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Irrigation Practice Adoption: Causes and Consequences in the Arkansas Delta

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Irrigation Practice Adoption: Causes and Consequences in the Arkansas Delta

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by

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Abstract

Concerns about groundwater depletion from conventional irrigation agriculture in the Arkansas Delta region have led to the promotion of more efficient irrigation practices. With Arkansas being the largest producer of rice, the 10th largest producer of soybeans and the 16th largest producer of corn in the United States, the irrigation demand of these crops has put pressure on producers to find ways to irrigate more efficiently. Not only are the alternative technologies supposed to reduce water use, it is also believed that their adoption can also yield economic benefits for the producer. Despite these assumed benefits, adoption of alternative technologies have been limited. The paper will address potential returns on investment in new irrigation practices for furrow irrigated soybeans, furrow irrigated corn and flood irrigated rice. More farms that adopt the efficiency enhancing practices will increase the return on investment in those practices because this stabilizes groundwater levels across the landscape.

The adoption of reservoirs and tail-water recovery systems are also being promoted as a way of minimizing groundwater depletion and promoting surface water irrigation. Despite the long term benefits of surface water use, many producers are reluctant to adopt the water saving practices. To better understand the barriers of adoption, this project uses the responses from producers who took part in the Arkansas Irrigation Survey in 2016. The responses from this survey are used to find which factors are correlated with the adoption of water storage facilities. The research finds that peer networks are positively correlated with the adoption of surface water irrigation.

Keywords: Irrigation, Groundwater conservation, Surface water delivery

JEL Classifications: Q15, Q24, Q25

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Introduction

Agriculture is a major industry in Arkansas contributing $21.4 billion in total value added to the state's economy in 2016 (English, et al., 2017). Irrigated crops such as rice, soybean and corn are key contributors to the large agricultural sector, with Arkansas being the number 1 producer for rice, 10th largest producer for soybean and 16th largest producer of corn for grain in the United States (University of Arkansas, 2017). Irrigated agriculture in Arkansas accounts for over 8% of all irrigated acres in the United States, making it the third most irrigation intensive state measured by irrigated acres behind Nebraska and California. Of all water extracted in Arkansas, irrigated agriculture accounts for 80% (United Stated Deprtment of Agriculture, 2012). Due to the reliance on groundwater to support irrigated agriculture, the industry is the main source of groundwater depletion, resulting in the practice being a focal point in finding ways to reduce the groundwater depletion and encourage natural recharge. The overconsumption of groundwater has led to greater difficulty in accessing groundwater as aquifer volumes decrease, leading to future challenges for irrigated agriculture in Arkansas (Nalley, et al., 2014). Arkansas Natural Resources Commission (ANRC) predict that by 2050 groundwater demands will be close to 7 million acre-feet per year, and groundwater sources will not be able to meet this demand (ANRC, 2014).

To address groundwater depletion concerns, this thesis will comprise two research chapters. The first chapter will use future modelling to better understand land-use, water-use, and economic changes over a 30-year period, subject to the adoption of two water saving irrigation technologies. As groundwater levels in the Delta continue to decrease, the price of pumping water increases, making the prospect of investment in new technologies more attractive. In this chapter, potential returns on investment of alternative irrigation practices for furrow-irrigated soybeans, furrow-irrigated corn and flood irrigated rice will be address. The depletion of the aquifer and the return on investment from alternative irrigation practices depends on the well-pumping decision of farms across the landscape. Findings include that the adoption of the water saving technologies have the potential to both decrease and increase groundwater use in the region. The adoption of the alternative technologies allow producers to increase their net returns and the rate of adoption of efficient irrigation practices on the landscape ultimately influences positive return on investments.

The second chapter will explore what factors influence the adoption of surface water irrigation methods by producers. On-farm infrastructure such as reservoirs and tail-water recovery systems promote a shift from groundwater to surface water irrigation. Despite the environmental and economic benefits of adopting surface water technology, producers in the Arkansas Delta region have been reluctant to adopt. To better understand the barriers of adoption, this project uses the responses from producers who took part in the Arkansas Irrigation Survey in 2016. The responses from this survey determine which factors correlate with the adoption of water storage facilities. The research finds that peer networks are positively correlated with the adoption of surface water irrigation. Producers, who know someone who has already adopted surface water irrigation practices are more likely to have also adopted. The results of this research can help extension agencies promote surface water irrigation.

Each chapter will use the following format: introduction to the topic, literature review, methods, data, results, discussion and conclusions and appropriate tables and figures. A full list of references for both chapters are at the end of the document.

Chapter I: Return on investment in irrigation practices in response to the rate of adoption on an agricultural landscape

Introduction

The growing concerns for groundwater availability in the Arkansas Delta Region have led to the promotion of more water efficient irrigation systems. This promotion of irrigation efficient systems is due to both the presumed environmental and economic benefits of investment in these technologies (Kebede, et al., 2014). Although efficient techniques may have a positive impact on groundwater availability, these techniques must also be economically beneficial to encourage farmers to adopt alternative methods. Producers make irrigation decisions mainly on the economic returns that the irrigation systems generate. The rate of adoption of efficient irrigation techniques will have an impact on aquifer volumes and groundwater use into the future. The rate of adoption of efficient irrigation techniques may reduce groundwater use across the landscape, since each farm is using less water than before. In this case, the economic returns to the producers should rise, and the return on investment in alternative irrigation practices would increase. Alternatively, the adoption of alternative irrigation practices could lead to a rebound effect, where increased aggregate water supplies could result in the maximization of irrigated acres, resulting in an increase in total water-use.

Using dynamic landscape modelling, this chapter will examine adoption rates of efficient irrigation techniques in the Arkansas Delta when comparing conventional irrigation systems with more efficient irrigation techniques for soybean, corn and rice. The efficient irrigation techniques include an alternative irrigated soybean and irrigated corn practice based on the Mississippi State University's Row-crop Irrigation Science and Extension Research (RISER) program and a rice package that uses a zero-grade irrigation system. These alternative practices have been chosen because of their water saving potential and increasing adoption costs. Each more efficient irrigation system differs from a conventional irrigation system (in this case the conventional systems is furrow irrigation for soybean and corn production and flood irrigation for rice production), in two aspects: water consumption, and irrigation set up costs. The model then maps the change in land use, water use, and economic conditions over five -year periods for a total of thirty years for each different scenario and crop type. The present value of the farm profits for the thirty-year time frame is the objective of every model run. The model is useful for examining how the adoption of the alternative irrigation systems influence the conservation of the Alluvial Aquifer and the economic benefit of the producer.

The model will use spatially explicit sites across the study area to estimate both the aquifer depletion and economic returns at each site based on the irrigation systems selected. The aggregation of these site specific values allow us to understand the total depletion volume of the aquifer and total economic benefits for producers. The rate at which the pumping depletes groundwater supplies will have an impact on the groundwater pumping costs. The model also tracks the adoption of alternative irrigation practices to determine the effects on the aquifer volume and groundwater pumping costs over the study area.

Literature Review

Studies that examine the influence of efficient irrigation system adoption on groundwater depletion each have their own specialized focus with the uniform goal of assessing the impacts on groundwater depletion and economic returns. These impacts are highlighted in the work conducted by West & Kovacs, (2017) which determines the effectiveness of monitoring methods on addressing groundwater decline. This research uses a similar modelling technique to maximize economic returns for producers while introducing two alternative water saving technologies; soil moisture sensors and unmanned aerial vehicles. West & Kovacs (2017), find that investing in the sensing technologies have a positive influence on aquifer volumes, pumping costs and economic returns. This chapter will incorporate similar techniques in modelling future land use scenarios, but will instead look at different irrigation technologies and introduces an adoption rate of the alternative irrigation practices over time. The use of surface water to replace groundwater use for irrigation has also been studied in the Arkansas Delta region. Looking at the influence of on-and-off-farm surface water investment on groundwater extraction, Kovacs & Durant-Morat, (2017) found that surface water use can change crop patterns in favor of irrigation-intensive crops. This can lead to an overall increase in groundwater use, unless off-farm water price is low enough to generate a shift away from groundwater. A key difference in this chapter is that it focuses only on groundwater use and not does not include the potential of surface-water use.

Gorelick, (1983) highlights that there are two key types of groundwater modelling categories; hydraulic and policy evaluation modelling. Our research falls under the policy evaluation category, and the paper uses more specific hydraulic-economic response models than in the past. Kovacs & West, (2016) use these modelling techniques to better understand the trade-offs between ecosystem services and economic returns associated with groundwater depletion, which depends on investment in on-farm surface water infrastructure. Ellis, et al., (1985) use a linear programming framework maximizing annual returns to estimate benefits in the adoption of new irrigation technologies in the Texas High Plains for a 40-year horizon. Like in this chapter, the authors track the changes in water-use, crop mix pattern and economic returns. The model also incoorportates data on crop yeilds and prices and county level saturated aquifer thickness levels.

The research finds that the intorduction of the alterantive irrigation results in constant or increased water use on the landscape. Despite increased water use in some scenarios, the paper does find that regions with greater depths to water do benefit from decreased water pumping costs, which results in greater economic benefits. Expanding on this literature, this chapter will look to apply similar modelling methods to understand the return on investment of alternative irrigation methods on a landscape. One difference in the model application for this chapter is that spatial data on initial crop acreages, groundwater depths and aquifer thickness is available at each site to give a more accurate representation of production trade-offs at site level. The importance of spatial modelling compared to single-cell modelling when quantifying aquifer changes is highlighted by Brozovic, et al., 2010, who believe that the majority of pervious economic analyses have used single-cell models, which can result in misleading policy outcomes.

One of the key reasons for introducing an adoption rate is the limited literature on the rate of adoption for irrigation technologies in the Arkansas Delta. To better understand the impacts of adoption on an agricultural landscape, we look at research conducted in central Arizona by Anderson, et al., (1999), which builds upon the work conducted by Griliches, (1957). Both papers help this chapter by better understanding the reasons for adopting zero grade technologies and the diffusion rates associated with the technology adoption. Griliches (1957) examines the adoption of hybrid corn across the United States, introducing the idea of the logistic function of adoption which includes; origins, slopes and ceilings of adoption for technological advancement. Anderson, et al., (1999), consider the 1969-1989 study period to gain insight into the adoption of zero-grade technology for cotton production. This is the same alternative irrigation technology that this papers uses for rice production. The research finds that the adoption follows the logistic function with a ceiling of 70% adoption and an aggregate diffusion rate of 0.227.

It is important when promoting alternative irrigation methods to understand some of the key reasons for adoption. Schaible & Aillery, (2012), explore some of the reasons why producers decide to invest in alternative irrigation methods, and one of the key reasons highlighted is income gains from investment. Other benefits of adoption such as water reduction, improved water quality and the reduced need for fertilizer application from improved run-off, seem to be perks of the positive investment decision. Farm characteristics also influence technology adoption decisions. These characterisitics can include land slope, which could influence the adoption of gravity irrigation systems and soil type which has an impact on the filtration of water through the soil. Type of crops grown can also impact adoption, producers are more likley to make larger investments in alternative water systems if they grow more water internsive crops. Schaible & Aillery, (2012) also highlight that despite long-term benefits of investing in alternative technologies, the cost of initial investment can have a detrimental impact on adoption.

Frequently, the assumption is that the adoption of efficient irrigation systems leads to a reduction in water use on the landscape, a scenario found by West & Kovacs, (2017). Policy often plays an important role in stimulating the adoption of alternative technolgies, or limiting negative externalities such as the overdraft of groundwater. One method of achieving both scenarios where alternative technolgies are adopted and groundwater use is reduced, is by subsidizing the adoption of alternative irrigation technologies. Scheierling, et al., (2006) examined the impacts of hypothetical subsidies for alternative irrigation technologies on hydrological, agronomic and economic outcomes. The research finds that subsidy polices are unlikely to reduce water-use on the landscape and therefore result in no real water savings. Another example of this outcome is the Upper Rio Grande Basin of North America where Ward & Pulido-Velazquez, (2008) found that irrigation polices to reduce water use actually increased the application of water on the landscape. This research used a river basin scale model to track water use, land use changes, and economic outcomes for the adoption of drip irrigation methods. Subsidies on the adoption of drip irrigation have a negative influence on water conservation and a positive impact on total net benefits for producers. This chapter will look to investigate the effectiveness of policy on the adoption of alternative technologies and the influences they have on land use, water use and returns on investment.

To better understand if efficient irrigation technology reduces groundwater extraction Pfeiffer & Lin, (2014) evaluate the impacts of producers converting from center pivot irrigation to efficient dropped-nozzle center pivot irrigation methods over the High Plains Aquifer in Western Kansas. They find that the increased adoption of the efficient irrigation method was correlated with increases in water use for the area. These increases in water use are attributed to crop-change patterns that lead to an increase in overall irrigated acres due to the increased water efficiency from the adoption of the efficient irrigation method. These are also similar to the results found by Ellis, et al., (1985). The increase in water use builds on the idea of “the rebound effect” found in energy economics where gains in efficiency result in an increase in consumption Greening, et al., (2000). From an irrigation perspective, producers can increase the cost effectiveness of their water use, which leads to a change in crop pattern, resulting in increased irrigated acres and, therefore, unintentional increased water-use (Schaible & Aillery, 2012).

Methods

The model will use different cells (m), also referred to as sites, to track aquifer volume, groundwater pumping, and economic returns based on the adoption rate of irrigation practices for soybean, corn and rice. The time frame will be over a thirty-year period from 2016 to 2046.

Land Constraint

The cumulative amount of land use (j) is tracked for n land types used for each of the crops in the study area (irrigated rice, irrigated soybean, irrigated corn and dryland soybean), using the different irrigation technologies (k). These technologies include conventional irrigation rice and soybean, RISER program irrigation for soybean and corn, and zero-grade irrigation for rice. The tracking of land use type and irrigation technology occurs over a given period (t) at each site (i) using the formula L_{ijk} (t). The land constraint formula will only allow for the amount of land use over time to be equal to the original land available for production at that specific site, giving the following (Eq.1):

$$\text{(Eq.1)} \qquad \sum_j \sum_k L_{ijk}(t) = \sum_j \sum_k L_{ijk}(0)$$

Acreages of each crop are constrained at site level based upon historical average acreages in the study area. The optimization of economic returns and maximizing aquifer volume are subject to the land balance equation.

Water Constraint

The different use of crops and irrigation technology (k) changes the irrigation demanded, wd_{jk}. The irrigation demanded is the total need for irrigation after natural rainfall. The amount of groundwater available in acre-feet stored in the aquifer below site (i) at the end of the time period (t) is the variable AQ_i (t). The amount of water pumped from the ground for irrigation use is GW_i (t) during period t. Precipitation, underlying aquifers, and streams all contribute to the natural recharge of groundwater at each site (i) over a given period, annotated as nr_i.

To get a true representation of the volume of water in the aquifer, the model must account for water that flows underground from site (i) into the aquifer in site (k). To account for the groundwater that is pumped from site k, a negative quadratic function of hydraulic diffusivity and distance between the sites (i) and k is annotated as p_{ik}. The total water that runs out from site (i) is shown in (Eq.2):

(Eq.2) $$\sum_{k=1}^{m} p_{ik} GW_k(t)$$

The total cost to pump an acre-foot of groundwater from site (i) in time period (t) is GC_i (t). Total pumping costs are dependent on three different aspects: 1) the cost of using a pump to lift one acre foot of water, c^p, 2) the depth of the aquifer to reach the groundwater, $dp_{i,}$ and 3) the capital costs of constructing and maintaining a well per acre-foot of water, c^c. As the groundwater availability declines due to the aquifer depletion rate, the cost to pump water from the well increases due to an increase in pumping costs to extract the water.

During each period for each crop grown at the site, the total amount of water used for irrigating the crops must be less than the total amount of groundwater that is pumped (Eq. 3). The aggregate volume of water present in the aquifer at site i is dependent on the volume of water in the aquifer at site i from the previous period plus the amount of water that is acquired from natural recharge, and minus the volume lost to lateral groundwater flows into neighboring sites (Eq. 4). The cost of pumping an acre-foot of groundwater for irrigation is the cost of pumping an acre-foot of water up by one foot, c^p, multiplied by the depth to reach the groundwater plus the capital costs per acre-foot of constructing and maintaining the well, c^c (Eq, 5).

(Eq.3) $$\sum_j \sum_k wd_{jk} \, L_{ijk}(t) \le GW_i(t),$$

(Eq.4) $$AQ_i(t) = AQ_i(t-1) - \sum_{k-1}^{m} P_{ik} GW_k(t) + nr_i,$$

(Eq.5) $$GC_i(t) = c^c + c^p \left[dp_i + \frac{(AQ_i(0) - AQ_i(t))}{\sum_j \sum_k L_{ijk}(0)} \right]$$

Economic Returns and Salvage Value Objective

The price per unit of crop is held constant in real terms over time, pr_j. All other production costs per acre of each crop, ca_{jk}, exclude the water use costs. The crop yield for land use (j) at site (i) using the irrigation system (k) is y_{ijk} and is held constant. The net value per crop (j) is then $pr_j y_{ijk}$ - ca_{jk}, and this exclude the costs for water pumping. A discount factor, δ_t, keeps monetary values comparable over time.

The equation for maximizing net returns of farm production and salvage value is in (Eq.6):

(Eq.6) $$\max_{L_{ijk}, GW_i(t)} : \sum_{t=1}^{T} \delta_t \left[\sum_{i=1}^{m} \sum_{j=1}^{n} \left(y_{ijk} - ca_{jk} \right) L_{ijk}(t) - GC_i(t) GW_i(t) \right] + SV$$

The use of a salvage value (SV) means the aquifer has a value to future generations of producers after the study period is complete. This allows for the consideration of future generations by current farmers Kovacs, et al., (2015). The salvage value is similar to what Tsur, (1990) describes as a buffer value which is the willingness to pay of producers in uncertain groundwater conditions for certain water sources. We combine (Eq. 6) with (Eq. 7) to derive the salvage value objective equation. The salvage value is:

(Eq.7) $$SV = \sum_{t=1}^{T} \delta_t \sum_{i=1}^{m} AQ_i(t)$$

Technology Adoption Constraint

The adoption, *Cp*, of the new irrigation technology systems are constrained at landscape level. At the landscape level, the acreage in conventional and alternative rice irrigation practices *kr*, plus the acreage in soybean irrigation practices *ks*, plus the acreage in corn irrigation practices *kc*, for all sites *i* at time period *t*, will be less than or equal to the total initial land acreage across all sites *i* in rice, soybeans and corn multiplied by the cumulative adoption proportion at time *t* (Eq.8.)

(Eq. 8) $$\sum_i (L_{i,kr}(t) + L_{i,ks}(t) + L_{i,kc}(t)) \leq \sum_i L_{i,kr,ks,kc}(0)Cp(t)$$

The origin acceptance level, rate of acceptance, and ceiling figure are then used to calculate both the marginal proportion and the cumulative proportion over the time period of 30 years, where marginal proportion is *Mp*, cumulative proportion is *Cp*, origin acceptance level is *O* and the ceiling figure is *C*. At time 0, the *Cp* is equal to *O*. For years 2 to 30, the marginal proportion can be calculated using the cumulative proportion from the previous year, Cp_p (Eq.9). The cumulative proportion for years 2 to 30 also uses the cumulative proportion from the previous year, which is added to the marginal proportion for the current year, Mp_c (Eq.10).

(Eq. 9) $$Mp = O \times Cp_{t-1} \times \left(\frac{1 - Cp_{t-1}}{C} \right),$$

(Eq.10) $$Cp = Mp_t + Cp_{t-1}.$$

Policies

The policy options for groundwater conservation include limiting groundwater use, tax groundwater pumping costs, and cost share of the RISER and zero-grade irrigation system set up costs. The limit on groundwater use at each site (*i*) is for pumping to be 60% less than the current groundwater use at each site (*i*) for each period. A tax on groundwater pumping costs of 2% achieves groundwater conservation similar to the limits on groundwater use. The cost share for the rice system (zero-grade leveling), and riser system (irrigation scheduling tool, soil moisture sensors, surge valves, and poly-pipe planner) is set at 60% based on the rates from the Natural Resource Conservation Service's (NRCS) Agricultural Water Enhancement Program NRCS, (2014).

Data

The study area is made up of 2,724 sites across 11 counties in Arkansas. These sites are within three eight-digit hydrological unit code (HUC) watersheds (Figure 1). The Arkansas Delta has been selected due to the unsustainable groundwater pumping that has been occurring in the area. The various sites allow for a better understanding of farmer decisions on crop allocation and water use over a spatially differentiated landscape. The initial crop acreage over each cell comes from the Crop Land Data Layer from 2013 (Johnson & Mueller, 2010). More detail regarding the crop acreage can be found in supporting information (Table 1). To reflect the agronomic constraints on the acreage of particular crops in the study area, average maximum acreages for each crop in the study area for the years 2011-2015 come from data collected by the National Agricultural Statistic Service (NASS) (USDA, 2017). The maximum percentage of each crop at the sites in the study area is set using the maximum percentage of crops for the study area: rice (27%), irrigated soybean (60%), irrigated corn (20%) and non-irrigated soybean (20%). For crop yields, a proxy of the average county crop yields is used for each of the crops using National Agricultural Statistic Service (NASS) data (USDA, 2017). Costs associated with the production of crops, the maintenance and ownership of irrigation technologies and wells are held at a constant rate in inflation-adjusted terms. A real discount rate of 2% is based on a 30-Year

Treasury Bond yield over the last decade of 5% minus an expected inflation rate of 3% (U.S. Department of The Treasury, 2011).

Groundwater Use and Recharge

The depth to the water table and the initial saturated thickness of the aquifer is taken from the Arkansas Natural Resources Commission Arkansas Natural Resources Commission (ANRC, 2012). This information can be found in supporting information (Table 1). A depletion of the aquifer occurs as the saturated thickness of the aquifer begins to reduce. The initial size of the aquifer is the product of the saturated thickness of the aquifer multiplied by acreage. A calibrated model of recharge from 1994 to 1998 from natural precipitation and surface streams is used to determine the natural recharge (nr_i) of the alluvial aquifer (Reed, 2003). As groundwater is pumped from surrounding areas, the size of the aquifer at that specific cell is reduced. With groundwater flowing from surrounding aquifers into the depleted cells, the volume of water is dependent upon diffusivity of the aquifer and the distance from the pump. By taking the hydraulic diffusivity and dividing it by the square of the shortest distance between the pumped well and the nearby aquifer, this defines how much pumping from a nearby well depletes the aquifer. Hydraulic diffusivity can be defined as the ratio of the transmissivity and the specific yield of the unconfined alluvial aquifer (Barlow & Leake, 2012). Transmissivity is the product of hydraulic conductivity and saturated thickness, while the hydraulic conductivity is the rate of groundwater flow per unit area under a hydraulic gradient. Specific yield is a dimensionless ratio of water drainable by saturated aquifer material to the total volume of that material. The hydraulic conductivity comes from spatially coarse pilot points digitized by (Clark, et al., 2013). The closer the distance to a pumped well and the larger the hydraulic diffusivity is, the greater the aquifer depletion is beneath the specific cell.

Farm Production

Table 2 includes the cost to produce each crop, which is derived from the 2011-2015 Crop Cost of Production estimates (University of Arkansas Division of Agriculture, 2015). These costs do not include the cost of irrigation. The costs of irrigation include the fuel, lube and oil, irrigation labor, and poly pipe for border irrigation plus the levee gates for the flood irrigation of rice, which are all dependent on the amount of water pumped (Hogan, et al., 2007). Capital costs of irrigation, which are not dependent on the amount of water pumped, include wells, pumps, gearheads, and power units, which are charged on a per acre-foot basis.

During the growing season, the average irrigation required for conventional soybeans is an acre foot, excluding natural rainfall. For conventional rice, the irrigation required is two and a half acre-feet and for corn the irrigation required is 1.17 acre-feet (University of Arkansas Division of Agriculture, 2015). Crop prices are determined by using the fifteen-year average annual prices paid for each crop using NASS data from 2001-2015 (USDA, 2017). The parameters, detailed in Table 2, are held constant over time, as it is difficult to understand the tradeoff between alternative irrigation system adoption, groundwater scarcity, and economic returns when prices, yields, and production costs change over time. A salvage value of $5.19, which is taken from (Kovacs et al. 2015), is the certainty equivalent value of an acre-foot of groundwater for irrigated soybeans over an average growing season.

The capital costs associated with irrigation are assumed to be paid off over time; these costs are then divided by the acre-feet of water that is pumped from the well to give a value for capital costs per acre foot applied. The cost of fuel per acre foot of water from the aquifer is dependent on amount of fuel that is needed to pump the water. The cost of fuel per acre foot of water from the aquifer is subject to the depth of the water table. Diesel use ranges from 13 gallons of diesel per acre foot for a 100 foot well to 26 gallons of diesel per acre foot for a 200 foot well (Hogan, et al., 2007). The diesel needed per acre-foot for pumping water to and from the reservoir is 6 gallons (Hogan, et al., 2007). The cost of diesel fuel used is $3.77 per gallon EIA, (2012) and add 10% to fuel cost to account for oil and lube for irrigation equipment (Hogan, et al., 2007).

Rate of Adoption

The rate of adoption of the irrigation conserving technologies are calculated for both a low adoption rate scenario and a high adoption rate. The calculation for each uses an origin acceptance level of 0.1 (Table 3). This figure represents a low adoption rate of 10%, which is the point at which adoption is carried out after an experimental stage Griliches, (1957). This origin acceptance level value is used for both low and high scenarios. The rate of adoption also accounts for rate of acceptance. This is the rate at which people will adopt the technology in the low adoption scenario is set at 0.1 and in the high adoption scenario is set at 0.2. A ceiling figure is also used for the rate of adoption, which is the maximum proportion of irrigators who will adopt. In this model, the ceiling figure for the low and high adoption scenarios is set at 15% and 30% adoption over the landscape. Despite the literature suggesting higher acceptance levels and greater ceilings of adoption, this research uses a much lower adoption rate scenario which reflects adoption rates within our study area. Another reason for using a lower adoption rate is that there are multiple types of irrigation technologies to adopt and multiple different land-use options available. In both the Griliches (1957) and Anderson (1999) studies, there is only one alternative technology and only one specific crop.

Irrigation Technologies

The conventional irrigation technique for soybeans and corn in the Arkansas Delta is furrow irrigation by passing water through poly-pipes. In this model, the alternative irrigation method for soybean and corn will be the Row-crop Irrigation Science and Extension Research (RISER) program that has been created by researchers as Mississippi State University. The program looks to irrigate row-crops more efficiently and economically by maximizing profits and minimizing water usage (Mississippi State University Extension, 2013)**.** The program uses a combination of tools, which include soil sensors and computer programming that determines the appropriate hole size for poly-pipes known as the Pipe Hole and Universal Crown Evaluation Tool (PHAUCET) which are combined with surge irrigation techniques.

In the Arkansas Delta, the conventional rice irrigation system is contour levee flood irrigation. The alternative method in this model is zero-grade flood irrigation. This irrigation technique looks to use precision leveling combined with drainage ditches to increase irrigation efficiency and improve water management Hignight, et al., (2009). This alternative irrigation technique will be known as the alternative rice practice.

Both the RISER program and the zero-grading of rice result in alterations in water use and production costs compared to conventional irrigation techniques. These changes are quantified as a percentage compared to conventional methods, and these parameters can be seen in the supporting information in Table 4. Literature to quantify the changes water use and technology cost can also be found within these tables. It can be seen that there is a decrease in water use for the alternative practices, 40% for rice and corn, and almost 29% for soybean, and an increase in production costs for the alternative practices, 5% for rice and 3% for both corn and soybean.

Although alternative technologies are already used in the study area, the model suppose that only the conventional irrigation method is in use initially to study how the introduction of the alternative irrigation systems influence model outcomes. The return on investment of the adoption of each crop is calculated by taking the total economic benefits at each site, minus the total economic returns at each site after adoption. This value is then divided by the total costs of adopting the alternative irrigation practice as each site.

Results

Alternative Irrigation Practice Costs

The landscape conditions in the final period vary depending on the differences in the set up costs for the alternative irrigation practices at a high adoption rate (Table 5). The first set of results are the landscape conditions if there was to be no adoption of the technologies. At the baseline level it can be seen there would be 246 thousand acres of conventional rice, 568 thousand acres of conventionally irrigated soybean, 78 thousand acres of conventionally irrigated corn and 74 thousand acres of non-irrigated soybean. The groundwater use in the final period would be 2.548 million acre-feet and the aquifer thickness would be 52.57 million acre-feet. The present value of economic returns across the landscape would be $1.99 billion.

We compare the no alternative irrigation practice results to the landscape when we introduce the alternative irrigation technology. First, we use our baseline cost parameters for our alternative irrigation practices; a 3% cost increase for the alternative soybean and corn irrigation practices and a 5% cost increase for the rice irrigation practices. It can be seen that the number of conventionally irrigated rice acres decreases to 288 thousand acres, this is due to the introduction of 65 thousand alternative irrigated rice acres. The overall rice acres increase from 246 to 293 thousand acres. There is a change in soybean acres with 488 thousand acres of conventionally irrigated soybean and 131 thousand acres of alternatively irrigated soybean. The overall irrigated soybean acres increase from 568 to 619 thousand acres. Conventionally irrigated corn acres decrease to 20 thousand acres as there is an introduction of 10 thousand acres of alternatively irrigated corn. The non-irrigated soybean acreages fall from 74 to 24 thousand acres.

Groundwater use in the final period decreases to 5.542 million acre-feet, over the total study period there is an increase in aquifer thickness of 52.88 million acre-feet. The present value of economic returns increases to $2.69 billion. For the introduction of alternative irrigation technologies, we track the costs and returns on investment associated with adoption. In this scenario the total alternative irrigation practice costs are $81 million, yielding a return on investment of 2.73. The alternative irrigation technologies also allow producers to irrigate with less water, and this lowers total irrigation costs for those producers using the alternative practices. The reduction in irrigation costs allows for higher present value of economic returns, resulting in a positive return on investment.

For the alternative irrigation practices we test different cost parameters, for the alternative irrigation RISER practice we decrease the cost to 1%, keeping the alternative irrigation rice practices cost constant. In the 1% cost scenario conventional and alternative rice acres remain the same at the 3% cost scenario. Conventionally irrigated soybean acres also remain fall to 481 thousand acres and alternatively irrigated soybean acres increase to 133 thousand acres compared to the alternative baseline results. Conventionally irrigated corn acres decrease to 19 thousand acres and alternative corn acres increase to 17 thousand acres. Non-irrigated soybean acres remain at 24 thousand acres. With these changes in crop mix groundwater use in the final period decreases to 2.534 million acre feet, and aquifer thickness increases to 52.92 million acre-feet.

Economic returns also increase compared to the alternative baseline to $2.29 billion and alternative irrigation costs decrease to $57 million. The return on investment of the alternative irrigation methods increases to 4.81.

A 5% cost increase for the alternative RISER practice is also introduced. Again, conventional and conservation rice acres rice acres remain the same as the alternative baseline scenario. Conventionally irrigated soybean acres increase to 509 thousand and alternatively irrigated soybean acres decrease to 111 thousand acres. Conventionally irrigated corn acres increase to 22 thousand acres and alternatively irrigated corn acres decrease to 7 thousand acres. In this scenario non-irrigated soybean acres increase slightly to 25 thousand acres. Despite the increase in dryland acres, there is an increase in groundwater use compared to the no alternative baseline and 3% cost scenario to 2.556 million acre-feet in the final period. The aquifer is thicker than the no baseline scenario, but is more depleted than the 3% cost scenario with a value of 52.76 million acre-feet. Economic returns decrease to $2.25 billion. Alternative irrigation costs increase to $95 million and return on investment decreases to 2.59. It can be seen in our results that the increased costs made the alternative irrigation soybean less desirable and a decrease in costs had the opposite effect.

Assuming no cost increase for the adoption of the alternative rice irrigation practice results in the same crop acreages and water use figure the same as the alternative irrigation baseline scenario. Our rate of adoption limits the amount of alternative irrigation acreages, which keeps the crop patterns and water use consistent. The absence of adoption costs for the most profitable crop means the present value of economic returns increases to $2.31 billion. There is still an alternative irrigation technology cost of $36 million due to the alternative irrigation soybean and corn acres.

When we increase the cost of the alternative irrigation rice practices by 10%, conventional rice acres increase to 232 thousand and the alternative rice acreages decrease to 60 thousand. Conventionally irrigated soybean acres increase to 490 thousand and alternatively irrigated soybean acres remain constant. Conventional and alternative irrigated corn acres remain constant, likewise with non-irrigated soybean acres. Groundwater use in the final period is the same as the no alternative adoption scenario (2.548 million acre-feet). The aquifer volume of 52.83 million acre-feet is thicker than the no alternative baseline meaning that has been overall water savings. The higher alternative irrigation rice practices reduce the present value of net returns to $2.22 billion. The alternative irrigation costs increase to $120 million, resulting in a decrease in return on investment to 1.50. The median return on investment of the technology thus decreases because net-returns are decreasing and practice costs are increasing.

Low and High Adoption Rates of Irrigation Practices

To understand the influence of adoption rate on the landscape, a model is run for both low and high adoption rates. The results in (Table 6) use the baseline alternative RISER and rice practice cost increases of 3% for RISER and 5% for zero-grade. The low adoption rate scenario causes irrigation acres for conventional rice to increase gradually to 244 thousand acres, however this is slightly lower than the no alternative practice adoption scenario. Alternative rice acres gradually increase to 32 thousand acres. Conventionally irrigated soybean acres decrease over time from 556 thousand acres to 547 thousand acres. The alternatively irrigated soybean acres increase over time to 66 thousand acres. Conventionally irrigated corn acres increase over time to 34 thousand acres, however like rice, this is a lower total than the no alternative practice baseline. Alternatively irrigated corn acres result at 11 thousand acres at the end of the 30-year period. Non-irrigated soybean acres decrease over time resulting in 33 thousand acres. In the find period, groundwater use is greater than the no alternative irrigation practice scenario at 2.588 million acre-feet, and there is a more depleted aquifer volume of 52.45 million acre-feet. Present value of economic returns increase to $2.26 billion, and there are alternative irrigation practice costs of $49 million. The return on investment in alternative irrigation practices for the low adoption rate is 2.98.

The changes on the landscape over time for the high adoption rate scenario are also in Table 6. Conventionally irrigated rice and soybean acres decrease over time to 228 and 488 thousand acres respectively. This results in the alternative acres for each crop to gradually increase. Irrigated corn acres do the opposite, with conventional acres increasing and alternative acres decreasing. Compared to the low adoption scenario, groundwater use decreases and the aquifer increases with faster adoption of the alternative irrigation practices. This can be seen by comparing the cumulative groundwater use over time. The return on investment for the high adoption of 2.73 is slightly lower than the return on investment of 2.98 for the low adoption scenario.

Agricultural Landscape Conditions for a Longer Time Horizon

To better understand the return on investment for a longer time horizon, we double the length of the time horizon from 30 years to 60 years (Table 7). Adoption over time is increased by doubling the adoption ceiling for the high adoption rate scenario to 0.6. The 60-year no alternative irrigation practice adoption baseline results in 240 thousand acres of conventional rice, 563 thousand acres of conventionally irrigated soybean, 68 thousand acres of conventionally irrigated corn and 95 thousand acres of non-irrigated soybean. The cumulative groundwater use is 14.29 million acre-feet and groundwater use in the final period is 2.486

million acre-feet. The aquifer thickness is 45.38 million acre-feet. These landscape and water outcomes result in a present value of economic returns being $2.25 billion.

With the introduction of the alternative irrigation practices, conventional rice acres steadily decrease in the first 30 years from 185 thousand acres to 140 thousand acres, the conservation acreages then rebound from years thirty to sixty, from 140 to 195 thousand acres. The conventional rice acres are lower in the final period compared to the no alternative baseline. Alternative irrigated rice acres gradually increase over time to 105 thousand acres. Conventionally irrigated soybean acres decrease over time, from 558 thousand acres to 336 thousand acres. Alternatively irrigated soybean acres increase over time to 255 thousand acres. Both conventional and alternative rice acres result in 14 thousand in the final study period. Non-irrigated soybean acres, like the conventionally irrigated soybean, decrease over time, from 104 thousand acres to 48 thousand acres. Compared to the no alternative scenario, cumulative groundwater use decreases to 13.68 million acre-feet and final period groundwater use also decreases to 2.372 million acre-feet. Aquifer thickness increases to 48.37 million acre-feet. The present value of economic returns increase to $3.78 billion and alternative irrigation costs are $244 million. The median return on investment over the 60-year period is 2.44.

Sensitivity Analyses

In (Table 8) a sensitivity analysis is conducted to compare the baseline alternative irrigation results over a 30-year period with the model parameters that influence our results. First, the impacts of halving and doubling the initial depth to groundwater is analyzed. By halving the initial depths of groundwater, the irrigation water is more accessible for the producer, this allow producers to increase the total acreage of irrigated crops and therefore increase their profits. There is an increase in acres of conventional rice compared to our baseline alternative results, with 240 thousand acres and alternative rice acres remain constant at 65 thousand acres. The acreages of both conventional and alternative irrigated soybean decrease to 482 thousand and 123 thousand acres respectively. Conventionally irrigated corn acres increase to 27 thousand acres, and alternatively irrigated corn acres decrease to 8 thousand. Non-irrigated soybean acres decrease to 21 thousand acres. Groundwater use in the final period increases 2.610 million acre-feet and aquifer thickness drops to 51.13 million acre-feet. Present value of economic returns increase to \$2.85 billion; alternative practice costs decrease to \$79 million, and the return on investment increases to 3.05.

When doubling the depths to groundwater, both conventional rice acreages decrease to 158 thousand acres, alternative rice acres remain constant. Conventionally irrigated soybean and alternatively irrigated soybean acres increase to 517 and 133 thousand acres respectively. Conventionally irrigated corn acres decrease to 8 thousand acres and alternatively irrigated corn acres increase to 16 thousand acres. Non-irrigated soybean acres increase significantly to 70 thousand acres. This switch from irrigated to dryland wheat acres causes groundwater use in the final period to fall to 2.244 million acre-feet and the aquifer thickness to increase to 56.93 million acre-feet as there is less use of water for irrigation. This switch in land-use causes the present value of economic returns to decrease to \$1.28 billion and groundwater alternative irrigation costs to increase to \$82 million, the median return on investment increases to 3.54.

When conducting a sensitivity of aquifer thickness, the volume of water available for irrigation is altered. By halving the thickness, conventional rice acres decrease to 221 thousand acres, there is also a reduction in alternative rice acres to 59 thousand acres. Conventionally irrigated soybean acres decrease to 477 thousand acres, with alternatively irrigated soybean acres remaining constant as 131 thousand acres. Conventionally irrigated corn acres increase to 19 thousand acres and alternatively irrigated corn acres remain constant at 10 thousand acres Non-irrigated soybean acres increase to 50 thousand acres. Groundwater use in the final period decreases to 2.466 million acre-feet and aquifer thickness is 22 million acre-feet. Present value of economic returns decrease to $1.9 billion; alternative irrigation costs decrease to $77 million, and the return on investment increases to 2.26.

Doubling aquifer thickness increases conventional rice acres to 235 thousand acres, while alternative rice acres remain at 65 thousand acres. Conventionally irrigated soybeans decrease slightly to 487 thousand acres, and alternatively irrigated soybean acres remain at 131 thousand acres. Both conventional and alternative irrigated corn acres decrease to 18 and 9 thousand acres. Non-irrigated soybean acres fall to 22 thousand acres. Groundwater use in the final period increases to 2.564 million acre-feet and the aquifer thickness is 116.5 million acre-feet. Present value of economic returns increase to $2.61 billion, and alternative irrigation costs remain $81 million. There is a decrease in return on investment of 2.72.

By halving the margins for each crop there was to be no feasible solution, instead in this scenario the margins are quartered. This results in 65 thousand acres of conventional rice and 47 thousand acres of alternative rice, both lower than the alternative baseline scenario. Conventionally irrigated soybean acres fall to 578 thousand acres and alternatively irrigated acres for soybean increase to 133 thousand. There is only 1 thousand acres of both conventional and alternative corn acres. Dryland soybean acres increase to 142 thousand acres, resulting in a decrease to 1.808 million acre-feet of groundwater used in the final period and an increase in aquifer thickness to 62.89 million acre-feet. Present value of economic returns reduce to -$1.38 billion; alternative practice costs decrease to $69 million, and the return on investment increases to 4.53.

When the margins are doubled for each crop conventionally irrigated acres for rice increase to 249 thousand acres and alternative rice acres remain at 65 thousand acres. Conventionally irrigated soybean acres decrease to 309 thousand acres and alternatively irrigated soybean acres also decrease to 125 thousand acres. Conventionally irrigated corn increase to 161 thousand acres and alternative corn acres also increase to 36 thousand. Non-irrigated soybean acres fall to 21 thousand acres. There is an increase to 2.666 million acre-feet of groundwater use in the final period and the aquifer thickness to decrease to 50.24 million acre feet. Present value of net returns increase to $19.2 billion; the cost of alternative irrigation practices also increase to $89 million, and the median return on investment increases to 7.92.

Policy Scenarios

Four policy scenarios are shown next to our alternative irrigation baseline (Table 9) and are compared to the alternative irrigation baseline. The first policy is a cap on groundwater pumping that prevents groundwater use in any period from exceeding 60% of groundwater use on the current landscape. The results show that conventional rice acres decline to 227 thousand acres and alternative rice remain at 65 thousand acres. Conventionally irrigated soybean acres increase to 489 thousand acres and alternatively irrigated soybean acres remain at 131 thousand acres. Both conventional and alternative irrigated corn acres remain the same as the baseline. The acreages of non-irrigated soybean increase to 25 thousand acres. The slight reduction in irrigation intensive conventional rice acres leads to a reduction in groundwater use in the final period to 2.530 million acre-feet and an increase in aquifer thickness to 52.95 million acre-feet. Present value of economic returns decrease to $2.265 billion since there are less acres of the profitable rice crop. There are no government transfers for this policy, and the cost effectiveness of the policy is $42.86 per acre-foot of water. Alternative practice costs remain at $81 million and the median return on investment decreases to 2.72.

The second policy is a tax of 2% on groundwater pumping costs. This policy leads to a reduction in conventional rice acres to 225 thousand acres, alternative rice acres remain at 65 thousand acres. Conventionally irrigated soybean acres increase to 491 thousand acres, and alternatively irrigated soybean acres remain at 131 thousand acres. Conventionally irrigated corn acres decrease to 19 thousand acres and alternatively irrigated corn acres remain constant at 10 thousand acres. Non-irrigated soybean acres increase to 25 thousand acres. The tax results in decreases in groundwater use in the final period to 2.53 million acre-feet and increases the aquifer thickness to 53.12 million acre-feet. The present value of economic returns fall to $2.23 million and the alternative practice costs are $81 million. A total of $33 million in tax revenue is generated for the government meaning there is a cost effectiveness of the policy of $4.17 per acre-foot. The median return on investment remains 2.72.

A 60% subsidy on the alternative rice irrigation practices reduces the costs of adopting the alternative irrigated rice practice. Landscape conditions remain the same as the alternative baseline scenario. The present value of economic returns increase to $2.29 billion, and the costs of the subsidized alternative irrigation practices fall to $54 million. As this is a subsidy, the policy will mean the government revenue will be -$5.3 million. There is no water savings because of this policy. The median return on investment is 5.13.

A 60% subsidy on alternative RISER practices reduce the amount of conventionally irrigated soybean acres to 481 thousand. Alternatively irrigated soybean acres increase to 133 thousand aces. Conventionally irrigated corn acres decrease to 19 thousand and alternatively irrigated corn acres increase to 17 thousand. Groundwater use in the final period decreases to 2.536 million acre-feet and the aquifer replenishes to 52.92 million acre-feet. Economic returns increase to $2.29 billion and the alternative practice costs decrease to $60 million. The government transfer is -$3.2 million resulting in a cost effectiveness of $355 per acre-foot of groundwater. The decline in the cost of the alternative irrigation soybeans because of the subsidy increases the median return on investment to 4.34.

Conclusion & Discussion

The main findings of this paper suggest that the adoption of the alternative irrigation practices yield positive returns on investment for producers in the Arkansas Delta region. Increased adoption of alternative irrigation technologies decrease the amount of groundwater pumped across the landscape in the majority of the scenarios tested. By adopting the alternative technologies in the high adoption scenario, groundwater use for irrigation is reduced, despite an increase in total irrigated acres. This reduction in groundwater use increases the aquifer thickness, resulting in reduced pumping costs. The savings from pumping costs are greater than the costs associated with adopting the alternative methods, resulting in greater returns for producers and positive returns on investment. Irrigated acres of rice can also be maximized with the adoption of the alternative technologies, which resulting in greater economic returns. However, in a lower adoption rate scenario, the adoption of the alternative technologies can cause an increase in total groundwater use. As the adoption of the alternative technologies increase total irrigated acres, the smaller proportion of alternative acres in the lower adoption rate scenario causes a greater depletion of the aquifer. In this case the water savings from the alternative irrigation practices are less than the increase in water use from the increased irrigated acres. As irrigated acres are maximized there is still a positive return on investment in the low adoption rate scenario.

When the cost of the alternative practices is increased the return on investment decreases, but remains positive. Increasing the costs of the alternative RISER practice leads to an increase in groundwater use, this is due to the alternative irrigated soybean and irrigated corn acres decreasing and being replaced by conventionally irrigated soybean and irrigated corn acres. The present value of economic returns also decrease as the price of the alternative RISER practice increases. This is due to the higher alternative practices costs, despite a reduction in alternative acres. When the cost of the practice is decreased to 1% there is a decrease in conventional irrigated soybean and irrigated corn acres, these are replaced by alternative acres for the two crops. This then reduces groundwater use and increases present value of economic returns as pumping costs are lower. Due to higher returns and lower irrigation costs, the return on investment increases.

Increasing the cost of the alternative zero-grade practice to 10% would decrease the returns on investment of adoption and also increases the amount of groundwater used. This increase in groundwater use is due to reduction in alternative irrigated acres of rice. The lower alternative rice acres from the increased cost of the alternative zero-grade practice leads to lower economic returns for producers. The lower economic returns, coupled with the increased cost of alternative practices is what results in a lower return on investment as prices increase. Have a zero cost increase for the zero-grade practice would have no impact on the landscape. Present value of economic returns increase in this scenario because alternative practice costs are reduced.

By altering the rate of adoption, there is a slightly higher return on investment for the low rate of adoption scenario. Our results here show that the lower adoption rate scenario increases overall groundwater use compared to the no alternative adoption baseline. This is because there is a larger total of irrigated acres compared to the alternative baseline and the proportion of conventionally irrigated acres is also greater. The economic returns for producers increase compared to the no alternative baseline despite the costs of adopting the water practices. This would suggest that the cost of adopting the technology is less than the pumping costs that would be associated in their absence, resulting in positive returns on investment. These results would suggest that with a lower adoption rate of the alternative irrigation practices there is the potential of a re-bound effect similar to the scenario described by Pfeiffer & Lin, (2014) where the crop patterns from technology adoption result in the increase in groundwater use.

In the high adoption rate scenario there is a greater total of irrigated rice acres on the landscape compared to both the no alternative and low adoption rate scenarios in the final period. Despite this, the high rate of adoption scenario uses less groundwater than the other scenarios. This is because there is a higher proportion of alternative irrigated rice in the high adoption rate scenario (18%) compared to the low adoption rate scenario (12%). There are also greater soybean acres compared to the no alterative baseline scenario, however compared to the low adoption scenario the total soybean acres are the same. Compared to the low adoption rate scenario, the proportion of alterative soybean acres is also greater (21% compared to 11%). For corn acres there is also a greater proportion of alternative corn acres (33%) compared to the low adoption rate scenario (24%). This increase in proportion of alternative acres in the higher adoption rate scenario is what allows for a decrease in groundwater use.

The high adoption rate scenario also has greater economic returns for producers, which is driven by the greater total acreages of irrigated rice and the reduced groundwater pumping costs. Alternative practice costs are greater, as there is more alternative acres adopted. This increase in alternative practice costs is what lowers the return on investment in the high adoption rate scenario. I also speculate that the producers in critical groundwater areas will be the first to adopt, and the low adoption rate scenario is capturing these producers. Adopters in the critical groundwater levels are more likely to yield greater benefits of alternative technology, thus increasing the return on investment. By looking at the results in more detail and looking at the change in landscape in 10 year increments allows us to better understand the how the changes in crop patterns influence both water and economic conditions. These results highlight the value of modeling irrigation technology adoption and land use choice together over time and how they can give a better understanding of future scenarios.

A longer 60-year time horizon shows that producers conserve more groundwater in the early years and maximize profits over a longer period. In the final period of the extended time horizon our results highlight pervious trends; that the increased adoption decreases groundwater use and increases economic returns, compared to the no alternative baseline. By looking at each 10-year increment that the results provide, it can be seen that in the 30-year period of the extended scenario, there is less groundwater used compared to both the no alterative practice and 30-year conservation baselines. These results show that if producers extend their time-horizon, they can not only conserve water over a longer period, but also achieve greater economic returns with a higher return on investment. This is highlighted by the re-bound in conventional rice acres after the 30-year period. Producers are taking the water savings from reduced corn and soybean acres to increase conventional rice acres between years 30-60. The reason there is no re-bound in groundwater use due to the increase in conventional rice acres is because there is a greater proportion of alternative rice acres. Again, this highlights the benefits of modelling land-use changes which include a rate of adoption as it allows for a deeper understanding of how different landscape changes impact water and economic conditions. There is a lower return on investment of the technologies in the 60-year period as there are higher alternative practice costs, due to greater adoption.

The sensitivity results are important for understanding how the return on investment of technologies may differ in other scenarios. By halving the depth to groundwater it can be seen that producers take advantage by increasing the acreages of rice which is the most profitable irrigation intensive crop. This is because pumping costs are lower for conventional crops. Returns on investment of alternative technologies increase since alternative practice adoption lowers pumping costs further and economic returns increase. When the depth is doubled, irrigated acres or conventional rice are replaced by dryland acres. This leads to lower economic returns and lower levels of groundwater used. As irrigated soybean acreages require less irrigation water than rice acres, there is an increase in both conventional and alternative soybean acres. There is an increase in returns on investment of the alternative practices as they have a greater contribution to the economic returns, as they lower the cost of pumping groundwater.

When the aquifer thickness is halved, there is less water available for irrigation meaning that compared to the alternative irrigated baseline, there are less irrigated acres and more dryland acres. Like when the depth is doubled, alternative irrigated acres have an increased influence on the economic returns as their water saving help protect the profit of producers. As there is more rice compared to when the depth is doubled, economic returns are greater in comparison. For this reason, combined with lower alternative irrigation costs, the return on investment is greater than all other scenarios. When the aquifer thickness is doubled, there is an increase in total irrigated acres, resulting in increased groundwater use and economic returns. Since the adoption costs of the alternative irrigation practices remain the same and economic returns increase, the return on investment is slightly lower than the alternative baseline scenario. Producers decide whether and how to irrigate based principally on the groundwater pumping costs rather than the amount of groundwater. The groundwater stock is abundant enough in the study area that the exhaustion of the aquifer at most sites over the 30 year time horizon is unlikely.

When quartering the margins of the crops there is less acres of rice and corn on the landscape and both irrigated and non-irrigated soybean have the highest total acreages. By quartering the margins of the crops, the production costs of the irrigated crops are now amplified. It also shows that non-irrigated soybean is not a profitable crop when used across the landscape. There is a positive return on investment, which is greater than the alternative baseline. This occurs because the alternative acres for irrigated soybean have a contribution in preserving economic losses, there is also reduced practices costs which also contribute to the positive return on investment. The reduction in water pumping costs from the alternative soybean practice preserves some of the economic benefits of having irrigated acres. When doubling the margins, it is clear that having conventionally irrigated rice is the most lucrative option as it yields much greater returns. The median return on investment is much greater the baseline as the contribution of the alternative practices are doubled. There is less soybean acres on the landscape, which are replaced by conventional rice acres and total corn acres. This is due to rice and corn yielding greater profits than soybean.

The tax on groundwater use would be the most cost-effective policy for the government to adopt. Producers would be more inclined to see a subsidy policy because this boosts the net present value of economic returns on the landscape and conserve groundwater, where as a tax would have negative impacts on economic returns. There is no major negative impacts in the median return on investment of the alternative irrigation practices for the policies, this shows that no matter what policy is used, investment will not be discouraged by the policy. A 60% subsidy for the RISER program doesn’t support the findings by Scheierling, et al., (2006) and Ward & Pulido-Velazquez, (2008), as there is an increase in groundwater use. When subsidizing the zero-grade technology, water savings remain the same as the alterantive baseline scenario.

Limitations to the modelling approach include the assumption of static weather patterns which do not influence crop production methods. Also, the risk of disease to crops is assumed to remain the same over time. Both previous examples of weather and disease are relevant in the discussion of the wider threats of climate change that could alter the landscape in the future. The model does not account for the potential of other water sources that could also influence the landscape, for example off- and on-farm surface water. There is also the potential for future farm management strategies, or technological breakthroughs that will eliminate even the need for the alternative practices that are used. Despite the best efforts to keep the model as realistic as possible, the limitations of the model mean that the actual choice of technology use and crop patterns will be different. What this model offers is insights into the trends of land-use and investment outcomes, when alternative practices are offered.

Tables and Figures

Table 1: Descriptive statistics of the model data across the sites of the study area

Variable	**Definition**	**Mean**	**Std. Dev.**	**Sum (thousands)**
$L_{i,rice}$	Initial acres of rice	81	99	220,624
$L_{i, corn}$	Initial acres of irrigated corn	52	77	142,632
$L_{i,isoy}$	Initial acres of irrigated soybean	165	97	448,469
$L_{i,dsoy}$	Initial acres of dryland soybean	57	49	154,946
$y_{i, ,rice}$	Annual rice yield (cwt per acre)	74	3	-
$y_{i, corn}$	Annual irrigated corn yield	175	9	-
$y_{i,, isoy}$	Annual irrigated soybean yield	48	5	-
$y_{i, dsoy}$	Annual dryland soybean yield	29	6	-
dp_i	Depth to water (feet)	57	32	-
AQ_i	Initial aquifer size (acre-feet)	16,315	9,992	44,443
K	Hydraulic conductivity (feet per day)	226	92	-
nr_i	Annual natural recharge of the aquifer per acre (acre-feet)	0.45	0.19	1,225
Crop profitability				
Variable	**Definition**	**Value**	**Std. Dev.**	**Sum (thousands)**
P_{rice}	Profitability of rice[1]	6.68	0.25	-
P_{corn}	Profitability of corn	5.47	0.27	-
P_{isoy}	Profitability of irrigated soybean	6.52	0.65	-
P_{dsoy}	Profitability of dryland soybean	4.67	0.90	-

[1] Profitability is calculated by taking the price of each crop, multiplied by the average yield of each crop at each site, divided by the cost of production for each crop. Note: Number of sites is 2,724.

Table 2: Value of model parameters

Parameter	Definition	Value
pr_{rice}	Price of rice ($/cwt)	11.60
pr_{soy}	Price of soybeans ($/bushel)	9.93
pr_{corn}	Price of corn ($/bushel)	3.81
ca_{rice}	Annual production cost of rice ($/acre)	638
ca_{corn}	Annual production cost of irrigated corn	611
ca_{isoy}	Annual production cost of irrigated soybean ($/acre)	362
ca_{dsoy}	Annual production cost of dryland soybean ($/acre)	313
wd_{rice}	Annual irrigation per acre of rice	2.5
wd_{corn}	Annual irrigation per acre of corn	1.17
wd_{isoy}	Annual irrigation per acre of soybean	1
c^p	Cost to raise an acre-foot of water by one foot ($/foot)	0.55
δ_t	Discount factor	0.98
SV	Salvage value of groundwater ($/acre-foot)	5.19

Table 3: Value of adoption rate parameters

Parameter	Definition	Value
O	Origin acceptance level	0.1
Ra_{min}	Minimum rate of acceptance	0.1
C_{min}	Minimum ceiling	0.15
Ra_{max}	Maximum rate of acceptance	0.2
C_{max}	Maximum ceiling	0.3

Table 4. Alternative technologies and adjustment coefficients for yields relative to standard irrigation.

Crop	**Conventional**	**RISER***	**Zero Grade[2]****
Adjustment coefficients for water use			
Corn	1.00	0.60[1]	--
Rice	1.00	--	0.60[2]
Full season irrigated soybeans	1.00	0.712[1]	--
Adjustment coefficients for production cost			
Corn		1.03[3]	--
Rice	1.00	--	1.05[4]
Full season irrigated soybeans	1.00	1.03[3]	--

* Soybean package is PHAUCET and Soil Sensors. ** Rice package is zero grade [1] (Mississippi State University, 2016) [2] (University of Arkansas, 2016) [3] (Mississippi State University , 2016) [4] (Hignight, et al., 2009)

Table 5. Agricultural landscape conditions for the final period and alternative irrigation practice costs for the high adoption rate

Landscape conditions	**No alternative irrigation practice adoption**	**Production cost increase: Alternative RISER irrigation practice**[a]			**Production cost increase: Alternative zero grade irrigation practice**[b]		
		1%	**3%**	**5%**	**0%**	**5%**	**10%**
Land use (thousand acres)							
Conventionally irrigated Rice	246	228	228	228	228	228	232
Alternative irrigated Rice	0	65	65	65	65	65	60
Conventionally irrigated Soybeans	568	481	488	509	488	488	490
Alternative irrigated Soybeans	0	133	131	111	131	131	131
Conventionally irrigated Corn	78	19	20	22	20	20	20
Alternative irrigated Corn	0	17	10	7	10	10	10
Non-irrigated Soybean	74	24	24	25	24	24	24
Water conditions (thousand acre-feet)							
Groundwater use in final period	2,548	2,534	2,542	2,556	2,542	2,542	2,548
Aquifer thickness	52,570	52,920	52,880	52,760	52,880	52,880	52,830
Economic conditions ($M)							
Present value of economic returns	1,994	2,293	2,268	2,245	2,312	2,268	2,224
Alternative irrigation practice costs	0	57	81	95	36	81	120
Median return on investment [c]	--	4.81	2.73	2.59	--[b]	2.73	1.50
Highest return on investment	--	53.36	17.48	10.42	--	17.48	17.35

[a] These model runs use the baseline 5% increases in the production cost for the alternative zero-grade irrigation practice [b] These model runs use the baseline 3% increase in the production cost for the alternative RISER irrigation practice [c] The median return on investment is the median value among the site specific return on investment calculated for every site.

Table 6: Agricultural landscape conditions for the final period for low and high adoption rates of irrigation practices.

Landscape conditions	**No alternative practice adoption**	**Low adoption**			**High adoption**		
		0-10 years	**10-20 years**	**20-30 years**	**0-10 years**	**10-20 years**	**20-30 years**
Land use (thousand acres)							
Conventionally irrigated Rice	246	229	237	244	222	214	228
Alternative irrigated Rice	0	26	30	32	38	61	65
Conventionally irrigated Soybeans	568	556	551	547	546	507	488
Alternative irrigated Soybeans	0	52	61	66	76	123	131
Conventionally irrigated Corn	78	27	29	34	17	18	20
Alternative irrigated Corn	0	12	13	11	14	11	10
Non-irrigated Soybean	74	66	45	33	53	33	24
Water conditions (thousand acre-feet)							
Cumulative groundwater use	7,566	2,462	5,002	7,590	2,468	4,962	7,504
Groundwater use in final period	2,548	2,462	2,540	2,588	2,468	2,494	2,542
Aquifer thickness	52,570	60,450	56,570	52,450	60,430	56,170	52,880
Economic conditions ($M)							
Present value of economic returns	1,994	2,164			2,268		
Alternative practice costs	0	49			81		
Median return on investment [a]	--	2.98			2.73		
Highest return on investment	--	29.48			17.48		

[a] The median return on investment is the median value among the site specific return on investment calculated for every site.

Table 7: Agricultural landscape conditions for a longer time horizon

Landscape conditions	**No alternative irrigation practice adoption**	**High adoption**					
		10 years	**20 years**	**30 years**	**40 years**	**50 years**	**60 years**
Land use (thousand acres)							
Conventionally irrigated rice	240	185	162	140	158	184	195
Alternative irrigated Rice	0	31	62	88	100	104	105
Conventionally irrigated Soybeans	563	558	511	452	391	351	336
Alternative irrigated Soybeans	0	70	139	204	242	256	255
Conventionally irrigated Corn	68	9	6	7	13	14	14
Alternative irrigated Corn	0	9	13	15	14	14	14
Non-irrigated Soybean	95	104	73	60	49	44	48
Water conditions (thousand acre-feet)							
Cumulative groundwater use	14,288	2,260	4,512	6,728	10,100	11,310	13,682
Groundwater use in final period	2,486	2,260	2,252	2,216	3,372	1,210	2,372
Aquifer thickness	45,380	61,450	59,000	56,720	54,290	51,430	48,370
Economic conditions ($M)							
Present value of economic returns	2,978	3,783					
Alternative irrigation practice costs	0	244					
Median return on investment [a]	--	2.59					
Highest return on investment	--	30.33					

[a] The median return on investment is the median value among the site specific return on investment calculated for every site.

Table 8: Agricultural landscape conditions for the sensitivity analyses of depth to the aquifer, aquifer thickness, and crop margins for high adoption rate.

Landscape conditions	**Baseline alternative irrigation**	**Sensitivity analysis**					
		Initial depth		**Initial aquifer thickness**		**Margins**	
		Half	**Double**	**Half**	**Double**	**Quarter**	**Double**
Land use (thousand acres)							
Conventionally irrigated Rice	228	240	158	221	235	65	249
Alternative irrigated Rice	65	65	65	59	65	47	65
Conventionally irrigated Soybeans	488	482	517	477	487	578	309
Alternative irrigated Soybeans	131	123	133	131	131	133	125
Conventionally irrigated Corn	20	27	8	19	18	1	161
Alternative irrigated Corn	10	8	16	10	9	1	36
Non-irrigated Soybean	24	21	70	50	22	142	21
Water conditions (thousand acre-feet)							
Groundwater use in final period	2,542	2,610	2,244	2,466	2,564	1,808	2,666
Aquifer thickness	52,880	51,130	56,930	22,000	116,500	62,890	50,240
Economic conditions ($M)							
Present value of economic returns	2,268	2,845	1,279	1,899	2,614	-1,380	19,160
Alternative irrigation practice costs	81	79	82	77	81	69	89
Median return on investment [a]	2.73	3.05	3.54	2.76	2.72	4.53	7.92
Highest return on investment	17.48	17.6	18	32	12.37	18	26.9

[a] The median return on investment is the median value among the site specific return on investment calculated for every site.

Table 9: Agricultural landscape conditions for policy interventions.

Landscape conditions	**Baseline alternative irrigation**	**Policy**			
		Cap on groundwater pumping	**Tax on groundwater pumping costs**	**Subsidy on zero-grade irrigation practice**	**Subsidy on RISER irrigation practice**
Land use (thousand acres)					
Conventional irrigated Rice	228	227	225	228	228
Alternative irrigated Rice	65	65	65	65	65
Conventional irrigated Soybeans	488	489	491	488	481
Alternative irrigated Soybeans	131	131	131	131	133
Conventional irrigated Corn	20	20	19	20	19
Alternative irrigated Corn	10	10	10	10	17
Non-irrigated Soybean	24	25	25	24	24
Water conditions (thousand acre-feet)					
Groundwater use in final period	2,542	2,530	2,528	2,542	2,536
Aquifer Thickness	52,880	52,950	53,120	53,460	52,920
Economic conditions ($M)					
Present value of economic returns	2,268	2,265	2,234	2,294	2,290
Alternative irrigation practice costs	81	81	81	54	60
Policy outcomes					
Government transfer ($M)	--	--	33	-5.3	-7.8
Cost-effectiveness($ per acre-foot)	--	42.86	4.17	--[b]	355
Policy Outcomes					
Return on investment [a]	2.73	2.72	2.72	5.13	4.34

[a] The median return on investment is the median value among the site specific return on investment calculated for every site [b] This policy does not result in the conservation of groundwater.

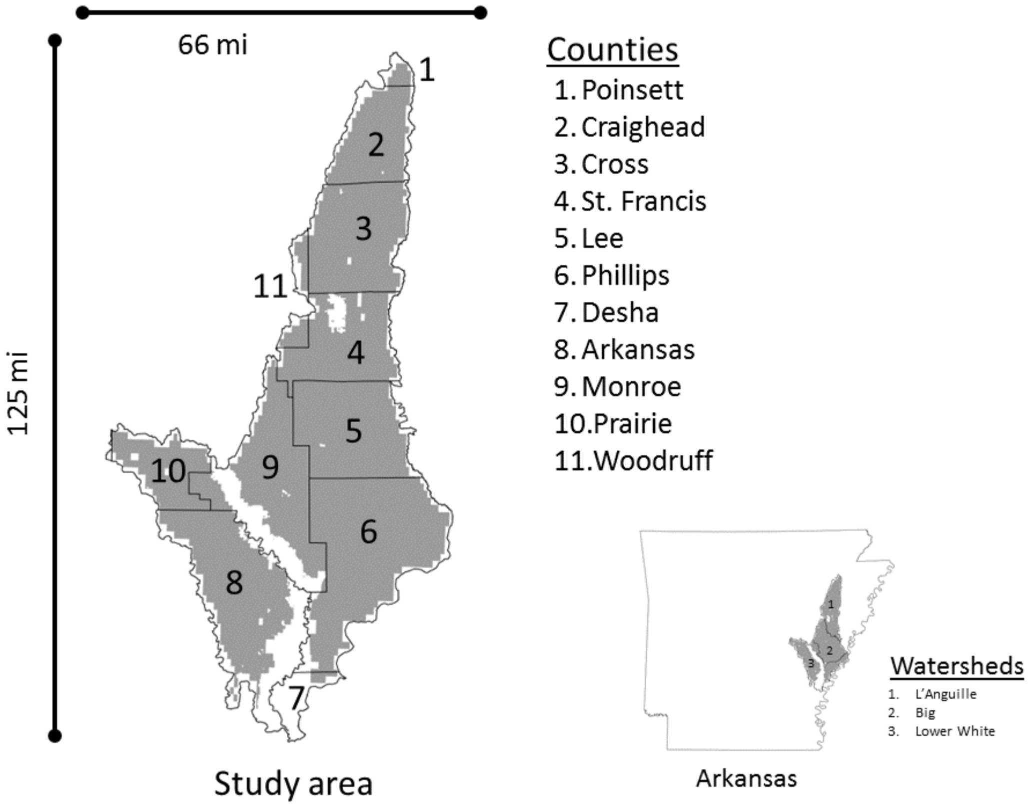

Figure 1: Three eight-digit HUC watersheds in the Mississippi Delta region of eastern Arkansas define the outer boundary of the study area. An eight-digit HUC defines the drainage area of the sub-basin of a river. County lines overlay the study area. Public land and urban areas are excluded. The location of the study area within the state of Arkansas is shown. Taken from Kovacs & Durant-Morat, (2017).

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Chapter II: Influence of Peer Networks on the Use of Surface Water Systems

Introduction

The use of reservoirs and tail-water recovery systems are ways of reducing groundwater use in irrigated agriculture. It can be seen in figure 2 that water stored in wetter seasons is preserved using tail-water recovery and reservoirs for use in months where there is a higher demand for irrigation water. The incoming flow comes from rainfall and residual surface and groundwater water for irrigation. This storage of water in previous months ensure that there is adequate irrigation water available in the months of high demand and limits the irrigation water being pumped from the ground.

The adoption of reservoirs and tail-water recovery systems have economic benefits for producers; pumping costs from the groundwater fall as water comes from the storage system. Despite the benefit, some farmers are reluctant to adopt reservoirs or tail-water recovery systems. This is due to the capital costs of implementing the water management methods, the lack of knowledge and interest in alternative methods of irrigation, and the removal of productive land for their construction. In a bid to encourage producers to adopt surface water irrigation, the Arkansas Natural Resource Commission offers producers a tax credit up to 50% of the project cost to install a storage reservoir (ANRC, 2013). Despite this incentive, there has been little stimulus to encourage producers to adopt the water saving methods.

The aim of this paper is to have a greater understanding of how the peer networks of producers influence the adoption of both reservoirs and tail-water recovery systems. The research tests a variety of different explanatory factors from the data of the Arkansas Irrigation Survey of 2016. The survey was conducted by telephone, targeting producers in the Arkansas Delta region to gain a better understanding of their production processes and preferences. By identifying the explanatory factors with the greatest correlation of adoption, agricultural extension services in the state may more effectively encourage producers to adopt the water storage methods in the future. The paper outlines the data, the methods to determine the most influential factors, the results from these methods, discussion of the results, and how to improve the research in the future.

Literature Review

The reasons for this research is to understand the issue of groundwater scarcity in the Arkansas Delta region. Despite the issue not being as severe as in other drought stricken states such as California, water scarcity that results from groundwater pumping could harm future agricultural production. One approach proposed by policy makers is to have more producers use groundwater saving technologies, in this case the focus is on reservoirs and tail-water recovery systems. In a paper addressing the impacts of reservoirs size and profit on water decline rate, Hristovska, et al., (2011) highlight the water storage potential of on-farm reservoirs through rain-water, groundwater and surface water. Not only do they store water, but these systems can reduce sediment volumes in water which increases water quality. Despite these benefits there are also negative implications of adopting on-farm reservoirs which include larger capital investments and the loss of productive land for construction, which are discussed in this literature. The benefits of adopting a tail-water recovery system are discussed by Popp, et al., (2002) which include the recycling of water which improves both water management and quality. This paper also indicates that tail-water recovery systems can function both with and without the presence of a reservoir.

It is often difficult to understand what factors influence the adoption of these kinds of technologies, especially when the problem is currently not a key issue for many producers. Much of the literature behind adoption of irrigation technology is in response to drought conditions, an example of this is the research conducted by Schuck, et al., (2005). The research looks to determine the responses from producers after the 2002 Colorado drought, and finds that there are in fact lower adoption rate responses than expected. The findings suggest that producers look for short term, low cost fixes to address irrigation shortages. These results highlight the issues that policy makers and interest groups, who look to preserve both economic and environmental assets in agricultural production face when trying to encourage the adoption of irrigation technologies. Our research will look to build on this literature by including a variety of factors that could influence the adoption of irrigation technologies.

One of these factors includes the influences of peer networks on the adoption of surface water systems. The work conducted by Genius , et al., (2013) looked to better understand the influences of both extension agencies and social networks on the promotion of agricultural technology adoption. They find that both extension agencies and social networks help increase the levels of technology adoption. To build on this, the paper also finds that the presence of extension agencies and social networks can act as complements to each other and increase the diffusion of adoption of agricultural technologies. The research for the Genius et al. (2013) findings were conducted in Crete, Greece. Our paper looks to understand the impacts of peer effects in the Arkansas Delta region. I believe that peer networks can increase the rate of adoption of surface water technologies, and this can be useful to extension agents.

Developing on the literature behind the influence of peer networks, Ramirez (2013), finds that the trust between farmers in a social network has a positive influence on the adoption of irrigation technology. The Ramirez paper also concludes that government-led information sessions through clubs and organizations can also have a positive influence on the adoption of water saving technologies. Our paper looks to expand on this literature, by looking at the influence of knowing others with reservoirs or tail-water recovery systems. The impacts that being involved in a conservation groups has on the adoption of irrigation technologies will also examined.

Socioeconomic and farm practice characteristics are also highlighted as possible factors in the adoption of alternative technologies. Knowler & Bradshaw, (2007) highlight that education, farming experience, farm size and income level have had both positive and negative correlations with the adoption of agricultural conservation practices. Alcon, et al., (2011) found that education had a positive influence in the adoption of drip irrigation systems in Spain, other studied including that of Koundouri, et al., (2006) also support the link between education and the adoption of conservation practices. Shrestha & Gopalakrishnan, (1993) found that farm size had a positive influence on the adoption if the same irrigation system in Hawaii for the production of sugarcane.

Methods

To examine the explanatory factors correlated with the adoption of surface water technology, a multinomial logit regression (MNL) is used.

The MNL estimation method maximizes the likelihood that each independent variable influences the dependent variables. This will allow for a better understanding of what variables are influencing producer’s choice when it comes to adopting reservoirs or tail-water recovery systems. For the MNL model, there are four dependent variables that take on a whole number value of 0, or 1. The dependent variables indicates whether producers have neither a reservoir nor a tail-water recovery system, producers that have a tail-water recovery system only, producers that have a reservoir only and producers that have both a tail-water recovery system and a reservoir. The dependent variables is unordered meaning that having both a reservoir and tail-water recovery system is not necessarily more preferable option than having a reservoir only, having a tail-water recovery system only, or neither a reservoir or tail-water recovery system.

This multinomial model is described below where *m* represents the alternative choice options and *y* is the dependent variable which takes the value of *j* if the j^{th} alternative is taken, $j = 1,\ldots m$. The probability that alternative *j* is chosen can be defined as (Eq.11):

(Eq.11) $$p_j = \Pr[\, y = j],\ \ j = 1,\ldots,m.$$

Where *p* and Pr is the probability. This introduces *m* binary variables for each observation *y* in (Eq.12),

(Eq.12) $$yj = \begin{cases} 1 \text{ if } y = j, \\ 0 \text{ if } y \neq j, \end{cases}$$

It can be seen that *yj* is equal to one if alternative *j* is the observed outcome and the remaining y_k are equal to zero, meaning that for each observation of *y*, one of $y_1, y_2, \ldots, y_m$ will be nonzero.

For the likelihood function a sample of *N* independent observations is shown as (Eq.13):

(Eq.13) $$L_N = \prod_{i=1}^{N} \prod_{j=1}^{M} p_{ij}^{yij} \ ,$$

where *i* represents the i^{th} of *N* individuals and *j* represents the j^{th} of *m* alternatives. The log-likelihood function is therefore (Eq.14):

(Eq.14) $$\Lambda = InL_N = \sum_{i=1}^{N} \sum_{j=1}^{m} y_{ij} \ In\, p_{ij,}$$

As our regressors do not vary over alternatives, MNL model is applied (Eq.15),

(Eq.15)
$$p_{ij} = \frac{e^{x\prime\beta_j}}{\sum_{l=1}^{m} e^{x\prime\beta_j}}, \qquad j = 1, \dots, m$$

Because $\sum_{j=1}^{m} pij$ = 1, a constraint is needed to ensure the model identification and the usual restriction of $\beta_1 = 0$.

Our model uses the Huber, White and sandwich estimator to calculate the variance-covariance matrix for the coefficients in the model. This allows for consistent estimation of the standard errors of the coefficients in the presence of heteroscedasticity

The results in our model are represented in terms of relative risk. For the MNL model a comparison from the base category is drawn, which is the alternative normalized to have a coefficient of zero. This is in (Eq.4) where it is implied that the probability of observing alternative *j* given that either alternative *j* or alternative *k* is observed is (Eq.16),

$$\Pr[y = j \mid j \text{ or } k \text{ or } r \text{ or } s] = \frac{p_j}{p_j + p_k + p_r + p_s}$$

(Eq.16)
$$= \frac{e^{x'\beta_j}}{e^{x'\beta_j} + e^{x'\beta_k} + e^{x'\beta_r} + e^{x'\beta_s}}$$

$$= \frac{e^{x'(\beta_j - \beta_k)}}{1 + e^{x'(\beta_j - \beta_k)} + e^{x'(\beta_r - \beta_k)} + e^{x'(\beta_s - \beta_k)}}$$

which represents a logit model with the coefficient ($\beta_j - \beta_k$). Simplifying allows for a second equality. Supposing that normalization is attributed to base alternative k, meaning $\beta_k = 0$. Then we get (Eq.17),

(Eq.17)
$$\Pr[y_i = j \mid \ y_i = j \ or \ k \ or \ r \ or \ s] = \frac{e^{x\prime\beta_j}}{1 + e^{x\prime\beta_j} + e^{x\prime\beta_r} + e^{x\prime\beta_s}}$$

β_j can carry the same interpretation as logit model where alternatives j has the binary choice 0 or 1. Likewise, it can be interpreted using relative risk of choosing alternative j rather than alternative k, this is shown as (Eq.18),

(Eq.18) $$\frac{\Pr[y_i=j]}{\Pr[y_i=k]} = e^{x'\beta_j}$$

meaning e^{β_j} explains the proportionate change in relative risk when x_{ir} changes by one unit. Results of the model will be output using the relative risk values. The relative risk value gives the proportionate change in odds of a surface water investment, when an independent variable increases by one unit. For example, suppose the coefficient for education is 0.43, this means that an additional unit of education lowers the odds of choosing that investment to less than one half.

The linear regression formula is shown as (Eq.19);

(Eq.19) $$y_i = \beta_0 + x_i'\beta_1 + c_i'\beta_2 + z_i'\beta_3 + w_i'\beta_4 + u_i \text{ where } i = 1,\ldots, n.$$

The parameter β_0 is the intercept of the model, $x_i'\beta_1$ is a vector of independent variables which are associated with conservation network. Variables which show producer socioeconomics are held in the vector $c_i'\beta_2$. Variables which represent farm practices are held in the vector $z_i'\beta_3$. Variables which represent aquifer are held in vector $w_i'\beta_4$. The final term is shown as u_i which includes all other possible variables that are not represented in the model.

Data

The data used in this paper are extracted from the Arkansas Irrigation Survey Questionnaire which was conducted in 2016 by the Mississippi State University Survey Research Laboratory. A total of 229 producers conducted the survey and were asked numerous questions about irrigation practices during a phone call interview. The survey targeted producers living in the Arkansas Delta region. The questions cover a variety of topics which looked to gain a better understanding of peer network relationships, farm ownership, crops grown, irrigation techniques and preferences, groundwater concerns, willingness to pay for irrigation, farm income and farmer education. The data will be used to better understand the reasons behind the current adoption of reservoirs and tail-water recovery. Responses such as peer networks, farm income, education, conservation preferences and groundwater concerns are useful for identifying a relationship with the use of storage water systems.

To gain a better insight of the current adoption of on farm water storage, the number of producers who use a reservoir per crop are presented in figure 3. The graph shows that for all crops the majority of producers do not use on-farm water storage. The majority of producers who do use on-farm storage reservoirs, use them for soybean, rice and corn. This could be because these crops are the most irrigation intensive crops. In figure 4 it can be seen that the current adoption of tail-water recovery systems by crop. Rice and corn growers are more likely to use tail-water recovery systems, with rice growers having the highest rate of adoption.

As this research looks to use a regression model, a selection of independent variables which would potentially have an impact on the of reservoir and tail-water recovery systems were selected, these are shown in table 11 of the table and figures section and divided into different characteristic groups. The same table also provides a description of each independent variable where the means and standard deviations of each of the independent variables can also be seen. Each independent variable is selected based upon findings from the review of literature.

Based upon the positive social network findings by Genius , et al., (2013) and Ramirez, (2013), the variables knowing someone with a tail-water recovery system, knowing someone with a reservoir and being part of a conservation group have been selected to better understand possible relationships between peer networks and rates of adoption. Being involved in the EQIP program is also introduced as it could be a factor that highlights a conservationist outlook and help better understand the awareness of such policy programs. Socio-economic factors such as education, income and farming experience are added to better understand their linkage in conservation irrigation adoption and build further on the findings by Alcon, et al., (2011) and Koundouri, et al., (2006). For the farm practice variables the use of irrigated acre by crop are introduced to investigate their impact on adoption, the idea is that producers will greater irrigated acres mean they will have greater farm size which could have a positive influence on adoption, supporting the findings by Shrestha and Gopalakrishana (1993). The use of cover crops, soils sensor and flowmeters are also studied as they could give insight into a conservationist mindset of producers and better understand the findings of Schuck, et al., (2005) who believe that producers may seek cheaper and easier to implement irrigation saving solutions in drought conditions. Variables that look at the perceptions of producers in terms of aquifer volume changes are also added to gain a greater insight into connections between perceived groundwater scarcity and conservation irrigation adoption.

Results

The results are presented by variable group, table 13. Results are recorded using relative risk ratios (RRR) which are recorded for each choice of surface water storage system; tail-water recovery only, reservoir only, and both tail-water recovery and reservoir.

Table 13 shows that being part of the EQIP program is significant at the 1% level with a RRR of 4.7 when adopting a both surface water practices. Knowing someone with a tail-water recovery system is significant at the 1% level with a RRR of 32.43 when adopting TWR only and significant at the 5% level with an RRR of 21.65 for the adoption of both reservoirs and tail-water recovery systems. Being part of a conservation group is significant at the 10% level when adopting both conservation practices with an RRR of 2.91.

Having 4 year college experience is significant at the 10% level, with an RRR of 0.24 when adopting both tail-water recovery and reservoirs. If producers have advanced college degrees the RRR for adopting only a reservoir is <0.00, and 0.01 for adopting both a reservoir and tail-water recovery, both are significant at the 1% level.

Irrigated corn acres have an RRR of 5.79 for reservoir adoption only and an RRR of 4.07 for the adoption of both which are significant at the 1% and 5% levels respectively. Irrigated soybean acres are significant at the 10% level with an RRR of 0.62 for tail-water recovery adoption only and significant at the 5% level for the adoption of both with an RRR of 0.45. Irrigated rice acres have an RRR of 2.45 for the adoption of tail-water recovery only and an RRR of 2.16 for both reservoir and tail-water recovery adoption, each have a significance level of 10% and 5% respectively. Use of cover crops is significant at the 10% level with an RRR of 0.26 for the adoption of tail-water recovery only. The use of flowmeters has an RRR of 8.07 and is significant at the 1% level for the adoption of both surface-water practices. Using soils sensors are significant at the 1% level when adopting reservoirs only, the RRR is <0.000.

A depth fall in the aquifer has an RRR of <0.00 for the adoption of reservoirs only, which is significant at the 1% level. The RRR for adopting both is 7.19 and significant at the 10% level.

Discussion and Conclusions

It can be seen that there is a peer network influence in the adoption of tail-water recovery systems and reservoirs. Knowing someone with a tail-water recovery system and a reservoir increases the odds of adopting both forms of water storage. There are multiple reasons why this might be the case, including that adopters have spoken highly of the surface water system and recommended it to their peers. This highlights that farmers trust their fellow peers when thinking about adopting new technologies. These claims are aligned with findings from previous literature where Ramirez, (2013) identified that farmers get the majority of their information from their peers, thus making the relationship between farmers key for increasing adoption rates. Our results are also aligned with the findings from the Genius , et al., (2013) paper which finds that social networks have a positive influence on the adoption of agricultural technology. One other key influence on adoption drawn from this literature is the participation of producers in like-minded organizations. It can be seen from the results that for the participation in conservation groups, there is only one significant outcome, which suggests an increase in likelihood for the adoption of both conservation practice when being part of a conservation group. A similar trend can be seen for producers who have taken part in the EQIP program. The significance of these two variables shows that producers who are adopting both surface-water methods could have a conservationist outlook and look to use surface-water as a means of preserving natural resources.

Our results show that as education levels increase the likelihood of adopting both surface water facilities decrease. This again goes against the findings of previous literature, such as Koundouri, et al., (2006) and Alcon, et al., (2011) who find that education has a positive influence on the adoption of other agricultural technologies. The findings are negative due to the low proportion of respondents with advanced education, as seen in the descriptive statistics, the variable for advanced education has a mean of 0.09. There is a higher proportion of respondents with 4 years college education, which has a negative correlation with the adoption of both surface water technologies. I also offer the possible explanation that producers who have advanced education are investing in alternative water conservation practices. The adoption of surface water technologies began as early as the 1960's, I speculate that adopters of these technologies are older may not have had the academic opportunities as younger producers. The younger producers are therefore more educated in newer precision agriculture and choose to adopt these methods, instead of building surface water infrastructures which reduce land availability on producer sites.

There are odds increases when the acres of both irrigated corn and rice increase. I assume that this increase is due to corn and rice being an irrigation intensive crops. The more irrigated acres a producer has, the more water they are going to use, which would make them more inclined to invest in water saving technologies to reduce water pumping costs in their production. Another positive variable is use of flowmeters when adopting both reservoir and tail-water recovery systems. Flowmeters are also considered to be a water conservation technology, it makes sense that people who are conscious of their water use would adopt both water storage facilities and flow meter technology as they are invested in water conservation. These findings could also support the findings of Schuck, et al., (2005) that suggest producers look for low cost fixes to address water issues. As flowmeters cost relatively less than other irrigation technologies, it could be that producers in our study area are looking for cheaper and easier alternatives to address groundwater concerns.

The results don't give concrete evidence for the adoption of water saving technologies compared to producer's beliefs in the changes of groundwater depths. I would expect to see that producers who believe their depths are falling, would be more likely to have adopted. Due to the nature of the question asked it is difficult to get a deep understanding the meaning of the response. I believe that adoption of water storage should be because of the falling groundwater depths. However, the respondents who have adopted could be more inclined to respond that their depths to groundwater have increased, therefore a positive RRR for producers who have adopted both reservoirs and tail-water recovery are observed, and who also see their groundwater depths rising.

Results give some key insights into the role of peer networks when adopting water conserving storage water facilities. There is evidence that knowing someone with a tail-water recovery system makes others more likely to adopt, creating a positive feedback scenario for future adoption trends. Being part of a conservation network and the use of the EQIP program increase the likelihood of adoption of both technologies, which would suggest that producers who are adopting both technologies have a conservationist mindset. Producers who use flowmeters are more likely to use both water storage facilities. This is due to producers being invested conservation agriculture meaning they are more likely to use water efficient systems. Understanding the reason behind the adoption of surface water methods could help extension agents in the Arkansas Delta Region increase levels of adoption and therefore limit the impacts of groundwater depletion that threatens the region.

A key limitation of our model is the small sample size for the adoption of reservoir only. There is also limitations in the way in which the data is collected. By using the telephone interview method, it could be that respondents are limited to time for their responses. This aspect of the collection method also reduces the response rate of the survey. Future research could involve face-to-face interviews, focus groups or internet surveys that mean producers set aside their own time and are not limited in their responses. Questions asked could be more focused on finding out explicitly reasons between adoption and non-adoption.

Tables and Figures

Table 10: Description of variables

Variable Name	**Description**	**Mean**	**Standard Deviation**
Conservation Network			
Eqip	Respondents were asked if they have ever been involved in the EQIP which is a program which offers financial incentive to adopt conservation practices	0.45	0.5
K_Twr	Respondents were asked if they know of any family members, friends or neighbors who have used a tail-water recovery system	0.66	0.47
K_Res	Respondents were asked if they knew any family members, friends or neighbors who use a reservoir	0.6	0.5
Cgroup	Respondents who have been part of a conservation group	0.51	0.5
Socioeconomics			
2Col	Respondents who have attained 2 years of college as their highest level of education	0.23	0.42
4Col	Respondents who have attained 4 years of college as their highest level of education	0.42	0.5
AdvEdu	Respondents who have attained above a 4 year college degree as their highest level of education	0.09	0.28
IncM	Respondents who have a 2014 household income between $75,000 and $200,000	0.39	0.49
IncH	Respondents who have a 2014 household income above $200,000	0.19	0.36

Table 10 (Cont.)

Variable Name	**Description**	**Mean**	**Standard Deviation**
FrmExper	The total years the respondent has been a farmer	32.7	15.35
Farm Practices			
IrrCornAcres	The total acres of irrigated corn the farmer has on their land	299	0.9
IrrSoyAcres	The total acres of irrigated soybean the farmer has on their land	1201	1.49
IrrRiceAcres	The total acres of irrigated rice the farmer has on their land	655	0.98
CoverCrop	Respondents who use cover crops	0.31	0.45
FlowMeter	Respondents who use flowmeters	0.35	0.48
SoilSensor	Respondents who use soil sensors	0.09	0.3
Aquifer Change			
DepthFall	Respondents who believe groundwater depths have fallen on their site over the past 5 years	0.13	0.34
DepthRise	Respondents who believe groundwater depths have increased on their site over the past 5 years	0.27	0.45

Table 11: Results of MNL regression for the adoption of surface water irrigation methods

Independent Variable	TWR ONLY	RES ONLY	BOTH
Conservation Network			
EQIP	1.0 (1.00)	0.60 (0.43)	4.7** (0.004)
K_Twr	32.43*** (0.000)	0.23 (0.20)	21.65** (0.003)
K_Res	0.58 (0.35)	201.5* (0.04)	4.56* (0.03)
Cgroup	1.09 (0.86)	0.60 (0.57)	2.91* (0.02)
Socioeconomics			
2Col	1.13 (0.87)	0.75 (0.75)	0.42 (0.15)
4Col	0.60 (0.44)	0.15 (0.25)	0.24* (0.02)
AdvCol	0.63 (0.58)	2.38e-07*** (0.000)	0.01*** (0.000)
IncM	1.41 (0.53)	0.36 (0.46)	1.99 (0.18)
IncH	2.65 (0.12)	5.92 (0.20)	1.48 (0.63)
Frm_Exper	0.99 (0.64)	0.93 (0.13)	1.01 (0.62)

Table 11 (Cont.)

Independent Variable	TWR ONLY	RES ONLY	BOTH
Farm Practice			
IrrCornAcres	3.20 (0.06)	5.79*** (0.001)	4.07* (0.02)
IrrSoyAcres	0.62* (0.03)	0.77 (0.51)	0.45** (0.003)
IrrRiceAcres	2.45** (0.003)	0.26 (0.34)	2.16* (0.02)
CoverCrop	0.26* (0.03)	0.22 (0.19)	1.03 (0.96)
FlowMeter	2.94 (0.04)	1.39 (0.75)	8.07*** (0.000)
SoilSensor	2.24 (0.33)	2.17e-07*** (0.00)	3.95 (0.11)
Aquifer Change			
Depth Fall	1.16 (0.85)	1.72e-06*** (0.00)	7.19* (0.01)
DepthRise	0.62 (0.39)	3.43 (0.20)	1.12 (0.83)
N	229		
Significance	*10%,**5%,***1%		

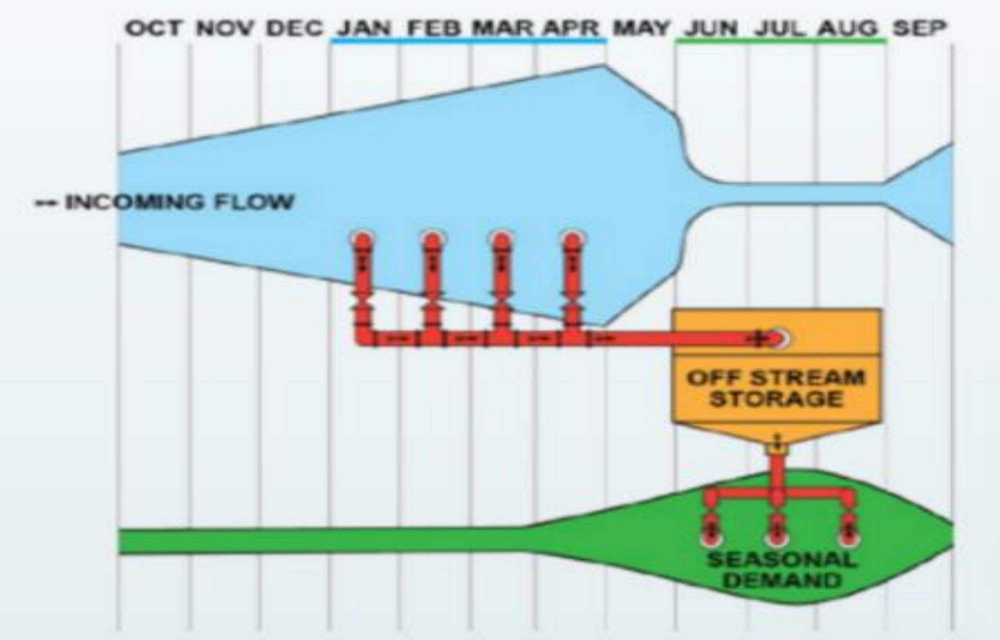

Figure 2: Visual representation of surface water storage process *ANRC, (2014)*

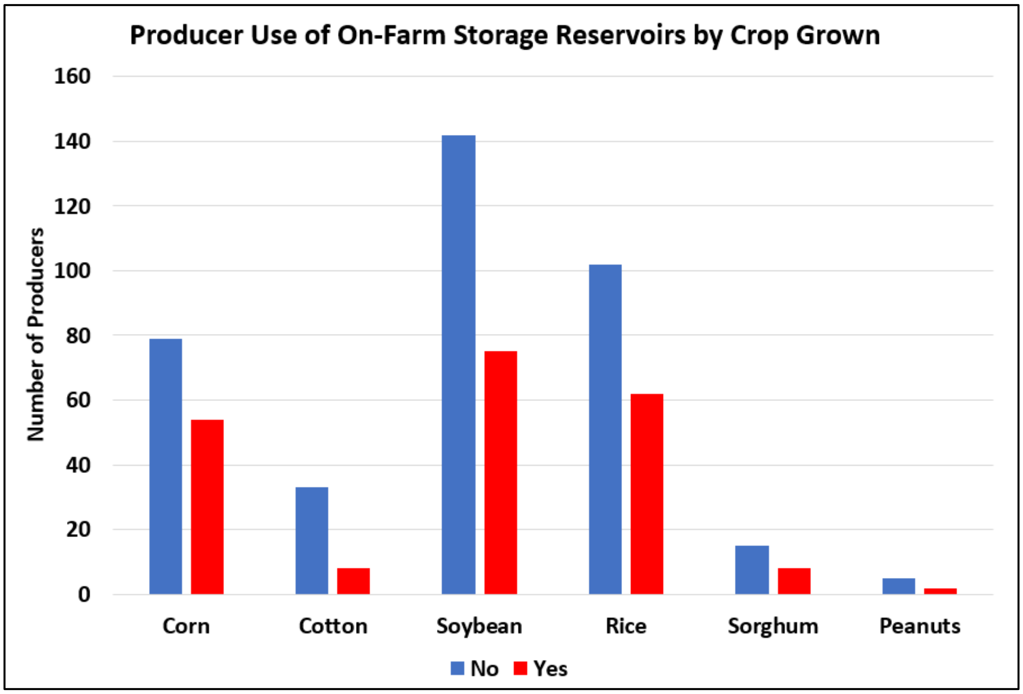

Figure 3: Number of producers who use on-farm storage reservoirs by crop grown

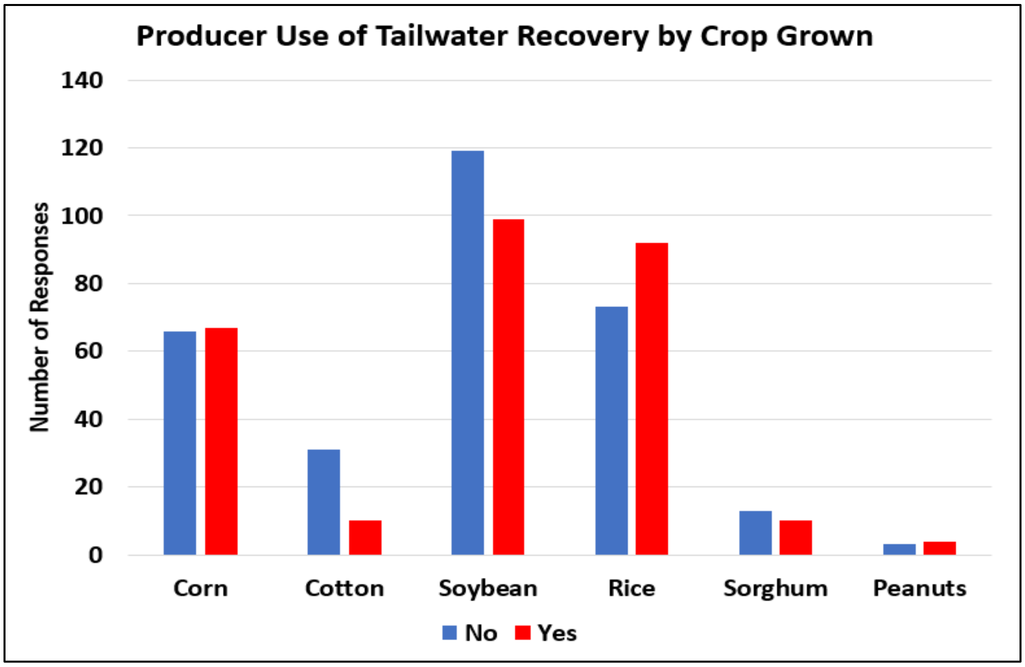

Figure 4: Number of producers who use tail-water recovery system by crop grown

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Conclusion

To address groundwater depletion in the Arkansas Delta region this paper includes two chapters, the first chapter looked to better understand potential returns on investment in new irrigation practices for irrigation intensive crops; rice, corn and soybean. The second chapter identifies which factors are correlated with the adoption of water storage facilities; reservoirs and tail-water recovery systems.

In chapter I it can be concluded that the alternative irrigation technologies, RISER and zero-grade results in positive return on investments for producers as total, more profitable, irrigated acres are increased and the costs of groundwater pumping are reduced. In higher adoption rate scenarios groundwater use is reduced as the proportion of alternative irrigated acres increase. In the lower adoption rate scenario groundwater use increases with the adoption of alternative technologies, as there are fewer alternative acres on the landscape meaning water savings cannot offset the increase in total irrigated acres, resulting in a re-bound scenario. When evaluating different policy options to increase aquifer volumes, the most cost-effective policy was the use of a 2% tax on groundwater use.

Results from chapter II show that peer-networks play an important part in the adoption of water storage technologies. Knowing people with reservoirs and tail-water recovery systems were correlated with adoption. The same can also be said for being part of a conservation group. This creates a potential conservationists outlook from certain producers that are more likely to adopt alternative technologies. In terms of socioeconomics, education had a negative correlation with the adoption of surface water technologies. This could be due do producers with higher education levels adopting more sophisticated technologies.