Optimal Investment in Reservoirs and Tail-Water Recovery for Economic Returns and Groundwater Conservation

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ABSTRACT

We examine the economic effectiveness of conjunctive water management with on-farm reservoirs and tail-water recovery to address groundwater scarcity in the Mississippi River Delta region of Arkansas. We find that reservoirs should be built when the depth to the aquifer exceeds 60 feet, and the average share of productive land in a reservoir should be about 2%. Soybean intensive areas use reservoirs sparingly to support shallow groundwater pumping depths, but groundwater remains the primary source of irrigation. Rice intensive areas use reservoirs to supplant groundwater with reservoir surface water when the depth to groundwater increases.

INTRODUCTION

The region for the application of our model is the Lower Mississippi River Basin in Arkansas (referred to as the Arkansas Delta) which has long relied on groundwater from the Mississippi River Valley Alluvial Aquifer. Producers choose among multiple crops that require varying intensities of irrigation along with whether to convert farm land to reservoirs. Reservoirs increase the surface water available for irrigation, and this may replace irrigation from wells. Most economic studies of conjunctive water management have been done at the individual farm level, however this ignores that withdrawal by one user lowers the water table and increases the pumping cost for all users. This pumping effect on others means the appropriate water management for a farm depends on the pumping done by surrounding farms and the agricultural region as whole. A regional depression in an aquifer emerges when many farms above the aquifer are growing irrigation intensive crops (ANRC, 2012).

PROCEDURES

Greater detail on the methods and data can be found in Kovacs and Mancini (2016). The farm production choices are likely to differ across regions that predominantly grow irrigation intensive rice and those that grow predominantly less irrigation intensive crops such as soybeans. These regions are different in terms of the relative yield of rice and soybean and in terms of their initial groundwater scarcity. There is a greater urgency to use reservoirs in the rice-intensive region than in the soybean-intensive region. To examine the differences across the two regions, a rice-intensive area is defined as the subset of all sites where the percentage rice land in 2033 is equal to or greater than 35% of the site area (539 sites or 254 thousand acres), and an irrigated soybean-intensive area is defined as the subset of all sites where the percentage soybean land in 2033 is equal to or greater than 35% of the site area (1219 sites or 532 thousand acres).

The cost and water storage capacity of reservoirs are key factors affecting whether reservoirs are built, how much land is made into reservoirs, and the return on investment (ROI) in reservoirs. There is uncertainty in the cost and water storage capacity of reservoirs because the cost of a reservoir depends on the unknown size of the reservoir and the water storage capacity depends on access to unknown amounts of surface water such as streams and ditches that fill the reservoirs. High cost/low water storage reservoirs function as a lower bound of the potential reservoirs on the landscape, and low cost/high water storage reservoirs act as an upper bound of the potential reservoirs on the landscape.

RESULTS AND DISCUSSION

Tables 1 and 2 show the economic, land, and irrigation results for the rice intensive land and the irrigated soybean intensive land. Both show that reservoirs lead to a reduction in the acreage of the non-irrigated sorghum and Conservation Reserve Program (CRP) land. There is an increase in rice for the rice intensive area while there is an increase in irrigated soybeans for the soybean intensive area. Reservoirs increase thirty-year farm net returns for all scenarios, and the magnitude of the profit increase depends on the reservoir costs more than the crop mix across the reservoir scenarios. Both Tables 1 and 2 indicate the baseline and the low cost/high water storage reservoir scenarios decrease groundwater use and increase the volume of the aquifer compared to the landscape without reservoirs. However, the groundwater use in the high cost/low water storage scenario is actually greater because a small number of reservoirs are built that store a limited amount of water. This leads to more groundwater use coupled with the reservoir water to support a greater acreage of high value crops like rice and soybeans.

The return on investment (ROI) of reservoirs is higher for the rice intensive area than for the soybean intensive area. The baseline reservoir scenario has a 14.6% ROI in the rice intensive area and a 2.2% ROI in soybean intensive area.

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More land is converted to reservoirs in the rice intensive area than in the soybean intensive area. A positive, low ROI in the high cost/low water storage scenario suggests reservoirs are worthwhile to producers even when their costs are at the high end and the water storage capacity is low. However, while ROI is still positive, the aquifer is more depleted than in the no reservoir scenario, indicating the high cost/low storage reservoirs do little for conservation. This suggests that lowering reservoir costs and/or increasing reservoir water storage would increase ROI and preserve the aquifer.

The results of the regression for explaining ROI in reservoirs for the baseline cost/water storage scenario are shown in Table 3 using explanatory site characteristics such as the initial volume of the aquifer, the initial depth of the aquifer, and the net returns per acre excluding irrigation costs for the crops grown on the landscape. There is a positive relationship between ROI and the initial depth to the aquifer for the rice area. At depths greater than 60 feet, the ROI increases at a rate of about 2% for every increase in depth of 10 feet. The coefficient for natural recharge is positive and significant for the soybean area and for the entire landscape. On the soybean intensive land, a limited number of reservoirs are built to maintain ample reserves of cheap groundwater, and this approach is especially effective with large natural recharge.

PRACTICAL APPLICATIONS

Reservoirs are most likely to be built when the depth to groundwater is more than 60 feet, and the average share of productive land in a reservoir is likely to be about 2% with an ROI of the reservoirs of about 11%. Rice intensive sites favor reservoirs when the depth to the aquifer, the net returns to rice, and the net returns to double-crop soybean are large because those site characteristics are associated with higher groundwater pumping costs. Reservoirs at soybean-intensive sites are built for their potential to increase the aquifer and thereby lower groundwater pumping costs rather than replace groundwater as the primary source of irrigation. Without the possibility to increase the aquifer, the soybean intensive sites avoid reservoirs and focus on mining the relatively shallow groundwater.

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LITERATURE CITED

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Kovacs, K., and M. Mancini. 2016. Conjunctive water management to sustain agricultural economic returns and a shallow aquifer at the landscape level. Unpublished data, available on request.

Table 1. Farm production and aquifer conditions in 2033 with and without reservoirs for rice intensive landscape.

Land, water, and economic conditions in 2033	No reservoirs	Reservoirs: Baseline	Reservoirs: High cost and low water storage	Reservoirs: Low cost and high water storage
Rice (thousand acres)	103	126	121	126
Soybeans (thousand acres)	18	20	18	20
Double crop soybeans (thousand acres)	74	68	70	66
Non-irrigated sorghum (thousand acres)	41	26	34	25
CRP land (thousand acres)	18	1	8	0
Reservoirs (thousand acres)	--	13	3	17
Annual reservoir water use (thousand acre-feet)	--	152	42	194
Annual groundwater use (thousand acre-feet)	330	233	332	189
Aquifer (thousand acre-feet)	11520	13473	11468	14323
30 year farm net returns (millions $)	658	738	684	765
Return on investment in reservoirs	--	14.6%	4.3%	20.9%

Note: 539 sites in the rice intensive landscape.

Table 2. Farm production and aquifer conditions in 2033 with and without reservoirs for soybean intensive landscape.

Land, water, and economic conditions in 2033	No reservoirs	Reservoirs: Baseline	Reservoirs: High cost and low water storage	Reservoirs: Low cost and high water storage
Rice (thousand acres)	45	47	47	47
Soybeans (thousand acres)	470	481	473	480
Double crop soybeans (thousand acres)	0	0	0	0
Non-irrigated sorghum (thousand acres)	6	2	2	2
CRP land (thousand acres)	11	0	9	0
Reservoirs (thousand acres)	--	2	1	3
Annual reservoir water use (thousand acre-feet)	--	20	6	32
Annual groundwater use (thousand acre-feet)	583	578	585	566
Aquifer (thousand acre-feet)	32835	32998	32813	33275
30 year farm net returns (millions $)	1775	1787	1779	1791
Return on investment in reservoirs	--	2.2%	0.7%	2.9%

Note: 1219 sites in the soybean intensive landscape.

Table 3. Parameter estimates for regressions of the return on investment in reservoirs.

	Rice intensive sites	Irrigated soybean intensive sites	All sites
Intercept	-1.37** (-4.01)	1.27 (1.24)	-0.60** (-2.69)
Aquifer	-3.33E-4 (-0.20)	0.02** (3.22)	-6.05E-3** (-4.82)
Depth	4.87E-3** (5.95)	1.69E-3 (0.51)	1.26E-2** (17.29)
Natural recharge	6.89E-3 (0.82)	0.19`** (4.38)	0.02** (3.05)
Net returns rice	3.07E-3** (3.16)	-9.09E-3** (-2.98)	-2.26E-3** (-3.31)
Net returns irrigated soybean	-1.53E-3 (-1.74)	-4.24E-3 (-1.52)	1.59E-3* (2.29)
Net return double crop soybean	2.16E-3* (2.42)	-5.40E-3 (-0.83)	5.09E-3** (5.20)
Net return sorghum	-1.01E-3 (-1.87)	-3.11E-3 (-1.08)	-4.66E-3** (-7.06)
Number of observations	539	1219	2724
Number of observations with ROI > 0	411	211	1249

Note: t-values in parentheses.

* $P < 0.05$.

** $P < 0.01$.