated thickness at well i in year t (ft)</td>
</tr>
<tr>
<td>$z_{it}$</td>
<td>Growing season average temp and precip (degrees C and mm)</td>
</tr>
<tr>
<td>$\alpha, \beta$</td>
<td>Parameters of WTP function</td>
</tr>
<tr>
<td>$a, b$</td>
<td>Parameters of groundwater extraction function</td>
</tr>
<tr>
<td>$d, f$</td>
<td>Parameters of well capacity function</td>
</tr>
</tbody>
</table>
Table A2: Well Retirement Policy Benefits, including Wells Outside The Arkansas River Basin

<table>
<thead>
<tr>
<th></th>
<th>Variable</th>
<th>15 years</th>
<th>30 years</th>
<th>50 years</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>All wells Saturated thickness</td>
<td>1.703</td>
<td>3.326</td>
<td>5.686</td>
</tr>
<tr>
<td>2</td>
<td>All wells Well capacity</td>
<td>5.748</td>
<td>10.496</td>
<td>14.651</td>
</tr>
<tr>
<td>3</td>
<td>All wells Value</td>
<td>1,530,901</td>
<td>4,729,176</td>
<td>18,358,190</td>
</tr>
<tr>
<td>4</td>
<td>All wells PV Value</td>
<td>736,389</td>
<td>1,094,225</td>
<td>1,600,903</td>
</tr>
<tr>
<td>5</td>
<td>All wells Value per well</td>
<td>132,660</td>
<td>409,807</td>
<td>1,590,831</td>
</tr>
<tr>
<td>6</td>
<td>All wells PV Value per well</td>
<td>63.812</td>
<td>94.820</td>
<td>138.726</td>
</tr>
<tr>
<td>7</td>
<td>Within 1 mile Saturated thickness</td>
<td>9.210</td>
<td>18.186</td>
<td>32.342</td>
</tr>
<tr>
<td>8</td>
<td>Within 1 mile Well capacity</td>
<td>32.332</td>
<td>57.484</td>
<td>80.663</td>
</tr>
<tr>
<td>9</td>
<td>Within 1 mile Value</td>
<td>542,969</td>
<td>1,962,197</td>
<td>5,658,792</td>
</tr>
<tr>
<td>10</td>
<td>Within 1 mile PV Value</td>
<td>261,177</td>
<td>454,008</td>
<td>493,467</td>
</tr>
<tr>
<td>11</td>
<td>Within 1 mile Value per well</td>
<td>847</td>
<td>3,061</td>
<td>8,828</td>
</tr>
<tr>
<td>12</td>
<td>Within 1 mile PV Value per well</td>
<td>407</td>
<td>708</td>
<td>769</td>
</tr>
</tbody>
</table>
Figure 1: Aquifer Depletion, 1935-2015

Figure 2: Valuation Model Components
Figure 3: Value of Change in Well Capacity
Figure 4: Predicted marginal willingness to pay, Finney County
Figure 5: Spatial Heterogeneity in Additional Well Capacity from 15 Years of Well Retirement

Figure 6: Spatial Heterogeneity in Additional Groundwater Stock Value from 15 Years of Well Retirement
Figure A1: Spatial Heterogeneity in Additional Groundwater Stock Value from 15 Years of Well Retirement, beyond the Arkansas River Basin