Estimating the Impact of the USDA Conservation Reserve Program on Groundwater Levels

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Abstract:

Many parts of the High Plains region are facing declining aquifer levels, which threatens the long-term viability of irrigated agriculture. Furthermore, some areas of the High Plains region, like the Republican River Basin in Nebraska, need to keep groundwater levels high enough in the short-term to ensure that hydrologically connected rivers have enough streamflow to fulfill surface water obligations, such as Nebraska's interstate river compact with Colorado and Kansas. To better manage groundwater, society needs to understand the unintended effects of policies that may not be aimed at groundwater conservation, such as the USDA- Conservation Reserve Program (USDA-CRP). CRP pays farmers to take cropland out of production and put them into conservation covers, like grassland. This is done for environmental benefits like reduced soil erosion, improved surface water quality, and increased wildlife habitat. But, the changes in landcover due to CRP enrollment could also impact the infiltration of precipitation through the soil, thus changing groundwater recharge. The paper estimates the potential effect of CRP on groundwater levels using data from the Republican River Basin. The analysis relates disaggregated aquifer level data with geospatial landcover data, weather, soil, and groundwater extraction data through a buffer analysis. Grassland landcover in general is used to represent grassland put in by CRP. Findings suggest that grassland has a lower yearly recharge rate than corn and soy landcovers. An implication of the result is that CRP enrollment should consider aquifer impacts in addition to other environmental changes when determining which parcels to enroll in the program.

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I. Introduction

Worldwide, trends such as population growth and climate change are putting stress on the available water resources desperately needed for agricultural production, other economic activity, and domestic consumption. Areas like the High Plains Aquifer (HPA) region of the United States are heavily dependent on groundwater for economic activities like irrigated agriculture, and about 90 percent of all water used is from groundwater (Dennehy, 2000). The HPA covers parts of eight states, and the greatest use in any single state is in Nebraska. In 2012, Nebraska had more irrigated acres than any other state (8.3 million acres), and almost 92 percent of the irrigation water used in the state was groundwater.[1] However, many parts of the HPA region are facing declining aquifer levels in the short and long-term. This puts the long-term economic viability of the region in peril. In addition, groundwater levels in many areas are hydrologically connected to surface water flows. In areas like the Republican River Basin of Nebraska, managers are mandated with ensuring that hydrologically connected rivers have enough streamflow to fulfill surface water obligations such as the interstate compact with Colorado and Kansas.

Therefore, there is an interest in finding and using policies that will maintain or increase groundwater levels, or in redirecting policies that may be harmful to that objective. Assessing the impact of current government programs, such as the USDA's Conservation Reserve Program (CRP), is an important step in that process. CRP pays farmers to take environmentally susceptible cropland out of production for ten to fifteen years to achieve environmental benefits. This involves putting the land into a new landcover, such as grassland, forests, or wetlands. The CRP was established in the 1985 U.S. Farm Bill as a program to reduce soil erosion, and it has been shown to have erosion reduction, surface water quality, and wildlife habitat benefits (Ribaudo et al. 1989, Tanaka et al. 2004). However, CRP can feasibly impact aquifer levels, as it pays farmers to take environmentally susceptible land out of production and put in a non-crop landcover, mainly grassland. While CRP is known to have several positive environmental benefits, such as reduced soil erosion; the connection between CRP and aquifer levels is less known. The hydrology literature suggests that differences in groundwater recharge between

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[1] See the 2013 U.S. Department of Agriculture Farm and Ranch Irrigation Survey (USDA-FRIS) at https://www.agcensus.usda.gov/Publications/2012/Online_Resources/Farm_and_Ranch_Irrigation_Survey/ for more information.

grassland (expected CRP landcover) and cropland exist, with grassland leading to a lower groundwater recharge rate (Scanlon et al. 1995). Any unintended effect of CRP is especially important because of recent changes in the amount of land enrolled in the program. Due to a combination of high commodity prices and decreased federal funding, total enrolled acreage in CRP has declined from 36.8 million acres in 2007 to 23.9 million acres in 2016. CRP acreage in the HPA states decreased from 14.7 million acres in 2007 to 10.1 million acres in 2016.[2] Simultaneously, the average CRP payment per acre has increased to compensate for changes in land values, and the associated cropland rental rates. Thus, these changes could have measurable effects on aquifer levels if the land coming out of CRP is put into crop production.

The goal of this paper is to estimate the impact of grassland, the predominant landcover associated with CRP, on aquifer levels. The results will allow policymakers and agency personnel to better target CRP enrollment, and to incorporate any positive or negative externalities on groundwater levels associated with changes in landcover. Our analysis uses observation wells and other spatial data from the Republican River Basin region of Nebraska from the years 2007 to 2014. The region and period is chosen due to the availability of groundwater extraction data. Incorporating extraction is a critical part of evaluating the net change in groundwater levels, as the system is affected by extraction and precipitation, as well as other variables. We use a buffer analysis to find annual local geospatial data about landcover, weather, groundwater extraction, and soil quality around observation wells. We relate the change in depth to the aquifer from observation wells with the local data using a fixed effects model. Grassland is used as a proxy for CRP-induced landcover changes. The paper and analysis make

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[2] This information is available on the USDA-Farm Service Agency website at https://www.fsa.usda.gov/programs-and-services/conservation-programs/reports-and-statistics/conservation-reserve-program-statistics/index.

several contributions to the existing literature. In contrast to previous work in economics that has examined enrollment in CRP or program efficiency through targeting (e.g. Ribaudo, 1989; Szentandrasi et al., 1995; Feng et al., 2004) and direct associated environmental benefits (e.g. Hansen, 2007; Knoche et al, 2015), the paper adds to the literature by measuring the potential unintended impact of CRP on aquifer levels. The paper adds to the literature in other fields by the methods used to estimate differences in groundwater recharge between grassland and cropland. It includes the impact of groundwater extraction, in addition to recharge factors, on aquifer levels, rather than just focusing on finding differences in recharge or evapotranspiration (Scanlon et al. 1995; Yun et al. 2011; Nosetto et al. 2011). Also, it uses hundreds of individual observation well locations when considering aquifer levels and local groundwater extraction, instead of larger aggregated regional groups (Rao and Yang 2010). Our results suggest that grassland covers, and therefore CRP grassland, will lead to decreased aquifer recharge compared to the common crops in Nebraska (corn and soy). The findings suggest a need to balance the known environmental benefits of CRP and associated programs like the USDA Conservation Reserve Enhancement Program (USDA-CREP) with expected reductions in aquifer levels and available funding.

Previous work in the economics literature has examined the environmental benefits of the CRP program or ways to target the program to enhance benefits. Babcock et al. (2001) use Gini coefficients and Lorenz curves to consider alternative methods of targeting CRP to gain reduced erosion, increased surface water quality, and wildlife habitat. Knoche et al. (2015) find optimal restoration areas in Michigan for pheasant populations to enhance hunter benefits. Ribaudo (1989) consider targeting CRP acres to reduce erosion in watersheds where the most damage per a ton of population or acre of land. Szentandrasi (1995) considers targeting of CRP to help maintain bio-diversity in Oregon under an assumption if decreasing CRP acres. Feng et al. (2004) look at targeting of CRP acres in the Mississippi River Basin in order to increase carbon sequestration while considering gains or tradeoffs to other benefits. Hansen (2007) combines several environmental benefit models to estimate the as much of the yearly US economic benefits of CRP as possible, and found that to be at least 1.3 billion dollars a year (in 2000 dollars). The benefits considered included various aspects of economic benefits of reduced soil erosion, reduced air pollution, improved water quality, and increased wildlife habitat. The 1.3 billion number accounted for 70 to 85 percent of CRPs annual costs, but Hansen suggests the true benefits are probably higher than the costs due to not being able to fully account for all of CRP's benefits (such as carbon sequestering or further soil and wildlife benefits), but also recognizes there are also unacted for costs (such as higher food prices). The impact of CRP on groundwater levels is one of the unknowns that still needs to be accounted for.

While the impact of CRP on aquifer conditions, including aquifer levels, is not well known in the economics literature, there is research in hydrology that evaluates the tradeoffs between cropland and grassland recharge. Scanlon et al. (1995) test differences in recharge for sample grassland and various crop production in Texas and Nevada by adding tracer chemicals to the soil and checking their presence at a later date using soil core samples. They find negligible rates of recharge for grassland. In contrast, they find recharge of 130 to 640 mm per year on irrigated cropland and 9 to 32 mm on non-irrigated cropland. However, they find that greater recharge is associated with greater mobilization of salts and other pollutants. Yun et al. (2011) use the WetSpass model to estimate landcover impacts on recharge in the Guishui River Basin, China. They find that non-irrigated cropland has about 122.74 mm in recharge compared to 116.80 mm for grassland due to lower evapotranspiration and runoff for cropland. Nosetto et al. (2011) focus on comparing the evapotranspiration (ET) differences between landcovers in central Argentina using ET estimates from Landsat satellite images. They find estimates of 2.13 mm of ET per day for native grassland and 1.85 mm of ET per day for single plated soybeans. These results suggest that CRP grassland may lead to a lower rate of recharge than cropland. However, this finding is not supported by all of the existing literature. Rao and Yang (2010) use a SWAT model and GIS analysis for sub-basins in Texas County, Oklahoma and find that sub-basins with more CRP acres are spatially correlated with a larger increase (smaller decrease) in groundwater levels between 1990 and 2000. Thus, additional research is necessary to distinguish the net impact of CRP.

II. Background on Relevant Policies

The primary goal of this work is to determine if CRP has unintended impacts on aquifer levels. As mentioned earlier, CRP enrolls previously farmed land for a 10 to 15 year contract. A landowner who wants to enroll a parcel into CRP needs to submit an offer, which is evaluated based on an Environmental Benefits Index (EBI). The six criteria that are used in the EBI to evaluate offers include wildlife habitat benefits, water quality benefits through reduced erosion, on-farm benefits of reduced erosion, enduring benefits, air quality benefits, and cost.[3] Impacts on water quantity are not one of the primary criteria. A submitted offer must outline the practices that a landowner will implement on the parcel and the per-acre payment rate the producer will accept. The maximum payment rates are based on average county-level non-irrigated rental rates. While there are obvious changes in water availability if land is shifted from irrigated crop production to grassland, it is unlikely that much of the CRP enrollment is from irrigated land

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[3] Details about the criteria considered for acceptance into CRP are available at https://www.fsa.usda.gov/programs-and-services/conservation-programs/conservation-reserve-program/ in the Signup 49 State Booklet.

since the maximum payment is based on the average value of non-irrigated land. If we find significant impacts of landcover on aquifer recharge, a change in the EBI formula could be made to incorporate water quantity impacts where relevant. This would involve higher scores if CRP has a positive effect on groundwater levels or lower scores if CRP has a negative impact on groundwater levels.

Another policy that is relevant to the analysis and to potential policy recommendations to alleviate negative environmental externalities associated with CRP is the Conservation Reserve Enhancement Program (CREP). While CRP is unlikely to lead to a significant change in irrigated acres since payments are based on non-irrigated rates, the same is not true for CREP. CREP environmental priorities are determined by individual states, and involve a partnership between the USDA and the state. In Nebraska, CREP has been used to retire 10,000 acres from irrigated production in the Republican and Platte river basins. Additional funding from the state allows CREP payments to be higher than standard CRP rates, making the program competitive with irrigated agricultural production. Any reduction in irrigated production will have a direct benefit on groundwater levels, but that benefit comes at a higher financial cost. Thus, an alternative to modifying the EBI criteria for CRP is to reallocate financial resources from CRP to CREP, although this reallocation will lead to fewer acres enrolled overall.

With the recent decline in CRP acreage, measuring the impacts on aquifer levels depend substantially on a landowner chooses to do with a parcel after taking it out of the CRP program. Past work suggests that only a limited number of acres exiting CRP might stay in their CRP landcover and out of production. Roberts and Lubowski (2007) found that land covered in grasses or legumes under CRP and exited CRP from 1992-1997, 65.8% returned to cropland by 1997. However, this depends on the relative value of crop production, and higher commodity prices in recent years may lead to even higher turnover back to crop production than indicated by earlier studies.

III. Additional Information on the Study Region

Our analysis uses data from the Republican River Basin (RRB) of Nebraska. The RRB overlies the High Plains Aquifer (HPA), and economic activity in the area is highly dependent on agricultural production. The HPA is a significant source of irrigation water for the overlying states (largely Nebraska, Kansas, and Texas). Groundwater levels in most of the HPA are declining due to groundwater extraction for irrigation. This has led to a variety of groundwater regulations and local groundwater regulatory bodies aimed at balancing current needs with future ones. These have resulted in varying levels of success in maintaining aquifer levels. Texas and Kansas still face a long-term decline, in part due to low groundwater recharge rates. Thus, both have management goals to keep the aquifer economically viable for a 50-year horizon. Nebraska has more stable or increasing groundwater levels, in part due to higher recharge rates, and thus has a goal of sustaining irrigated production.

Nebraska still needs to limit groundwater use, especially due to the hydrological connectivity between rivers and aquifers. Extraction of groundwater from aquifers hydrologically connected to local rivers can lead to decreased streamflow. This has been an immediate concern in the Republican River Basin due to an interstate compact that requires Nebraska to provide enough streamflow to meet compact requirements. Nebraska’s groundwater allocations are managed through a network of Natural Resource Districts (NRD). Each NRD is governed by a locally elected board of directors with some state oversight. The local nature of NRD governance allows regulations to differ to meet local conditions and requirements. The four NRDs in the Republican River Basin (the Tri-Basin, Upper Republican, Middle Republican, and

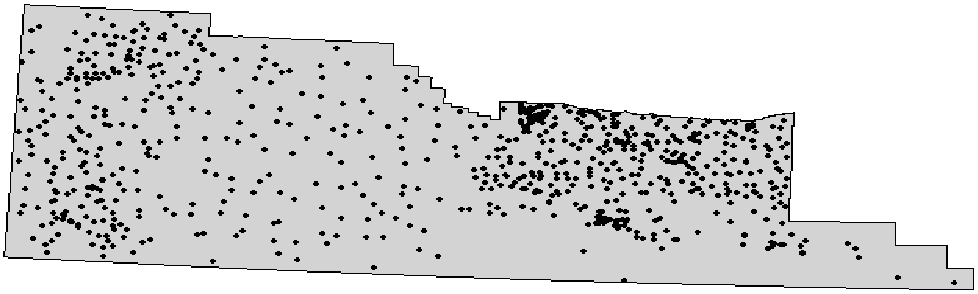
Lower Republican) have some of the strongest groundwater regulations in the state in order to meet the requirements of the Republican River Compact. These requirements include required irrigation metering, official meter inspections, and groundwater use limits. Given the needs for maintained groundwater levels in the Republican River Basin and the existence (and availability) of groundwater extraction data (needed to create a complete groundwater model), the Republican River Basin is used as the study area.

IV. Data

Data Sources

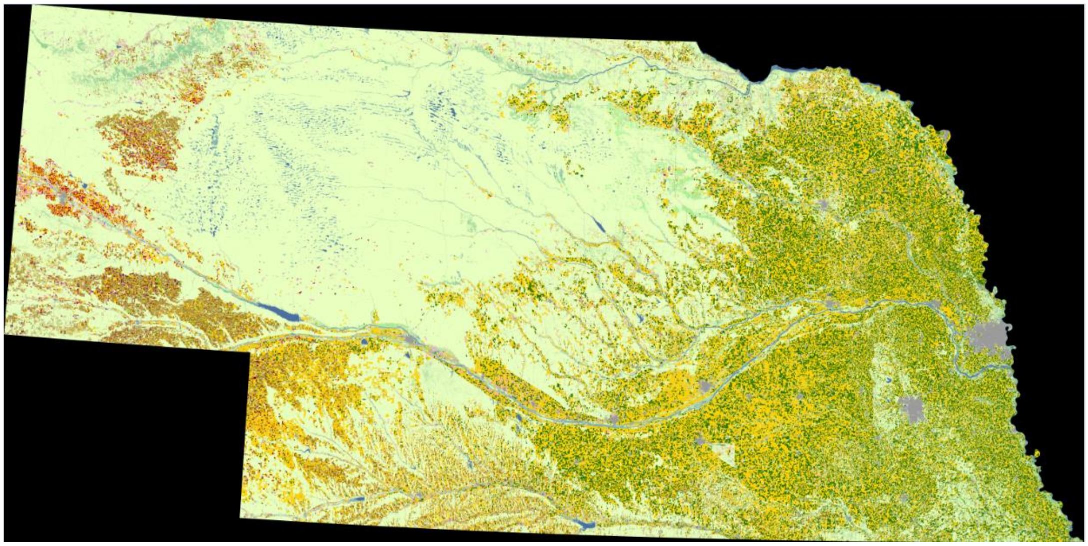
The dependent variable for our econometric estimation is the annual change in the depth to water table (DWT) for individual groundwater wells. The DWT data in the study area is from the well database maintained by the United States Geological Service (USGS). The USGS data provides measurements of DWT, the date of measurement, and the geographic coordinates of wells. These observation wells are designated specifically for the purpose of keeping track of depth to water change over time, and they are not used for any other purposes, such as agricultural irrigation. Figure 1 shows the distribution of observations wells in the study area. While the observations in the data set include measurements of DWT from dates throughout the year, we only use values from March and April. The reason for this is that we only observe groundwater extraction on an annual basis, and we want the DWT values to reflect conditions where aquifer levels have recovered from the dynamic impacts of intraseasonal pumping as much as possible. Observations in March and April are shortly before the irrigation starts, ensuring that the impact of groundwater extraction is fully captured in changes in DWT, and reducing the likelihood of seasonal cones of depression that bias the DWT values. When multiple measurements are reported in a single year, we take the average of March and April measurements.

Figure 1: Distribution of Observation Wells



The annual landcover data is from the National Agricultural Statistics Service (NASS) CropScape, which is a gridded geospatial data layer of landcover types, such as corn, soy, and grassland. Figure 2 gives an example of the CropScape landcover data for Nebraska in 2014.

Figure 2: 2014 Nebraska CropScape Map



Notes: *Yellow is Corn, Dark Green is Soy, Light Green is Grassland*

Geolocated annual groundwater extraction data is obtained from some of the Nebraska NRDs located in the Republican River Basin: the Upper Republican, Middle Republican, Lower

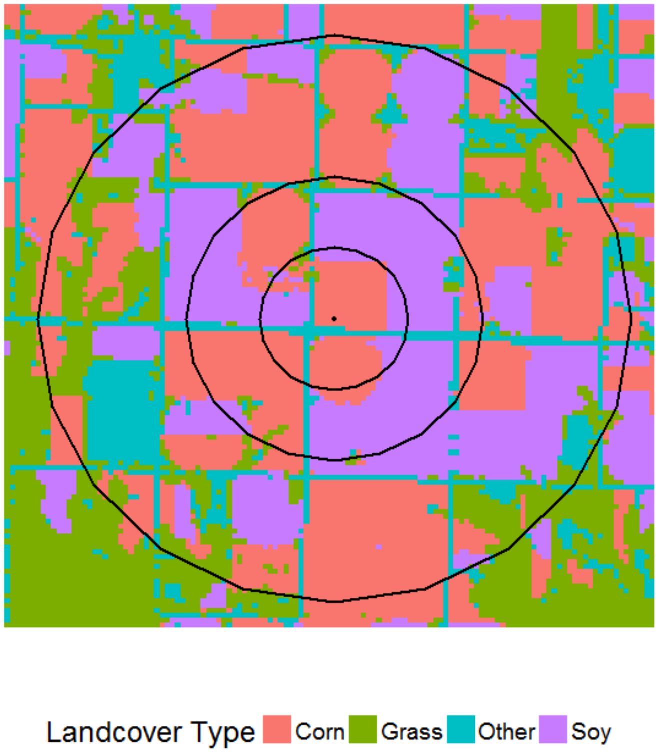
Republican, and Tri-Basin NRDs. These records are expected to be largely complete and mostly accurate due to regulations in the region requiring the use of meters, and NRD inspection of those meters.

Annual weather data is from the PRISM climate data group at the Oregon State University. It reports daily precipitation, minimum temperature, and maximum temperature with the spatial resolution of 4 by 4 (kilometer). The data is used to calculate the in and off crop season precipitation (inches) and in-season growing degree days in the study area. The in-season is defined as April to September for a given year, and the off-season is October to March of the following year. Soil data is from the USGS SURRGO dataset. This data includes the percentage of soil types (sand, clay, silt).

Data Processing

In order to find the local conditions of weather, soil, landcover, and groundwater extraction around the observation wells, we draw buffers around each of the observation wells and then summarized information within the buffers. Figure 3 shows an example with a half mile, one-mile, and two-mile radius buffers used in the study on a portion of the CropScape map.

Figure 3: Buffer Analysis Example



For landcover, we calculate the number of grids for each landcover type by overlaying the buffer onto the CropScape layer. The share of each landcover type is calculated based on the percent of total grid cells. For the weather and soil data, we overlay the buffer on the PRISM grids (SSURGO polygons) to identify which grids (polygons) intersect or are contained in the buffer. Then we calculate the grid (polygon) area-weighted weather (soil) variables. Groundwater extraction uses total irrigation water extracted by all irrigation wells within the buffer. We do not do any spatial discounting to reflect the distance between the observation and extraction wells.

Table 1 shows the summary statistics of the data for the two-mile buffer. The summary statistics for the one-half and one-mile buffers are very similar. The only key difference is in the groundwater extraction variables, as larger buffers have greater extraction quantities, reflecting more irrigation wells.

Table 1: Summary Statistics for Two Mile Buffer

	Mean	Standard Deviation	Minimum	Maximum
Change in Depth to Groundwater (inches)	1.573	25.600	-591.960	537.120
Groundwater Extraction (acre feet)	2116.672	1470.326	0	10533.56
In Season Precipitation (inches)	19.686	4.654	7.751	33.038
Off Season Precipitation (inches)	5.136	2.649	1.443	13.966
In Season Growing Degree Days	1664.309	147.200	1337.763	2133.195
Local Corn Landcover (0-100%)	32.752	17.293	0	80.646
Local Soy Landcover (0-100%)	8.2705	10.663	0	45.904
Local Grass Landcover (0-100%)	41.737	23.605	2.156	95.910
Local Other Landcover (0-100%)	17.387	11.141	1.412	79.220
Sand in Soil (0-100%)	39.659	29.469	8.783	94.998
Clay in Soil (0-100%)	16.887	7.276	2.509	29.847

Table 1 shows that the landcover is dominated by grass and corn, with soy making up a smaller portion in this region. Extraction for the two-mile buffer case is shown to have a large range (from 0 to 10533.56 acre feet), but has a mean near 2116.672 acre feet, suggesting many small values. Approximately 5 percent of the sample has zero observed groundwater extraction.

Figures 4 through 7 show yearly box plots for depth to groundwater changes, in-season precipitation, and extraction for the two-mile buffer case.

Figure 4: Yearly Distributions of Depth to Groundwater Changes (Two-Mile Buffer)

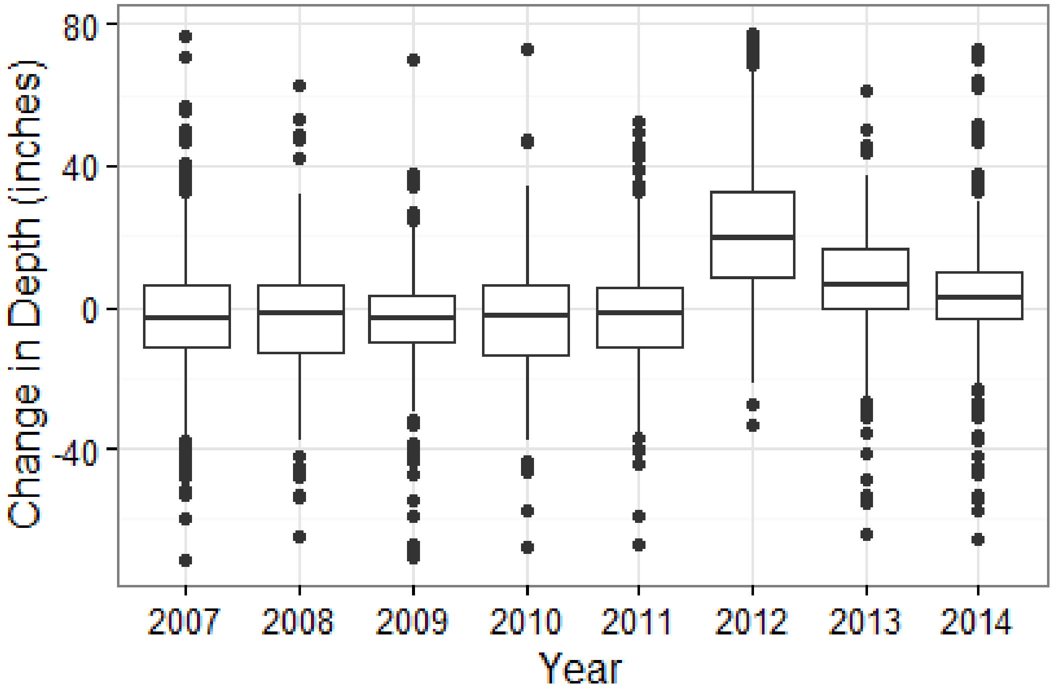


Figure 5: Yearly Distributions of In Season Precipitation (Two-Mile Buffer)

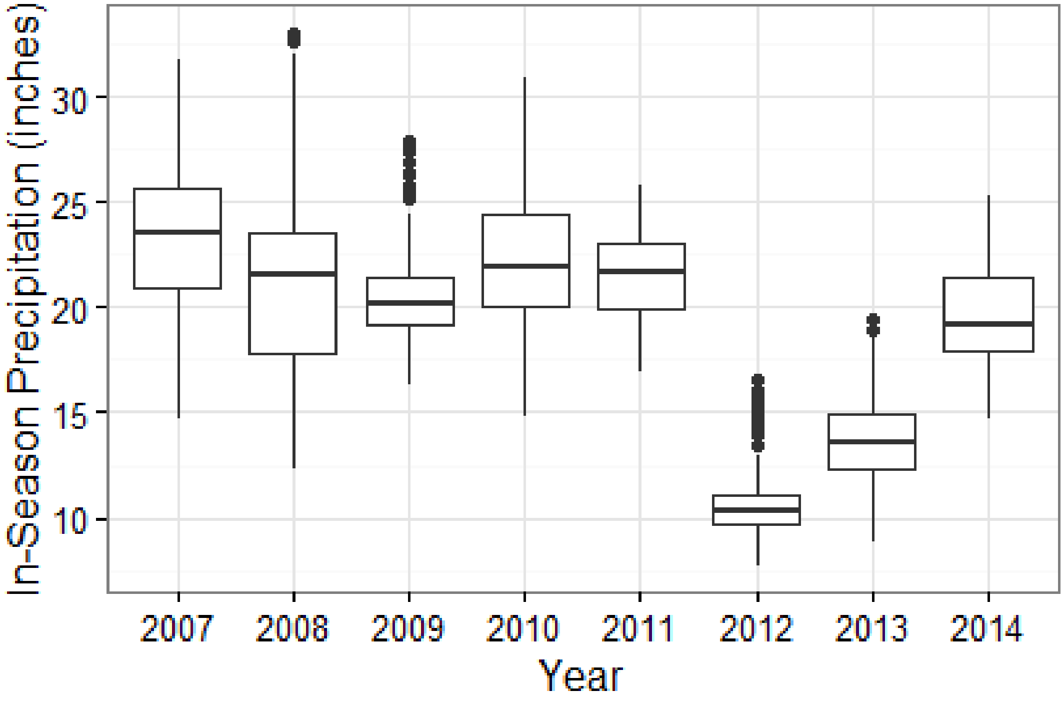


Figure 6: Yearly Distributions of Groundwater Extraction (Two-Mile Buffer)

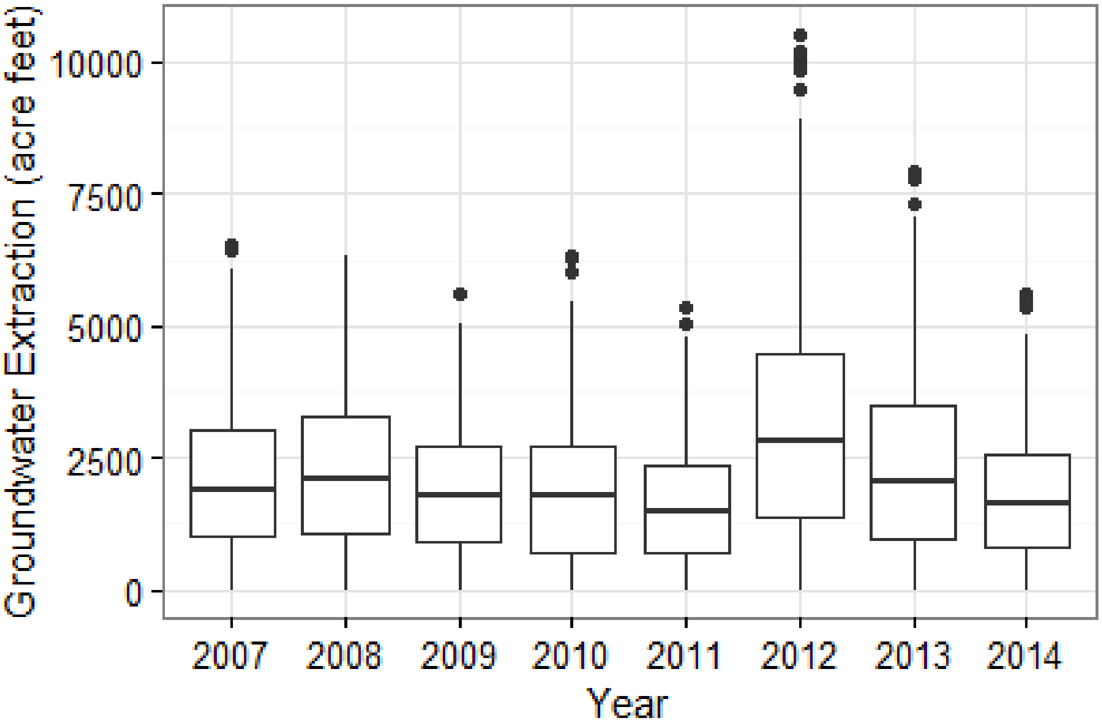


Figure 4 shows that in most years the change in the depth to aquifer levels stays within a few inches, and for most years, has more wells with increasing aquifer levels (negative depth changes). Noticeable however, is the jump in 2012, which coincided with the drought seen in Figure 5. Figure 6 shows that extraction of groundwater increased in 2012 adjust for the drought. Precipitation remained lower than usual in 2013, with extraction and depth to aquifer changes staying higher than usual. By 2014, levels returned close to pre-drought conditions.

V. Econometric Method

The main goal of this article is to quantify the impacts of landcover changes on aquifer depletion via econometric analysis. The estimating equation is:

$$\Delta DWT_{i,t} = \beta_0 + \beta_L L_{i,t} + \beta_{GW} GW_{i,t} + \beta_W W_{i,t} + \beta_{SW} S_i \times W_{i,t} + \alpha_i + \phi_t + \varepsilon_{i,t}$$

where i denotes the USGS observation well and t the year. The dependent variable is changes in depth to groundwater table ($\Delta DWT_{i,t}$). This means that variables that increase aquifer levels will have a negative coefficient for decreasing the depth to groundwater while variables the decrease aquifer levels will have a positive coefficient.

Included covariates are a vector of landcover shares ($L_{i,t}$), a vector of groundwater extraction variables ($GW_{i,t}$), a vector of weather variables ($W_{i,t}$), a vector of soil-weather interactions ($SW_{i,t}$), individual well fixed effect (α_i), year fixed effect (ϕ_t). Finally, $\varepsilon_{i,t}$ is the error term.

The landcover vector separates land into four categories: corn, soy, grassland, and everything else. The grassland share is omitted so that the coefficient estimates on corn and soy are their impacts on depth to groundwater table relative to grassland. Other potential CRP landcover types like forest and wetland are not considered due to extremely low values in the study area. Corn and soy are modeled separately because they are the predominant crop covers in Nebraska and therefore most likely to be converted to grassland in CRP. The hydrology literature suggests that recharge is greater on cropland than grassland (Scanlon et al. 1995), which suggest that increased crop cover should be related to increased aquifer levels (decreased depth to groundwater).

The groundwater extraction vector includes the extraction and extraction squared to create a quadratic relationship between groundwater extraction and ΔDWT. This relationship is used to capture the possibility that additional groundwater extraction at higher levels of local groundwater extraction may be more noticed at the observation well than at lower levels.

Because extraction is removing water from the aquifer, it should be related to decreased aquifer levels (increased depth to groundwater).

The vector of weather variables includes in- and off-season precipitation and growing degree days. The precipitation variables are expected to increase groundwater levels (decrease the depth to groundwater) as precipitation that infiltrates through the soil is one of the main sources of aquifer recharge. Of the two, off-season precipitation could have a larger effect on aquifer levels if there is less crop cover in the off-season, which encourages greater percolation. Growing degree days on the other hand should lead to decreased aquifer levels (a higher depth to groundwater) because higher temperature should lead to more evapotranspiration of water before it infiltrates through the soil.

The soil-weather vector ($SW_{i,t}$) includes interactions between the share of two soil types (clay and sand) and the in- and off-season precipitation variables. The third soil category (silt) is dropped and is the reference category. Sand and clay are expected to allow more recharge than silt, so sand and clay are expected to be associated with higher aquifer levels (decreased depth to groundwater). The soil types are not considered outside of interactions as they are fixed over time and would thus be eliminated by the fixed effects model.

VI. Results

The primary fixed effects results for the one-half, one, and two-mile buffers are shown in Table 2, while Table 3 shows the marginal effects for precipitation at the means and the marginal effects for extraction at the 25th, 50th, and 75th percentiles. Table 4 shows the values of the means and percentiles used in calculating the marginal effects listed in Table 3. We use Newey-West standard errors to account for heteroskedastic and autoregressive errors. The dependent variable is depth to groundwater (in inches). Thus, a negative (positive) coefficient suggests that a variable increases (decreases) aquifer levels.

Table 2: Regression Results (Dependent Variable is Change in Groundwater Level in Inches)

	Half Mile Buffer	One Mile Buffer	Two Mile Buffer
Groundwater Extraction (thousands of acre feet)	8.871	-1.939	-0.107
	(24.080)	(11.892)	(4.015)
Groundwater Extraction Squared (thousands of acre feet)	8.368	4.239	0.435
	(18.619)	(3.512)	(0.318)
In-Season Precipitation (inches)	2.725***	2.671***	2.838***
	(0.724)	(0.785)	(0.947)
Off-Season Precipitation (inches)	-0.560	-0.580	-0.203
	(1.281)	(1.332)	(1.527)
Growing Degree Days	-0.031*	-0.035**	-0.046**
	(0.017)	(0.018)	(0.019)
Local Corn Landcover (0-100%)	-0.495***	-0.733***	-1.127***
	(0.121)	(0.179)	(0.211)
Local Soy Landcover (0-100%)	-0.496***	-0.691***	-1.055***
	(0.129)	(0.211)	(0.296)
Local Other Landcover (0-100%)	-0.568***	-1.028***	-1.455***
	(0.150)	(0.195)	(0.246)
Percent Soil Clay * In Season Precipitation	-0.136	-0.136***	-0.143***
	(0.029)	(0.032)	(0.039)
Percent Soil Clay * Off-Season Precipitation	-0.060	-0.061	-0.085
	(0.046)	(0.047)	(0.054)
Percent Soil Sand * In-Season Precipitation	-0.044***	-0.044***	-0.047***
	(0.007)	(0.007)	(0.008)
Percent Soil Sand * Off-Season Precipitation	-0.020*	-0.020*	-0.026*
	(0.012)	(0.012)	(0.014)
Observations	3852	3,772	3,596
R^2	0.076	0.063	0.049

The primary goal of our research is to estimate the impact of CRP on aquifer levels. Thus, the parameters of greatest interest are the landcover variables, since they are a proxy for changes associated with enrolling land into, or taking land out of, CRP. In all cases corn and soy landcovers have similar coefficients and have higher aquifer recharge than grassland (the omitted category). As expected, the absolute value of the estimated coefficients increases with a larger buffer size, as each percentage reflects a larger change in total area. Because of this, it is informative to transform the coefficients into a per-acre marginal effect. One percent of the buffer is approximately 5 acres in the half-mile case, 20 acres in the one-mile case, and 80 acres in the two-mile case. Using the coefficients on corn from Table 2, we estimate that an additional acre of corn reduces the depth to the aquifer by 0.100 inches in the half mile case, 0.037 inches in the one-mile case, and 0.014 inches in the two-mile case. The difference in the per-acre could be the result of two factors. First, land closer to the observation well will have a higher impact on the groundwater depth at the observation point. Second, there could be a stronger spatial correlation between landcover outside of the buffer and changes in aquifer levels for smaller buffers. A weighted regression, where weights are based on the distance to the observation well, may be a way to discern these factors.

Table 3: Marginal Effects at the Means and at a Range of Extraction Percentiles

	Half Mile Buffer	One Mile Buffer	Two Mile Buffer
Mean - In Season Precipitation	-1.362***	-1.424***	-1.484***
(inches)	(0.175)	(0.206)	(0.233)
Mean - Off Season Precipitation	-2.377***	-2.436***	-2.675***
(inches)	(0.361)	(0.375)	(0.423)
25th Percentile – Extraction	10.095	0.223	0.703
(thousands of acre feet)	(21.507)	(10.167)	(3.438)
50th Percentile – Extraction	11.631	2.646	1.536
(thousands of acre feet)	(18.341)	(8.265)	(2.852)
75th Percentile – Extraction	13.610*	5.322***	2.520***
(thousands of acre feet)	(9.851)	(1.680)	(1.021)

Table 4: Range of Extraction Percentile Values Used

	Half Mile Buffer	One Mile Buffer	Two Mile Buffer
25th Percentile – Extraction (thousands of acre feet)	0.073	0.255	0.931
50th Percentile – Extraction (thousands of acre feet)	0.165	0.541	1.889
75th Percentile – Extraction (thousands of acre feet)	0.283	0.856	3.020

The percentile values for each buffer size are listed in Table 4. Although extraction represents withdrawals from the aquifer, the marginal effect is only statistically significant at the 75th percentile level. Groundwater extraction might need to reach a critical level before it has a noticeable impact on nearby observation wells. More work needs to be done in order to determine the quantities and distances at which this threshold is reached. Additionally, the impact of groundwater extraction increases with smaller buffers. When evaluating the average per-acre extraction values, we find that the values are not constant across the different buffer sizes. For example, the 75th percentile of annual extraction represents approximately 6.8 inches per acre with a one-half mile buffer, 5.1 inches per acre with a one-mile buffer, and 4.5 inches per acre with a two-mile buffer. One possible explanation is that extraction wells and observation wells are close to each other (or the same wells), and the winter season is not sufficient time for groundwater levels to equalize across the buffer. Extraction, like landcover, that is closer to the observation well should also have a higher impact, as seen with the coefficients, but it is not clear if the total increase is due to closer proximity, or due to higher spatial correlation in extraction with land outside the buffer. As with landcover, a weighted regression or using multiple buffers with varying coefficients is needed to better capture the impact of extraction.

As expected, additional precipitation increases aquifer levels, with a greater impact in the off season than during the production season. The lack of planting and lower temperatures in the off season are likely to increase the proportion of precipitation that contributes to recharge. The soil interactions also suggest that sand and clay soils hinder it less than the base silt case, at least in the in-season precipitation case.

VII. Conclusions

The findings suggest that grassland, a major CRP landcover, has reduced recharge compared to corn and soy landcovers. This matches with the work of Scanlon et al. (1995), Yun et al. (2011) and Nosetto et al. (2011). If aquifer depletion is a concern of policy makers, this could be addressed by better targeting of CRP enrollment to areas where the impact is smaller or less significant. Another option is to direct funding towards CREP, or a similar irrigation reduction scheme to gain irrigation offsets. However, the marginal effect of taking land out of irrigated production through a program like CREP needs to account for the fact that a change in landcover may have a secondary effect on recharge that reduces the benefits of decreased extraction. More work needs to be done with the estimation of landcover and groundwater extraction impacts on aquifer levels in order to determine the irrigation offset necessary to account for recharge losses from landcover change. On the other hand, large amounts of land leaving CRP may have a positive impact on aquifer levels if the land exiting CRP is moved into non-irrigated production. However, these benefits need to be tempered by the loss of other environmental benefits that result from CRP exit.

More work is needed to fine tune the spatial and temporal relationships between spatially disaggregated aquifer levels and the surrounding conditions. Additional locations, such as the other states over the HPA (e.g. Kansas and Texas) should be analyzed as well. The differences in aquifer characteristics in different parts of the HPA may lead to a range of estimates of differential recharge rates. Lower recharge in Kansas and Texas may allow a better estimation of the relationship between local groundwater extraction and aquifer levels. Work needs be done to find ways of targeting CRP acres to reduce CRP losses to aquifer recharge while maintaining other environmental benefits of CRP, as well as the recharge rates associated with different CRP practices.

This study does have some important limitations. The groundwater extraction variable only includes agricultural irrigation for groundwater extraction (due to availability), while other types of groundwater extraction should have an impact if present. This study does not consider some the impact of hydrologically connected surface water on groundwater levels or the impacts of lagged changes in landcover. It is not entirely clear though, what impact the additional variables would have. While this study does show a negative relationship between grassland and aquifer recharge, more work should be done to better understand the specifics of the spatial relationship. Another important problem is that the CropScape map used for landcovers only considers grassland in general. Certain varieties of grasses could have different recharge impacts.

Ultimately, the study provides a useful first step in considering the tradeoffs in environmental programs like CRP that focus on a subset of all possible environmental benefits. It also highlights the fact that unintended consequences of otherwise beneficial programs may be important, although the importance will vary across different regions.

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