Image caption: Rice field in Arkansas. Photo from Valley Irrigation.

Assessment of Strategies to Address Future Irrigation Water Shortage in the Arkansas Delta

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Abstract: Conversion to surface water irrigation has been identified as one of the critical initiatives to address the decline in groundwater supply in Arkansas. Using the Arkansas Irrigation Use Survey conducted by the PIs with collaborators, this study uses statistical analysis to estimate Arkansas agricultural producers' willingness to pay (WTP) for off-farm surface water and examine which factors have predictive powers of producers' WTP for irrigation water. The estimated mean WTP for irrigation water is $33.21/acre-foot. Comparison indicates a significant share of producers are likely to have higher WTPs for surface water than the average pumping cost in the study area. Producers located in areas with less groundwater resources have higher WTPs. Producers that are more concerned with a water shortage occurring in the state in the next 10 years have higher WTPs. A somewhat unexpected result is that participation in the Conservation Reserve Program predicts lower WTPs. One possible explanation is that farmers see the transfer of land out of crop production as a more viable financial decision when groundwater supply decreases.

Key Points:

- More than 70% of sampled producers in Arkansas are likely to be willing to pay more than the average pumping cost of groundwater to purchase surface water from an irrigation district.
- The level of willingness to pay for surface water is positively correlated with the extent of groundwater shortage as perceived by producers.
- The existence of other conservation programs may lower the level of willingness to pay for surface water.

Introduction

Irrigation is the most important input in Arkansas's crop production. Nearly 86% of irrigation water in Arkansas in 2013 was sourced from groundwater in the Mississippi River Valley alluvial aquifer (MRVAA, NASS, 2014; Schrader 2008). However, the continuous and unsustainable pumping has put the MRVAA in danger by withdrawing at rates greater than the natural rate of recharge. In the 2014 Arkansas Water Plan by the Arkansas Natural Resources Commission (ANRC), an annual gap in groundwater as large as 8.6 billion cubic meters (7 million acre-feet) is projected for 2050 and most of the expected shortfall is attributed to agriculture (ANRC, 2015). To combat growing projected scarcity, two critical initiatives have been identified: conservation measures to improve on-farm irrigation efficiency and infrastructure-based solutions to convert to surface water (ANRC, 2015). Surface water in Arkansas is relatively abundant and is allocated to farmers based on riparian water rights. The ANRC (2015) estimates that average annual excess surface water available for interbasin transfer and non-riparian use is about 7.6 million acre-feet. Currently, the purchase of off-farm surface water is relatively rare in Arkansas. In the Farm and Ranch Irrigation survey conducted by the National Agricultural Statistics Service (NASS) of the USDA, only 4.82% of all farms reported utilization of off-farm surface water in Arkansas in 2012 (NASS, 2014).

In total, ANRC (2015) estimates that the construction of needed infrastructure to shift groundwater irrigation to surface water irrigation in the nine major river basins of eastern Arkansas will cost between $3.4 and $7.7 billion. Financing these projects has grown increasingly difficult because of decreases in the availability of federal grants, cost-share and loans (ANRC, 2015). As such, understanding the nature of water use and quantifying the full value of irrigation water to agricultural producers in the Delta will be critical for continued funding and long-run success of irrigation district projects, as well as the long-run viability of agricultural production in Arkansas.

This study has two objectives: 1). to estimate Arkansas agricultural producers' willingness to pay (WTP) for off-farm surface water; 2). to examine which factors have predictive powers of producers' WTP for irrigation water. This study is the first to provide estimates of Arkansas producers' WTP for irrigation water. In areas where infrastructure needs to be constructed to deliver surface water, estimates of the economic value of irrigation water to producers would be needed to conduct cost-benefit analysis of such projects as well as assess the financial viability of surface water irrigation systems. Our research findings also help water policy makers design polices to facility infrastructure projects that bring surface water to farming communities in Arkansas.

Methods

The data set comes from the Arkansas Irrigation Use Survey conducted by the PIs with collaborators from Mississippi State University. The survey was completed in October 2016 via telephone interviews. Potential survey respondents come from the water user database managed by the ANRC and all commercial crop growers identified by Dun & Bradstreet records for the state of Arkansas. The final sample size is 199 producers that completed the survey in its entirety.

The key information used in this study comes from the WTP section. Each producer first answered an initial question "Would you be willing to pay $___ per acre-foot of water to purchase water from an irrigation district?" When a respondent answered "yes" ("no"), the question was repeated at a higher (lower) bid value with a 50% increment; by increasing the interval between the first and second bid as the initial bid level increase we control for acquiescence bias (Alhassan et al., 2013; Lee et al. 2015). For respondents who answered "no" to the initial bid and "no" to the following lower bid, a third WTP question with a nominal bid amount of 50¢/acre-foot was used to determine whether true WTP was zero or if the respondent was offering a protest bid. To reduce starting point bias, when a respondent was interviewed, one out of the six values in the unit of $/acre-foot (10, 20, 30, 40, 50, 60) was randomly selected to ask the producer (Aprahamian, Chanel and Luchini 2007; Flachaire and Hollard 2006). This range of values was tested in a pilot survey and confirmed as appropriate. The responses to the questions are summarized in Table 1.

The mean WTP, E(WTP), is related to the cumulative density function, F(·) as

$$E(\mathrm{WTP}) = \int[1-F(b)]\,db \qquad (1)$$

where b is any positive amount of money and F(b) is Prob(WTP≤b). With the assumption of a logistic distribution,

$$\mathrm{Prob}(\mathrm{WTP}\leq b) = 1/[1+\exp(-\alpha-\beta b-z'\delta)] \qquad (2)$$

where z is the vector of variables that measure farm and producer characteristics such as farm location, total irrigated acres, crop mix, year of farming, gross income, education, producers' awareness of and past participation in conservation programs and producers' rating of the severity of water shortage in Arkansas. Using equations (1) and (2), the mean WTP can be imputed as (Koss and Khawaja, 2001):

$$E(\mathrm{WTP}) = -\ln[1+\exp(\alpha+z'\delta)]/\beta \qquad (3)$$

The parameters needed to calculate WTP, α, β and δ, are estimated using the method of maximum likelihood estimation

Table 1. Number of Yes and No Responses at Each Bid Level.

		Bid	Yes	(%)	No	(%)	Total Responses
	Lower bid:	0.4¢/m³ ($5/aft)	2	(0.33)	4	(0.67)	
Bid Set 1	**Initial bid:**	0.8¢/m³ ($10/aft)	14	(0.70)	6	(0.30)	20
	Upper bid:	1.2¢/m³ ($15/aft)	10	(0.71)	4	(0.29)	
	Lower bid:	0.8¢/m³ ($10/aft)	5	(0.63)	3	(0.38)	
Bid Set 2	**Initial bid:**	1.6¢/m³ ($20/aft)	5	(0.38)	8	(0.62)	13
	Upper bid:	2.4¢/m³ ($30/aft)	4	(0.80)	1	(0.20)	
	Lower bid:	1.2¢/m³ ($15/aft)	5	(0.56)	4	(0.44)	
Bid Set 3	**Initial bid:**	2.4¢/m³ ($30/aft)	9	(0.50)	9	(0.50)	18
	Upper bid:	3.6¢/m³ ($45/aft)	5	0.56	4	(0.44)	
	Lower bid:	1.6¢/m³ ($20/aft)	7	(0.44)	9	(0.56)	
Bid Set 4	**Initial bid:**	3.2¢/m³ ($40/aft)	9	(0.36)	16	(0.64)	25
	Upper bid:	4.9¢/m³ ($60/aft)	6	(0.67)	3	(0.33)	
	Lower bid:	2.0¢/m³ ($25/aft)	5	(0.38)	8	(0.62)	
Bid Set 5	**Initial bid:**	4.1¢/m³ ($50/aft)	5	(0.28)	13	(0.72)	18
	Upper bid:	6.1¢/m³ ($75/aft)	2	(0.40)	3	(0.60)	
	Lower bid:	2.4¢/m³ ($30/aft)	3	(0.23)	10	(0.77)	
Bid Set 6	**Initial bid:**	4.9¢/m³ ($60/aft)	7	(0.35)	13	(0.65)	20
	Upper bid:	7.3¢/m³ ($90/aft)	1	(0.14)	6	(0.86)	

*Out of the 199 producers that completed survey, 6 respondents refused to answer both WTP questions and 1 refused to answer the second bid level. Twenty-four respondents answered "no" to this third question. Of the remaining 169 respondents, 54 registered "don't know" responses to one or more of the proposed bid levels. All three groups of respondents were excluded from analysis. In total, 114 respondents were retained for final analysis.

(MLE). In MLE, the log likelihood function, the sum of the probabilities of observing each data point in the log form, is maximized. For each observation, a "yes" response to the question "Would you be willing to pay $___ per acre-foot of water to purchase water from an irrigation district?" means a respondent's WTP is greater than or equals the amount listed in the question (Hanemann, Loomis and Kanninen, 1991; Koss and Khawaja, 2001). The estimation is done using the STATA statistic software package. Summary statistics of variables are reported in Table 2.

Results and Discussion

Table 3 reports the results of the MLE estimation. If the sign of the estimated coefficient of a variable is positive, it means the variable has a positive effect on the level of WTP. The size of the effect of a variable on WTP is determined by the size of its coefficient as well as the coefficients of other variables. The coefficient of the bid variable is negative and statistically significant at the 1% level, indicating that respondents are more likely to say no to a large bid. A producer located east of Crowley's Ridge is less likely to say yes to any bid. This is probably because groundwater resources are more abundant in areas east of Crowley's Ridge and so producers are likely to exhibit lower WTP. The coefficient of respondent's rating of groundwater shortage in the state is positive and statistically significant at the 5% level, indicating greater willingness to pay for irrigation water when groundwater resources are perceived as scarce. Respondents who indicated awareness of Arkansas' tax credit program for construction of on-farm surface water infrastructure display a greater likelihood to answer yes to a higher bid. These results highlight the importance of increasing extension efforts to raise awareness of growing and long-term groundwater scarcity in the Delta as well as providing information that explains financial or technical assistance available to farmers who wish to transition to surface water irrigation.

A somewhat unexpected result is that Arkansas producers' WTP for irrigation water from irrigation districts decreases if they have participated in or are currently enrolled in the CRP. Previous studies have shown that producers who participate in conservation programs, such as the CRP, have better access to conservation information and make production decisions based on the impact of their choices

Table 2. Variable Definitions and Summary Statistics.

Variable	Description	Mean	St. Dev.	Min.	Max.
Crowley's Ridge	Binary variable where 1 = lives in a county to the east (in part or fully) of Crowley's Ridge, 0 = not	0.342	0.477	0	1
Years Farming	Total years of farming experience	30.91	14.41	1	60
Years Farming, Squared	The square of total years of farming experience	1161.35	909.89	0	3,600
Gross Income	Binary variable where 1 = gross income from all sources is greater than $75,000 and less than or equal to $150,000, 0=not	0.412	0.494	0	1
Percent Farm Income	Percent of gross income from farming	81.69	26.23	0	100
Bachelor's or Higher	Binary variable where 1 = education greater than or equal to a Bachelor's degree, 0 = not	0.561	0.498	0	1
Total Hectares	Total irrigated in 2015	939.2	774.5	0	4,046.80
Percent Rice	Percent irrigated rice production of total hectares in 2015	27.51	26.42	0	100
Percent Soybean	Percent irrigated soybean production of total hectares in 2015	53.93	27.37	0	100
Awareness of State Tax Credit	Binary variable where 1 = is aware of state tax credit program, 0 = not	0.483	0.502	0	1
Conservation, CRP	Binary variable where 1 = has participated in the Conservation Reserve Program, 0 = not	0.491	0.502	0	1
Groundwater Shortage	Respondent rating of the severity of water shortage in Arkansas, from 0=no shortage to 5=severe shortage, in the state	2.66	1.96	0	5

in future periods (Lubbell et al., 2013). One possible explanation for this finding is that farmers see the transfer of land out of crop production as a more viable financial decision when groundwater supply decreases. The squared term of years of farming experience is added to investigate if it has a nonlinear effect on WTP. The estimated coefficients are both statistically significant at 1%. The coefficient of years of farming experience is positive and that of the squared term is negative, revealing an inverted U-shaped relationship between years of farming experience and WTP. The values of estimated coefficients indicate that the turning point is 38. That is, in contrast to findings from previous studies that age is strictly negatively correlated with WTP for irrigation water (Mesa-Jurado et al., 2012), we find that WTP for water from irrigation districts increases with years of farming experience until approximately 38 years of experience, after which, WTP decreases with years of farming experience.

The estimation results are used to derive the willingness to pay for each observation. Of producers sampled, the minimum WTP is $3.09/acre-foot and the maximum WTP was $78.98/acre-foot. The mean WTP is $33.21/acre-foot (Table 4). One important finding is that for a significant share of the producers, the estimated WTP for surface water is likely to be greater than the energy cost they are currently paying to pump groundwater from the Aquifer. The Arkansas Irrigation Use Survey did not collect information on pumping cost by producer. Using the data on the depth-to-groundwater from the Natural Resources Conservation Service (Swaim et al., 2016) and energy prices, we calculate the pumping cost producers are currently paying to pump groundwater out. About 72% of our sample producers use both electric and diesel pumps, 12% uses electric pumps and 13% uses diesel pumps. For most producers, it is more expensive to pump using diesel fuel. The price of diesel used for the calculations is $3.77/gallon, which is about

Table 3. Maximum Likelihood Estimation Results.

	Coefficient	Standard Error
Intercept	-1.684	1.382
Bid	-0.0615***	0.008
Crowley's Ridge	-1.0586**	0.436
Years Farming	0.2124***	0.066
Years Farming, Squared	-0.0029***	0.001
Gross Income	0.460	0.399
Percent Farm Income	-0.193	0.764
Bachelor's or Higher	0.504	0.424
Total Irrigated Hectares	-0.0001**	4.05E-5
Percent Rice	-0.101	0.942
Percent Soybean	0.820	0.942
Awareness of State Tax Credit	1.1214***	0.418
Conservation, CRP	-1.1974***	0.419
Groundwater Shortage	0.2044**	0.099

***significant at 1%, **significant at 5%, and * significant at 10%

Table 4. Willingness to Pay (WTP) and Average Groundwater Pumping Cost.

Region	Average Depth-to-groundwater [a]	Estimated Cost of Pumping [b]	Estimated WTP	Percentile in the Distribution of Estimated WTPs
Arkansas Delta	12.3m (40.49 ft)	1.8¢/m^3 ($22.17/acft)	2.7¢/m^3 ($33.21/acft) [c]	29th
Lonoke County (greatest average depth-to-groundwater in Arkansas)	25.6m (83.35 ft)	3.7¢/m^3 ($45.62/acft)	3.4¢/m^3 ($42.03/acft) [d]	72th
Mississippi County (lowest average depth-to-groundwater in Arkansas)	4.9m (16.22 ft)	0.7¢/m^3 ($8.9/acft)	2.0¢/m^3 ($24.81/acft) [d]	5th

a. Data on the depth-to-groundwater are obtained from Arkansas Natural Resources Commission (Swaim et al. 2016).
b. Pumping cost is computed using the average depth-to-groundwater and the cost of diesel fuel reported by the Energy Information Administration.
c. Mean WTP is reported.
d. Due to small sample size in each of the two counties, median WTP is reported.

the 80th percentile of the weekly diesel prices between 1994 and 2016 reported by the US Energy Information Administration. Thus our estimates of pumping cost are on the high end of the distribution of pumping costs. The estimated pumping cost for the Arkansas Delta is $22.17/acre-foot, which is about the 29th percentile using the distribution of the estimated WTPs. This means 71% of the sample producers have estimated WTPs higher than the estimated average pumping cost.

The comparison is also carried out for Lonoke County, which is located to the west of Crowley's Ridge and has the greatest average depth-to-groundwater in Arkansas. Although the median WTP is lower than the average pumping cost ($42.03/acre-foot versus $45.62/acre-foot), 28% of the sample producers have estimated WTPs higher than the estimated average pumping cost in the county with the greatest average depth-to-groundwater. Mississippi County is located east of Crowley's Ridge, where the average depth-to-ground water is as shallow as 16 feet and pumping costs rarely exceed $9/acre-foot. The estimated median WTP is $24.81/acre-foot, much higher than the average pumping cost of $8.9/acre-foot. Thus, even in areas of the state where groundwater is most abundant, producers' WTP for surface water is likely to exceed the energy cost paid to pump groundwater from the aquifer.

Conclusions

The most significant finding of this study is that for the majority of the sample producers, their estimated WTPs for surface water are likely to be greater than the average pumping cost of groundwater producers are currently paying. Our study also identifies a set of factors that influence producers' WTP. For example, higher awareness of water shortage problems seems to predict increases in producers' WTP for irrigation water. This finding highlights the importance of continued outreach by the extension service to increase awareness of water problems in Arkansas. While producers are aware of growing state-level groundwater scarcity, few producers believe that scarcity is a problem which directly impacts their farm operations.

The finding that participation in the CRP decreases WTP could have important policy implications. While large water savings could be achieved by increasing producers' awareness of the CRP, such practices may also decrease the level of producers' WTP for water from irrigation districts. If the downward influence on the WTPs of such programs is to the extent that irrigation districts cannot set the price of surface water to a level that allows them to recover the cost of delivering water, then the financial viability of such projects may be hampered. Similar conflict may also arise between conservation programs that focus on improving irrigation efficiency and programs that focus on conversions to surface water. Both types of programs would positively impact the health of the Aquifer by reducing groundwater use or moving producers towards surface water resources. However, the effectiveness or viability of one program may be negatively influenced by the existence of the other program. If such changes limit the revenue earned by irrigation districts, the financial viability of such projects may also be limited. Policymakers and extension need to take such unintended consequences into account when promoting these programs. For example, conservation programs that focus on improving irrigation efficiency may be more fruitful in areas where conversion to surface water is not an option (e.g., due to lack of infrastructure).

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