Final Report

Economic Assessment of Alternative Groundwater Management Strategies in Laramie County

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Abstract. Groundwater levels are declining in parts of Laramie County, Wyoming, and have been for decades. In this study we estimate the economic impacts, both direct and indirect, of four alternative management strategies: the status quo (area agricultural producers continue to pump at current rates), allocation (producers reduce pumping on all acres to a specified number of acre-inches over a specified number of years), and two versions of buyout (irrigators are paid to retire land from irrigation; irrigators transfer water to oil/gas). One key result is that for farms already feeling the effects of aquifer depletion – maybe as reduced pumping capacity – the economic impacts of an allocation strategy are lower because their farming system is already well-adapted for limited water. In contrast, farms not yet feeling the effects of aquifer declines – those currently able to fully irrigate on all of their pivots – would experience larger economic impacts from an allocation strategy. Another key result is that the more hydrology varies within a community, the more difficult to choose one management strategy that benefits – or at least does not harm – all water users in a community. Results provide stakeholders and the State Engineer with insights that agricultural producers and policymakers could use to quantify tradeoffs of applying more water today at the risk of having less water in the future, or applying less water today to increase the chances of having more water in the future.

Statement of Problem

Groundwater levels are declining in parts of Laramie County, Wyoming, and have been for decades. The Laramie County Control Area (LCCA) was established in 1981 in response to local concerns about declining aquifer levels. Groundwater levels continued to decline. In 2015 the State Engineer to issue an Order requiring adjudication of all unadjudicated groundwater rights and installation of flow meters on high-capacity wells in the LCCA by 2017; and implementation of well-spacing requirements for new wells. The State Engineer also encouraged groundwater users in the LCCA to develop their own groundwater management plan for the region. A stakeholder group met regularly for one and a half years (2014-2016) with the intent to develop creative and effective options for reducing groundwater use in the LCCA. Part of their mission was to determine an overarching goal for aquifer management. They might decide to allow but manage future aquifer decline; stabilize the aquifer at its current level; or recover the aquifer to a previous level. Questions were raised throughout those discussions about the potential economic impacts of alternative strategies on subareas within the LCCA and Laramie County more broadly. Decision-making without a common understanding of the economic impacts of alternative courses of action is difficult at best.

Objectives

The objectives of this study are to:

1. Determine the farm-level economic impacts of alternative policies, or groundwater management strategies, that could be implemented to relieve pressure on the High Plains Aquifer from existing uses: quantity restrictions (allocation) and price incentives (buyout of irrigation rights). We allow farms to choose how best to respond to these policies, through reductions in irrigation on existing crops or changes to the crop mix.

2. Analyze the indirect impacts of the four groundwater management strategies on the broader regional economy (e.g., direct income, induced income, and employment).

Significant groundwater depletions in Colorado, Kansas, Nebraska, and other states overlying the High Plains Aquifer have motivated policymakers and researchers to evaluate the economic and hydrologic impacts of alternative groundwater management strategies in those regions. They generally compare the economic impacts of continuing current pumping rates to alternative groundwater management strategies, including permanent and temporary conversion to dryland production, irrigation restrictions, a water rights buyout program, and technology adoption. Golden et al. (2008), Amosson et al. (2009), Golden and Guerrero (2017), Hrozencik et al. (2017) are recent examples.

The earlier of these studies tend to model hydrologic flows using a single-cell aquifer, which greatly simplifies how groundwater flows laterally across space and how withdrawals in one time period affect water availability in subsequent time periods (see for example Golden et al. 2008). Golden and Guerrero (2017) use a hydrologic model that incorporates equations developed by the Kansas Geologic Service (KGS) that capture saturated thickness and other aquifer parameters, instead of relying on an overly simplistic single cell aquifer model. Brozovic et al. (2010) develop an economic model of groundwater management that explicitly incorporates spatial dynamic groundwater flow equations, so that groundwater use by irrigators is incorporated more fully. Hrozencik et al. (2017) and Golden and Guerrero (2017) rely on MODFLOW models for their hydrologic inputs.

These studies that have taken place in neighboring states provide us with valuable insights for our study's approach, data collection, methods, and policy scenarios. This study is the first to analyze the economic impacts of alternative groundwater management strategies in the portion of southeastern Wyoming overlying the High Plains Aquifer.

Methodology

Study Area. The study area consists of three agricultural communities located within the Laramie County Control Area in eastern Laramie County, Wyoming: Albin, Carpenter, and Pine Bluffs. This is a rural area located 50 miles east of Cheyenne, Wyoming. The combined population of the three communities is approximately 1,500 people (U.S. Census Bureau, 2016). As a direct result of the High Plains Aquifer, Laramie County produces more hogs, milk from cows, and wheat for grain than any other county in the relatively dry state of Wyoming. These agricultural communities rely almost entirely on water supplied by the High Plains Aquifer. Although some irrigation does occur from two creeks that run through the LCCA, approximately 97% of irrigated acres within the control area are irrigated with groundwater (Dahlgren, 2018).

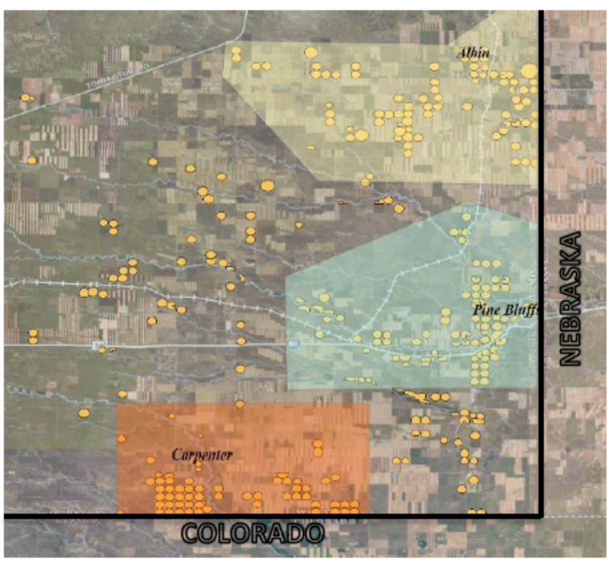

Figure 1. Laramie County Control Area "Hot Spots"

In general, the three communities share similar growing techniques and crops, commonly using center pivot irrigation sprinkler systems to grow alfalfa, corn, dry edible beans, and winter wheat. The crop rotation is generally wheat-corn-alfalfa-bean, avoiding planting the same crop in consecutive years to prevent pest and disease issues. Other crops grown in the area include millet, sunflowers, chick peas, oats, and sorghum. For modeling purposes, we focus on the four major crops: alfalfa, corn for grain, dry edible beans, and winter wheat.

If the aquifer continues to decline at the current rate, the region is at risk of reaching pumping depths that are not hydrologically sustainable beneath Albin, Carpenter, and Pine Bluffs. (AMEC 2014). Without agricultural operations, these three communities would likely struggle to remain economically viable.

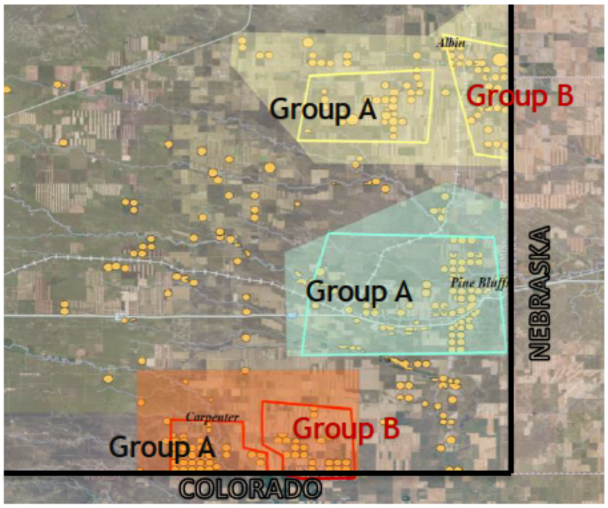

Figure 2. Representative Farm Hydrology Groups

Modeling Approach. Our modeling approach is informed by the regulations that govern Wyoming groundwater, data limitations, and unique community characteristics. We construct representative farms for each of the three communities identified above: Albin, Carpenter, and Pine Bluffs. We constructed two representative farms for Albin, two for Carpenter, and one for Pine Bluffs. We chose to divide Albin and Carpenter into two representative farms because of significant hydrologic differences present within each community. Representative farms with superior hydrologic conditions are referred to as hydrology group A. Superior hydrologic conditions are characterized as having greater initial saturated thickness of the aquifer, lower lift distance, higher effective porosity, and some level of recharge to the aquifer. Representative farms with inferior hydrologic conditions are referred to as hydrology group B.

Each farm has five pivots of 130 acres each. Water use in the model is on a farm-level basis, so a representative farm is able to spread its allocation anywhere on the farm it chooses in a single year. (This assumption is relaxed in the first buyout scenario discussed below.) These representative farms are not identical to all operations in a community but provide a general and shared baseline for all producers.

We develop an economic optimization model to determine how these representative farms will change behavior in response to reduced water availability. The model has three components.

Economic Component. The representative farms choose what crops to grow and how much to irrigate them in order to maximize net returns to their farm operations, over a 40-year period.[1] Irrigated crops included in the model are alfalfa, corn for grain, dry edible beans, and winter wheat. Dryland crops included in the model are alfalfa, corn for grain, winter wheat, and a dryland rotation. Irrigation levels are 100%, 90%, 80%, 70%, 60%, and 50%, and 0% of crop needs. Decisions about what crops to grow and irrigation levels are made based on constraints and assumptions regarding water availability, crop prices, input costs, and crop rotational requirements.

Our key source of current crop production data for this study is conversations with local producers. Through interviews with willing producers from each community, we collected information about typical crop yields, maximum yields, water use, rotation, and current

[1] Please see Willis (2019) for more details on model construction, explanation of assumptions, and data used in the analysis. Willis (2019) is the M.S. thesis of Ms. Kaila Willis, entitled, "Farm-Level Economic Assessment of Alternative Groundwater Management Strategies over the Ogallala Aquifer in Southeastern Wyoming."

technologies and management, and used these to construct partial enterprise budgets for each crop, in each community.

The basic results (farm-level economic impacts, crop mix, and aquifer drawdown) are first presented in a "status quo" scenario, where irrigators continue to pump water at current rates (subject to local groundwater availability). Results are then presented for alternative groundwater management scenarios that limit groundwater withdrawals in three different ways. The analysis assumes that producers respond to reduced water supplies by either continuing to irrigate the same crops but with less water, switching to crops that use less water, or switching to dryland farming.

Agronomic Component. We used a crop yield response to water function developed by the Food and Agricultural Organization (Doorenbos and Kassam 1979). This crop yield response function uses the ratio between actual and potential evapotranspiration for the growing season to generate crop-specific linear production functions. These production functions indicate how much reduction in yield occurs in response to reductions in water availability.

Hydrologic Component. We use a single-cell aquifer model to capture the hydrology underlying each representative farm (Gisser and Mercado 1973). By using this single-cell model, we assume that the aquifer beneath each representative farm can be described as a bathtub (i.e., the level of water in a given year equals the level from last year minus any water taken out plus any water coming in). Since this is a farm-level model, the bathtub beneath each farm is assumed to have no interaction or connection to neighboring farms; and to respond uniformly and instantaneously to any groundwater pumping done on the farm or any incoming recharge. To determine initial depths to water and other hydrologic parameters, we first used a combination of United States Geological Survey (USGS) and Wyoming State Engineer's Office (SEO) data sets to estimate groundwater availability over the study period, assuming no change in pumping patterns. We then adjusted these estimates in conversation with local producers. The parameters were adjusted until the year 1 optimization results matched each area's current crop production and water use, and results for the full study period matched area producers' expectations regarding possible future crop production and water use in the region. Therefore, our optimization results indicating the economic impacts of different groundwater management strategies are conditional on our assumptions about hydrology.

<u>Management Strategies</u>. We compare four alternative management strategies to the status quo: allocation, buyout #1, and buyout #2, and complete conversion to dryland.

Allocation. The allocation scenario enforces a 12 acre-inch allocation in each individual year of the 40-year model. A 12 acre-inch allocation represents an approximately 20% reduction from current water use in all three communities. Allocations of approximately 12 acre-inches have actually been implemented in the vicinity of Laramie County. The North Platte and South Platte Natural Resource Districts just across the state border in Nebraska range from 12 to 14 acre-inches averaged over a three- or five-year period (UBB NRD, 2015). An allocation is enforced in the Horse Creek Basin within Laramie County, northwest of the study area, where a 12 acre-inch allocation averaged over three years was implemented for all groundwater users in the area (WY SEO 2015). The present study does not allow representative farms to bank water from year to year to meet an allocation; in a model such as the present one without uncertainty or variability in annual precipitation, the benefit of allowing farms to bank water within an allocation would be minimal.

Buyout #1: Retirement of Irrigated Acres. In this second alternative management strategy, retiring irrigated acres for a fixed per-acre price basically enters into the representative farm model as an additional cropping activity that producers can select. This is similar to the federal Agricultural Water Enhancement Program (AWEP) that was initiated in 2010. Through the Laramie County Conservation District, producers could voluntarily abandon their irrigation water rights on acres they wished to retire from irrigation. A price was paid for each irrigated acre producers were willing to retire. Just over 2,000 acres were retired through the program in Laramie County during its five-year duration and was deemed successful in relieving pressure on the aquifer, reducing water consumption by more than 40,000 acre-inches annually (NRCS 2015). The per-acre price is based on our estimates of the current difference in returns over variable costs (ROVC) between irrigated and dryland crops.

Recall that a simplifying assumption in the model is that each representative farm is able to move water around between its five pivots. This allows water not applied on a bought-out pivot section to be applied on neighboring pivots. In this alternative buyout #1, we restrict the neighboring pivots of bought-out pivot sections to historical consumptive use.

Buyout #2. Leasing Water to Oil and Gas. In this third alternative management strategy, oil and gas companies pay producers for water extracted from their wells to use for hydraulic fracturing operations. Producers are able to complete this transaction by filing Temporary Water Use Agreements (TWUAs), which is authorized under Wyoming Statute § 41-3-110. This allows producers with an existing water right to temporarily change the permitted water use through the Wyoming State Engineers Office. TWUAs allow producers to "sell" up to 12 acre-inches. Prices received in exchange for water is negotiated on an individual basis between the producers and the oil and gas companies. We assume that the negotiated price is $0.20 per barrel of water, which results in a per-acre price of $1,551.60.

Dryland. We also determine the economic impacts of a dryland scenario, in which the representative farms convert entirely to dryland. This scenario sets water availability for the farms to zero. Any fixed costs associated with transitioning from irrigated to dryland operation are not included, so the results may overestimate the economic returns to transitioning to dryland.

Results: Farm-Level Impacts

We model each representative farm for the status quo and the four alternative groundwater management strategies. Summary results for allocation, buyout 1, and buyout 2 are presented below in Table 1. Results are presented as differences from the status quo. Recall that "group A" denotes regions of Albin, Carpenter, and Pine Bluffs with superior hydrology compared to the "group B" regions of Albin and Carpenter. More detailed results (how crop mix changes over time in each scenario as a result of reduced groundwater availability, changes in ROVC and aquifer levels through time) are available in Willis (2019) and Appendix B of Willis (2019).

Table 1. Economic and Hydrologic Impacts of Alternate Management Strategies

	Hydrology Results		Economic Results
	Reduction in Total Water Use	*Change in Total Water Use*	*Change in ROVC*
Group A: Albin			
Allocation	74,271 ai	-19.8%	- 11%
Buyout #1	78,000 ai	-20.8%	+ 0.9%
Buyout #2	62,400 ai	-16.7%	+ 320%
Group A: Pine Bluffs			
Allocation	85,800 ai	-21.7%	- 13.5%
Buyout #1	124,800 ai	-31.6%	+ 1.0%
Buyout #2	83,200 ai	-21.1%	+ 291%
Group A: Carpenter			
Allocation	135,975 ai	-32.0%	- 21%
Buyout #1	136,916 ai	-32.2%	+ 1.0%
Buyout #2	113,490 ai	-26.7%	+ 298%
Group B: Albin			
Allocation	312 ai	-0.21%	- 0.4%
Buyout #1	780 ai	-0.52%	+ 37%
Alt. Buyout #1	87,048 ai	-57.7%	+ 22%
Buyout #2	390 ai	-0.26%	+ 291%
Group B: Carpenter			
Allocation	13,682 ai	-5.7%	- 6.6%
Buyout #1	310 ai	-0.1%	+ 27%
Alt Buyout #1	171,327 ai	-71.4%	+ 6.9%
Buyout #2	1,198 ai	-0.5%	+ 343%

Economically, Buyout #2 is the clear choice for our representative farms among the strategies we modeled, with the largest increases in ROVC compared to the status quo. Even more, Buyout #2 conserves a significant amount of water over the study period, particularly on group A representative farms. From a hydrologic perspective, Buyout #1 and Alternative Buyout #1 (Buyout #1 with an historical consumption restriction) results in the greatest water use reductions and associated positive impacts on the aquifer. Group B farms also experience relatively high increases in ROVC under Buyout #1 (though minimal for group A), as well as under the Alternative Buyout #1.

While Buyout #2 seems like the obvious management strategy from our representative farms' perspective, in terms of farm-level economic and hydrologic benefits, there are some unrealistic assumptions embedded in this scenario. In the short-term our results for this scenario may be realistic, given that our model parameters for this scenario are based on current conditions. However, the oil and gas industry is known for being uncertain and volatile.

There is no guarantee that the Buyout #2 prices we assumed in our model would remain constant throughout the study period. There is also no guarantee that the demand for water by oil and gas companies in this area would be sufficiently large or constant, especially in the long-term.

Complete Conversion to Dryland Scenario. Our final scenario estimates the impacts of converting from a fully-irrigated operation to a completely dryland operation, where 0 acre-inches of irrigation water are applied. This represents a farm whose wells are no longer capable of pumping at sufficient capacity for irrigation purposes. If aquifer levels continue to decline, some operations in the area may eventually experience to this scenario. The timing of this potential outcome depends on management decisions made today. ROVC for this scenario are dramatically lower than the status quo. (Table 2 presents dryland ROVC as percentage reductions from the status quo scenario). This dryland scenario is only hypothetical. Furthermore, it is important to note that our status quo model never actually produced or predicted such an outcome. In no status quo scenarios was it necessary for our representative farms to convert completely to dryland crops.

Table 2. Dryland ROVC

	ROVC
	% Change
Group A:	
Albin	-80.20%
Pine Bluffs	-82.32%
Carpenter	-81.96%
Group B:	
Albin	-69.81%
Carpenter	-76.23%

Based on the relative success of real-life dryland operations in our study area, we acknowledge that our model's estimates of ROVC for the dryland scenario are likely an underestimation. Dryland operations currently operating in our study area are able to mitigate reduced ROVC through proactive farming strategies, such as reduced tillage and effective marketing. We do not incorporate any such innovative farming practices or marketing strategies into our dryland scenario. Nonetheless, it is an important scenario to include because, even though it may overestimate the negative impacts associated with a loss of irrigation, it shows the large positive impact that groundwater has on agriculture in the area.

Results: Community-Level Impacts

We use the software program IMPLAN to conduct an input/output analysis of the scaled-up economic impacts for each groundwater management strategy. This analysis estimates the level of income and employment generated by each combination. These are indirect economic impacts to the community associated with changes in groundwater availability and use over time.

Farm-level impacts (change in revenues, water use, crops) associated with alternative management scenarios are reported above. Here we report the community-level impacts of the different management strategies over time. The analysis takes place using an economic input-output model called IMPLAN (IMpact analysis for PLAN-ning, IMPLAN Group, LLC 2009). The IMPLAN model has been used before to quantify the economic impact of changes in water use (Guerrero et al., 2011; Whited, 2010). The model determines the response of a region's economy to a "shock" based on changes in expenditures and gross receipts that occur as a result of the shock. IMPLAN provides multipliers that specify how changes in expenditures and gross receipts ripple through the local economy. We contracted with Dr. Bridget Guerrero of West Texas A&M University to perform this regional economic impacts analysis.

This analysis requires three data inputs. First is irrigated acreage in eastern Laramie County (Dahlgren 2018). We assign irrigated acres to each of the three communities: 9,600 acres to Albin, 7,100 acres to Carpenter, and 13,400 acres to Pine Bluffs. Second is partial enterprise budgets costs for each alternative management scenario (Willis 2019). Third is gross receipts for irrigated and dryland crops for each management scenario (Willis 2019).

The results measure two economic indicators. First is income, which is the income or wealth portion of industry output (includes employee compensation, proprietary income, other income, and indirect business taxes). Second is the total number of jobs (both full-time and part-time) throughout the economy that derive, directly and indirectly, from the activity.

The results measure three types of economic impacts. First is direct impacts, which is the direct economic impact to agricultural producers (farm effects). Second is indirect impacts, which is the economic effects of industries buying from other industries to supply inputs to agricultural producers. Third is induced impacts, which result from changes in household income caused by direct and indirect effects. Results by scenario are presented in Table 3.

Status quo scenario. This scenario also includes reductions in water use as aquifer levels decline. Numbers consequently presented here represent the changes to the local economy that can reasonably be anticipated to occur, subject to assumptions made in the analysis, if current pumping rates continue into the future, subject to water availability.

Allocation. Numbers for the allocation scenario represent differences (average annual) from the status quo scenario. For example, annual direct income to farms are $1.19 million lower on average annually than in the status quo scenario; and there are 22 fewer jobs on average annually than under status quo.

Buyout 1. The drop in direct income is higher ($1.92 million reduction) than it was in the allocation scenario ($1.19 million reduction). The drop in direct employment is higher (48 fewer jobs) than it was in the allocation scenario (22 fewer jobs). Induced impacts (resulting from changes in household income) are positive for the buyout 1 scenario. This is even more true for the Buyout 2 scenario, where gross receipts are higher due to the high prices received from leasing water out to oil and gas.

Table 3. Regional Economic Impacts of Alternative Groundwater Management Scenarios

	Direct Impacts	Indirect Impacts	Induced Impacts	Total Impacts	Change from Baseline	Percent Change
	Status Quo					
Value Added	$5.71	$1.55	$0.66	$7.92		
Annual Employment	198	100	8	306		
	Allocation					
Value Added	$4.84	$1.41	$0.47	$6.72	-$1.19	-15%
Annual Employment	184	94	6	284	-22	-7%
	Buyout 1					
Value Added	$4.04	$1.09	$0.87	$5.99	-$1.92	-24%
Annual Employment	176	72	11	258	-48	-16%
	Buyout 2					
Value Added	$0.01	$0.02	$9.47	$9.49	$1.58	20%
Annual Employment	1	1	120	122	-184	-60%
	Dryland					
Value Added	$0.40	$0.88	$0.33	$1.61	-$6.30	-80%
Annual Employment	43	75	4	122	-184	-60%

Notes: Income is measured in millions of dollars and employment is measured in number of jobs. These numbers are annual averages over 40 years. Income and employment numbers are higher in early years than in later years for a particular scenario, reflecting higher water use.

Dryland Scenario. Direct dryland impacts are significant. Indirect and induced are less severe than anticipated because relative to an irrigated acre dollar, more of a dryland rotation dollar circulates through the economy.

Scope of the Analysis. These results are based on irrigated crop agriculture in eastern Laramie County. Agricultural in central and western Laramie County are excluded from the analysis, as are non-agricultural sectors of the economy everywhere in Laramie County. Also excluded are the dairy and hog farm operations and feedlots in eastern Laramie County. The analysis also does not incorporate “forward linkages,” which are the economic contributions of crop production through purchasing industries (such as the dairy and hog farm operations and feedlots in eastern Laramie County). Actual impacts will be higher than those presented here, for this reason. Finally, because the farm-level economic impacts upon which this analysis are based do not include more rigorous hydrology and neighbor interactions, this community-level analysis does not include them, either.

Significance

Economic modeling of alternative groundwater management strategies in eastern Laramie County, in the State of Wyoming reveals the existence of economic winners and losers, depending on how the aquifer behaves under individual farms or parts of a community. For farms already feeling the effects of aquifer depletion – maybe as reduced pumping capacity – the economic impacts of an allocation strategy are lower because their farming system is already well-adapted for limited water. In contrast, farms not yet feeling the effects of aquifer declines – those currently able to fully irrigate on all of their pivots – would experience larger economic impacts from an allocation strategy. Of course, the more hydrology varies within a community, the more difficult to choose one management strategy that benefits – or at least does not harm – all water users in a community.

A buyout strategy could create economic and hydrologic benefits but a source of funding would be needed to support the program. Economic and hydrologic benefits of a buyout program also depend on whether pivots near those enrolled in the program are restricted to historical consumptive use. If there is no restriction, economic benefits to remaining pivots are higher, but hydrologic benefits are lower.

Finally, a significant challenge for local water users is the lack of generally accepted hydrologic studies. Producer perceptions of future hydrology (as were used to inform the present study) may or may not match reality, but they may nonetheless be a good starting point for regional conversations regarding groundwater management.

Publications (Research and Extension)

Willis, K. 2019. "Farm-Level Economic Assessment of Alternative Groundwater Management Strategies Over the Ogallala Aquifer in Southeastern Wyoming." M.S. Thesis. University of Wyoming Department of Agricultural & Applied Economics. 104 pp.

Willis, K. and K. Hansen. 2019. "Eastern Laramie County wrestles with water use today versus conserving for future." *Wyoming Livestock Roundup*. April 2019.

Willis, K., K. Hansen, D. Peck, S. Miller and V. Sharma (forthcoming). Farm-Level Economic Assessment of Alternative Groundwater Management Strategies over the High Plains Aquifer in Southeastern Wyoming. University of Wyoming 2019 Field Days Bulletin.

The following manuscripts will be submitted for publication.

> Farm-Level Economic Assessment of Alternative Groundwater Management Strategies over the High Plains Aquifer in Southeastern Wyoming. (In preparation for submission to *Water Economics and Policy*).
>
> Community-Level Impacts of Alternative Groundwater Management Strategies. (In preparation for submission to *Journal of Regional Analysis and Policy*).

The following Extension bulletin manuscripts will be submitted for publication upon conclusion of peer review for the above journal manuscripts.

> Glendenning, S., K. Hansen, and K. Willis. 2019. "Groundwater Management in Laramie County."
>
> Willis, K., K. Hansen, D. Peck, S. Miller, and V. Sharma. "Alternative Groundwater Management Strategies in Laramie County."

Presentations

Willis, K., K. Hansen, D. Peck and S. Glendenning. 2017. "Water Use and Management in Laramie County, WY." Invited poster presentation at the UW Extension 2017 Organic Farming Conference. Cheyenne, WY (February 2017). Presentation by K. Willis.

Hansen, K., D. Peck, and K. Willis. "Alternative Groundwater Management Strategies over the Ogallala Aquifer in Southeastern Wyoming. Invited presentation at the Universities Council on Water Resources Annual Meeting. Fort Collins, CO (June 2017). Presentation by D. Peck.

Willis, K. K. Hansen, D. Peck and S. Miller. 2018. "Farm-Level Economic Assessment of Alternative Groundwater Management Strategies over the Ogallala Aquifer in Southeastern Wyoming." Invited presentation and selected graduate student paper competition at the Western Agricultural Economics Association Annual Meeting. Anchorage, AK (June 2018). Presentation by K. Willis.

Hansen, K., K. Willis, D. Peck, S. Miller. 2018. "Direct Community-Level Impacts of Alternative Groundwater Management Strategies over the Ogallala Aquifer in Southeastern Wyoming." Invited presentation at the Agricultural & Applied Economics Association Annual Meeting. Washington, DC (prospective, August 2018). Presentation by K. Hansen.

Willis, K., K. Hansen, D. Peck, S. Miller and V. Sharma. 2018. "Farm-Level Impacts of Alternative Groundwater Management Strategies over the Ogallala Aquifer in Southeastern Wyoming. "Poster Presentation at SAREC Field Day. Lingle, WY (August 22, 2018). Presentation by K. Willis.

Hansen, K. 2018. "Real-Time Energy Monitoring Pilot Program to Improve Producers Understanding of Irrigation Costs and Water Use." SAREC Field Day. Lingle, WY (August 22, 2018).

Willis, K. 2018. Public thesis presentation, conducted at the University of Wyoming in Laramie with a Zoom link for distance participation. December 7, 2018.

Willis, K., K. Hansen, D. Peck, S. Miller and V. Sharma. 2019. "Farm-Level Impacts of Alternative Groundwater Management Strategies over the Ogallala Aquifer in Southeastern Wyoming."

Poster Presentation at Organic Farming Conference. Cheyenne, WY (February 27-8, 2018). Presentation by K. Willis.

Guerrero, B., K. Willis, K. Hansen, D. Peck. "Regional Economic Analysis of Crop Production in Laramie County, Wyoming." Presidential Symposium on Understanding the role of water in farm-dependent communities at the Mid-Continent Regional Science Association. Madison, WI (June4-6, 2019). Presentation by B. Guerrero.

Student support information

Kaila Willis, M.S. Agricultural and Applied Economics. Ms. Willis started her two-year M.S. program in the University of Wyoming Department of Agricultural & Applied Economics in January 2017 (completion date: May 2019). Ms. Willis' thesis comprised the farm-level objectives and components of the study.

Alicia Grahmann, M.S. Agricultural & Applied Economics. Ms. Grahmann was supported through this WRP grant beginning in September 2018 through June 30, 2019. She assisted the PIs with data acquisition for the county-level objectives of the study. Her thesis research (anticipated completion date: May 2020) builds on the findings of this WRP grant to examine the profitability of water-use saving irrigation technologies under a range of relevant agricultural input and output prices and water availability conditions. This WRP grant allowed us to leverage additional funding for the second year of Ms. Grahmann's M.S. studies.

Information Transfer

In addition to the peer-reviewed articles, Extension publications, and presentations listed above, the PIs also did the following:

- Organized a groundwater management workshop in Cheyenne, WY to report summary findings to interested parties. Presentations included: an overview of hydrology in the region by a hydrologist from the Wyoming SEO; a presentation of farm-level economic impacts by graduate student Ms. Willis; and a presentation of community-level impacts by PI Dr. Hansen. Attendees included one County Commissioner, representatives from the Wyoming State Engineer's Office, and many irrigators and other water users in the county.

- Ms. Willis and Dr. Hansen attended the Ogallala Aquifer Summit (Garden City, KS; April 9-10, 2018). Ms. Willis and Dr. Hansen made connections with researchers, policymakers, and producers in other states overlying the Ogallala that will benefit the research project as well as UW's capacity to work on groundwater management problems in Wyoming moving forward.

- Drs. Peck and Hansen organized a special session at the 2017 Universities Council on Water Resources Annual meeting (Fort Collins, CO; June 2017) on groundwater management. Target audience: researchers and policymakers from across the western U.S.

Synergies Created by this Funding

This study:
- Allowed the PIs to leverage additional funding from the Dept. of Agricultural & Applied Economics, to fund Ms. Grahmann's M.S. research, which extends the work completed through this study.
- Led to initiation of a real-time energy metering project through UW Extension, including installation of flow meters on the three irrigation pumps located at the UW Sustainable Agriculture Research and Education Center (SAREC).
- Prompted collaboration/discussion within Wyoming and western Nebraska on how to improve agronomic modeling of irrigated crops in the region.
- Prompted discussions in the Intermountain West among agricultural economists on the pros and cons of different economic modeling approaches in the absence of good hydrologic information.
- Facilitated the anticipated submission of a new Water Research Program proposal in October 2019 (PI: Dr. Miller), to focus on improved hydrologic modeling whose focus will be management.

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