Journal of Agricultural and Applied Economics, 35,2(August 2003):371–379

Use of On-Farm Reservoirs in Rice Production: Results from the MARORA Model

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The present article uses the modified Arkansas off-stream reservoir analysis and the environmental policy–integrated climate models to examine the impacts of on-farm reservoirs and tail water recovery systems in conjunction with other best management practices on profitability, water use, and sediment control for rice-soybean farming operations. Results suggest that, under limited water availability conditions, reservoirs and tail water recovery systems can improve profitability, reduce ground water dependence, and reduce the movement of sediment, nutrients, and pesticides off-farm. Although reservoirs may not be profitable under plentiful water conditions, cost-sharing opportunities may make them a viable means of addressing environmental concerns.

Key Words: on-farm reservoirs, sediment control, water management

JEL Classifications: Q25, Q15, Q29

Roughly 4 million of a total 7.7 million acres of harvested cropland are irrigated annually in Arkansas (US Department of Agriculture–National Agricultural Statistics Service). More than 75% of the irrigated acres are in rice and soybean production; the remainder is in cotton. Irrigated agriculture in eastern Arkansas is heavily dependent on groundwater pumped from the alluvial aquifer. Extensive pumping is resulting in the steady depletion of this aquifer. At this rate, aquifer-dependent rice and soybean production in much of eastern Arkansas will not be sustainable for more than 20 years. Eastern Arkansas is part of the Mississippi Delta region, and these resource conditions are representative of the Mississippi Delta region as a whole.

Farmers are turning to on-farm reservoirs and tail water recovery systems to assist in meeting their water requirements. The reservoirs store rainwater, groundwater, and surface water until water is needed on the field. Tail water recovery systems capture runoff water as it is leaving the field so that it can be recycled throughout the production system. These reservoirs and tail water recovery systems may produce an added benefit by reducing the amount of runoff sediment, nutrients, and pesticides that leave a farm. This is especially important because sedimentation is the number one problem affecting surface wa-

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The authors thank Diane Hite and the participants of the 2002 SERA-IEG-30 conference for their useful comments.

ters in Eastern Arkansas and is also the focus of the total maximum daily load discussions in the state.

Researchers at the University of Arkansas have developed a simulation model to study the use of on-farm reservoirs and tail water recovery systems in the management of rice and soybean production in Eastern Arkansas (Smartt et al.). This model, the modified Arkansas off-stream reservoir analysis (or MARORA) model, is a farm-level irrigation management and investment simulation framework that evaluates the economics of multiple-source (ground and surface) water supplies for Arkansas rice and soybean farms under various farm resource conditions. The model can be used to provide an analysis of the economics of on-farm reservoirs in conjunction with other best-management practices (BMPs) that can protect ground water availability, sustain irrigated agricultural production, and perhaps improve surface water quality in the Arkansas Delta.

The purpose of the present article is to apply the MARORA model to evaluate the use of on-farm reservoirs/tail water recovery systems in conjunction with other BMPs with respect to (1) economic costs and returns, (2) amount of water used in the production process, and (3) sediment loadings captured in the field. Similar production conditions will be modeled in the environmental policy–integrated climate (EPIC) model to validate MARORA's estimations of per acre sediment movement and illustrate other environmental benefits, such as reductions in nutrient and pesticide movement, that might be achieved with reservoir/tail water recovery systems.

Background and Literature Review

Water Quantity and Quality Concerns

All of eastern Arkansas is underlain by the deep-water Sparta Aquifer and the more shallow Mississippi River Valley Alluvial Aquifer. Groundwater from the Mississippi River Alluvial Aquifer has been the primary source of irrigation water in Eastern Arkansas. Because of intensive pumping of groundwater in the Arkansas Delta, the aquifer has developed major cones of depression. Recharge of the aquifer is limited by a hard pan soil stratum to 2 cm per year (Ackerman). The current irrigation system relies on ground water sources that are not sustainable in the long run (Czarnecki, Hays, and Terry).

To reduce the dependence on groundwater use, some proposals such as the White River Diversion Project have called for large scale stream diversion of surface water for irrigation purposes (US Army Corps of Engineers). The White River Diversion Project has been challenged by environmentalists who are concerned about that ecosystem damage associated with large-scale water withdrawal. Large-scale water divisions churn the surface waters as water is removed from the source. As a result, the in-stream flow of the surface water source may be reduced, and the water itself may be more turbid. Thus water division at this scale may exacerbate the sedimentation problems that already plague surface waters in the Delta.

BMPs for Irrigated Rice and Soybean Production

Farms can decrease water needs for rice and soybean production by increasing irrigation efficiency with approved BMPs. Some of these BMPs include shorter season rice varieties, land leveling, irrigation pipelines, on-farm reservoirs, and tail water recovery systems. Shorter season rice varieties reduce the amount of time the field needs to be flooded. Some varieties can reduce flood time by 5–20 days. Irrigation pipelines can increase irrigation efficiency by roughly 10% compared with open canals by reducing evaporation and seepage losses (Tacker). Land leveling eliminates high spots in a field, which decreases the irrigation flood depth requirement and allows better drainage. As a result, irrigation is approximately 10%–20% more efficient because less water is needed to flood the field (Tacker).

Factors That Influence Use of Reservoirs and Tail Water Recovery Systems

There are many factors that can influence the decision to construct a reservoir and/or tail water recovery system. Major factors include construction costs, water availability, crop mix, environmental concerns, farm size, and length of production period. Reservoir construction does not represent a negligible expense. The cost of moving the soil alone has been estimated up to $1.00 per cubic yard (Farmer Panel). However, the federal government provides cost-sharing opportunities for practices that sustain ground and surface water quality. Under the 2002 Farm Bill, the Environmental Quality Incentives Program allows participants to implement a plan for water conservation if "the assistance will facilitate a net savings in ground or surface water resources in the agricultural operation of the producer," (US Department of Agriculture–National Resource Conservation Service, section 1466.9[e]). Producers who qualify may be eligible for up to 75% of the costs of certain conservation practices, including reservoir construction. Furthermore, beginning and limited resource farmers may be eligible for up to 90% cost share (US Department of Agriculture–Natural Resource Conservation Service, sections 1466.23 and 1466.24). Additionally, limited access to ground water and a large amount of acreage, a crop mix that includes water-intensive crops like rice, and surface water quality problems may provide additional incentives for producers to adopt reservoirs and tail water recovery systems in their operation. The wide variety of economic, resource, and production conditions that any given producer may face suggests that the decision to adopt or not adopt these management practices is not an easy one. The MARORA model has been developed to assist in this type of decision making.

The MARORA Model

Previous research has estimated the net economic benefits to the current groundwater irrigation management of supplementing groundwater with surface water sources, on-farm reservoirs, and tail water recovery systems using the MARORA model (Wailes et al., 1999, 2002). MARORA can be run two ways. When run in optimization mode, the model determines the optimal size and use of the on-farm reservoir needed to maximize a 30-year time stream of net returns to the farming operation (Young, Wailes, and Smartt). When run in nonoptimization mode, MARORA calculates costs and returns for a specified reservoir size.

The MARORA simulation model evaluates daily weather data to predict the crop yield response, irrigation demand, reservoir use and water balance, well use and well yield, and associated pumping costs in each growing season. The weather data are generated stochastically with the Wingen model applied to Stuttgart, Arkansas. Major changes in the irrigation system include construction of on-farm reservoirs to supplement well use and access to surface water sources such as bayous and canals. These modifications are evaluated over a 30-year period to determine the impact on the discounted net present value of annual net farm income over the projected period. Recent improvements in the model allow for the tracking of sedimentation movement. However, currently, the model is not fully developed to calculate nutrient and pesticide movement.

The EPIC Model

The EPIC (formally known as the erosion productivity impact calculator) model was designed to investigate the costs of soil erosion in agricultural production. Since that time, EPIC model has been used extensively to evaluate crop productivity, degradation of the soil resource, impacts on water quality, response to different input levels and management practices, response to special variations in climate and soils, and risk of crop failure (Mitchell et al.). The EPIC model was designed to simulate biophysical processes over a long period of time in a wide range of soil, climate, and crop conditions. The EPIC model is also capable of simulating agricultural yields and related environmental parameters under various management scenarios (Sharpley and Williams 1990). The model uses a daily time step to simulate, among other things, weather, crop production, soil characteristics, erosion-sedimentation loss, pesticide and nutrient movement with water and sediment, and field-scale costs and returns. EPIC cannot simulate reservoir or tail water recovery systems. However, it can estimate sediment, nutrient, and pesticide movement from a field. For example, EPIC calculates the amount of phosphorus and organic nitrogen that binds with the soil and is lost off the fields through erosion. It also calculates the amount of pesticide and nitrates that leave the field through runoff.

Methodology

This analysis uses the MARORA model to evaluate the impacts of on-farm reservoirs and tail water recovery systems in conjunction with other BMPs with respect to economic returns, water use, and sedimentation losses. Per-acre sedimentation movement is validated with the EPIC model. Two baseline models were developed. The strong-groundwater scenario assumed a 50-foot saturated thickness and a 0.5-foot annual decline in the water level. The weak-groundwater scenario assumed a 30-foot saturated thickness and a 1.0-foot annual decline in the water level. These assumptions represent two general cases in Eastern Arkansas. Both baseline models include the following assumptions. (1) Weather and silt loam soil conditions are used that are representative of Stuttgart, Arkansas, one of the largest rice producing areas of the state. (2) A reservoir is assumed to service a 320-acre field, and the construction of a reservoir would result in the reduction of the available crop land in the field by the amount of area occupied by the reservoir. (3) A reservoir is filled once during the spring from surface water, and field runoff and tail water is returned throughout the crop growing season. (4) Because rice and soybeans are grown in a 1-to-1 rotation, the model field is comprised of 50% rice and 50% soybeans during the first year of the simulation. The ability to maintain that rotation in future years can be affected by weather and water availability. (5) The maximum annual soybean and rice yields were 50 and 160 bushels per acre, respectively. These are conservative estimates based on 10-year averages in Stuttgart, Arkansas. (6) Water recovery efficiency was 80%, based on relift pump and temporary on field storage availability (Fooks). (7) Baseline irrigation efficiency with no water conservation improvements was 50% for rice and 45% for soybeans (Tacker). (8) Production costs reflected those in the 2002 University of Arkansas Crop Production Budgets (Windham and Laferty 2002a, 2002b, 2002c). (9) The discount rate used to calculate net present value of costs and returns was 8%. (10) Crop prices were adjusted to reflect price plus government payments. (11) Laser leveling was priced at $300 an acre. (12) Excavation costs for reservoir construction were priced at $1.00 per cubic yard. (13) Underground piping was priced at $50.00 an acre. (14) Cost share opportunities do not exist. (15) The projection period is 30 years.

Using these assumptions, the two baseline models are run to determine whether an on-farm reservoir is an economically efficient management practice for rice and soybean production on the 320-acre field under strong- and weak-groundwater situations. Economic returns, water use, and sedimentation runoff were monitored for the baselines. Next, in the event that a reservoir is deemed profitable, effects of on-farm reservoir and tail water recovery systems in conjunction with other BMPs were examined. These BMPs included shorter season rice varieties which result in removal of flood waters 5, 10, 15, or 20 days earlier than full-season rice; improvements to irrigation efficiency by adding underground pipe only; and improvements to irrigation efficiency by adding underground pipe and laser leveling the field. Underground pipe is expected to increase irrigation efficiency by 10% (such that rice/soybean irrigation efficiency increases from 50/45 to 60/55, respectively), whereas laser leveling can increase irrigation efficiency by 10%–20% (Tacker). Results from the EPIC model are then presented to suggest other types of environmental benefits that may arise

Table 1. Results of Baseline Scenarios

Groundwater Scenario	Optimal Reservoir Size (acre/ft.)	Average Annual Income ($)	Average Annual Water Use: Rice (in)	Average Annual Water Use: Soybeans (in)	Average Annual Soil: Loss (tons)	Average Annual Soil: Recovered (tons)
Strong	0	63,227	39.9	26.2	381.8	0.0
Weak	620	49,280	38.9	25.4	65.5	262.1

with the use of on-farm reservoirs and tail water recovery systems.

Results

Baseline Scenarios

Rice and soybean production was first simulated using the strong- and weak-groundwater baseline characteristics. Results of these simulations are found in Table 1. The reservoir and tail water recovery system was not profitable in the strong-groundwater scenario. However, sensitivity analysis suggests that the reservoir does become profitable when a 75% cost share opportunity exists.

In this strong-groundwater scenario, the manager of a 320-acre field earned an average annual return of $63,277 over the 30-year period. Water usage was relatively high—39.9 acre inches and 26.2 acre inches for rice and soybeans, respectively—and contributed to average annual production of 160 bushels per acre of rice and 50 bushels per acre of soybeans. Although economic returns to this system were great, sediment losses were also large, averaging 382 tons annually or 14,460 tons over the full 30-year period. Because reservoirs are not profitable in this strong-groundwater scenario, no further analyses of the impacts of reservoirs and BMPs were done.

Reservoir construction for the weak-groundwater scenario was profitable. A 620-acre foot reservoir and tail water recovery system was constructed that removed 70.66 acres from the available cropping acreage. In using the reservoir, a manager could use, on average, 38.9 acre-inches of water on rice and 25.4 acre inches on soybeans. The remaining 249 acres of cropland averaged 49.5 bushels per acre annually for soybeans and 156 bushels per acre for rice, which are nearly as good as the yields in the strong-groundwater scenario. Average annual returns were reduced from the strong-groundwater situation to $49,280. Under the weak-groundwater scenario over the 30-year period, roughly 66 tons of soil, nutrients, and pesticides were lost on average from the field annually (or 1,965 tons over 30 years), whereas 262 tons annually (or 7,863 tons over 30 years) were retained. Although economic returns may have been less than in the strong-groundwater scenario, environmental benefits with respect to sediment control were created in two ways. First, reservoir construction reduced the amount of surface area from which soil can move. Total (lost and recovered) soil movement in the weak-groundwater scenario was less (9,828 tons) than in the strong-groundwater scenario (11,460 tons). Second, reservoirs and tail water recovery systems have the capability to capture much of what is moved before it can leave the farm and potentially cause environmental damages elsewhere. That is, over the 30-year period, less than 2,000 tons of sediment escaped the field in the weak-groundwater scenario, whereas more than 5 times that left the field during that same time period in the strong-groundwater scenario.

Because reservoirs were found to be profitable in the case of a weak-groundwater situation, effects of reservoirs along with other BMPs were examined to determine whether the addition of other BMPs affected the reservoir size, economic returns, water use, and soil movement.

Table 2. Effects of Short Season Varieties and On-farm Reservoirs and Tail Water Recovery Systems, for Weak Groundwater Scenario

Rice Season Shortened By (days)	Optimal Reservoir Size (acre/ft.)	Average Annual Income ($)	Average Annual Water Use		Average Annual Soil	
			Rice (in.)	Soybeans (in.)	Loss (tons)	Recovered (tons)
Baseline	*620*	*49,280*	*38.9*	*25.4*	*65.5*	*262.1*
5	580	51,673	37.1	25.3	66.8	267.0
10	580	53,376	35.5	25.5	66.8	267.0
15	540	54,672	33.4	25.0	68.5	273.9
20	520	55,886	31.7	25.2	69.6	278.4

Shortened Season Varieties

Simulations were run next to determine what the impact of a reduction in the rice growing season would be on returns, reservoir size, water use, and soil movement. Four scenarios were run under the assumption of a 5-, 10-, 15- and 20-day reduction in the needed growing season. Results are presented in Table 2. Results from the weak-groundwater baseline scenario are also presented again for comparative purposes. The study found that, compared with the baseline scenario, the reduction in the growing season by 5–20 days can increase average annual income by $2,393–$6,606, reduce needed reservoir size by 40–100 acre feet, and reduce total annual water needs by roughly 2–7 inches. Increases in economic returns are made mainly through reductions in costs. Total (lost and recovered) soil movement increased by up to 20 tons annually because less land area was needed for reservoir construction; however, the majority of that was captured within the system. At most, only an additional 3 tons annually was lost over the 30-year period. Thus, the inclusion of reduced season rice was found to greatly improve economic returns and reduce water needs without creating large additional amounts of sediment movement off farm.

Increased Irrigation Efficiencies

Increases in irrigation efficiencies over the baseline level were examined three ways: (1) 10% from added underground pipe, (2) 10% from pipe and 10% from laser leveling, and (3) 10% from pipe and 20% from laser leveling. These three scenarios represent an increase in irrigation efficiencies for rice/soybeans from 50/45 to 60/55, 70/65, and 80/75, respectively. As expected, results suggest that the greater the irrigation efficiency, the smaller the reservoir needs to be. Actual reservoir sizes fell from 620 acre feet in the baseline scenario, to 560 acre feet with the addition of underground pipe, to only 440 acre feet when irrigation efficiency increased to 80/75 for rice/soybeans with underground pipe and laser leveling. Although each additional water conservation practice did result in additional water savings, as shown in Table 3, these savings accrued at a diminishing rate. Economic returns increased slightly. For reasons stated earlier, annual total soil movement increased as optimal reservoir size decreased. However, compared with the weak-groundwater baseline scenario, the magnitude of the changes in soil lost off the field (6 tons annually or 10% increase) was minor compared with the changes in water use (24.7 inches or 38% reduction) and changes in annual returns ($5,528 or 11% increase).

Other Environmental Benefits—MARORA-EPIC Comparison

Similar production scenarios were generated with both EPIC and MARORA to compare estimates of sedimentation loss and to suggest other potential benefits of reduced sedimentation and runoff movement. EPIC and MARORA rice–soybean production system simulations were constructed under the

Table 3. Effects of Various Irrigation Efficiencies and On-farm Reservoirs and Tail Water Recovery Systems, for Weak Groundwater Scenario

Increase in Irrigation Efficiency (improvements to rice yields)	Optimal Reservoir Size (acre/ft.)	Average Annual Income ($)	Average Annual Water Use: Rice (in.)	Average Annual Water Use: Soybeans (in.)	Average Annual Soil: Loss (tons)	Average Annual Soil: Recovered (tons)
Baseline	*620*	*49,280*	*38.9*	*25.4*	*65.5*	*262.1*
10%, pipe only	560	51,202	32.8	20.8	67.2	268.8
20% pipe and leveling	460	51,946	28.0	17.0	71.3	285.0
30% pipe and leveling	440	54,808	24.7	14.9	72.1	288.4

assumption of a 1-acre field. Differences in estimations between the two models were small. EPIC estimated annual sedimentation movement at 1.08 tons, whereas MARORA estimated annual sedimentation movement at 1.19 tons. Future research will be conducted with actual farm-level data and other watershed models such as agricultural policy environment extender and soil and water assessment tool to validate sedimentation movement. However, given the similarity between sediment movement calculations, we look to EPIC for an idea of the types of added benefits that might be captured through reservoir and tail water recovery systems.

Reservoirs and tail water recovery systems have the potential to provide additional environmental benefits such as a reduction in off-farm losses of nutrients and pesticides. As shown in Table 4, EPIC results suggest that, without reservoirs and tail water recovery systems, each acre of production will result in movements of active ingredients from pesticides (such as Propanil [Stam] Pendmethalin [Prowl], and Flauzifop-P-butyl [Typhoon] used in rice or soybean production) and movements of nutrients such as organic nitrogen, nitrates, and phosphorus during any given year. By recycling water and capturing sediment throughout the farm, on-farm reservoirs and tail water recovery systems could reduce the occurrence of pesticide and nutrients in surface waters off the farm. Once actual quantities of nutrients and active ingredients are identified for the farm or even watershed level, they could be compared with state and federally established tolerable limits. Reductions in the movement of nutrients and pesticides could be very important to areas where surface waters are affected by nutrient and pesticide pollution.

Summary and Conclusions

This research was conducted to determine the impacts of reservoirs and tail water recovery systems in conjunction with other BMPs on annual returns, water use, and sediment nutrient and pesticide movement along and off the field under two assumed groundwater situations. A strong-groundwater scenario was developed that assumed an initial saturated thickness of 50 feet and an annual decline rate of 0.5 feet. Results suggest that reservoir construction under these groundwater conditions is not profitable. However, the lack of reservoir and tail water recovery systems results in a missed opportunity to reduce sediment losses from the field. Under the current regulatory environment, irrigators do not have a financial

Table 4. Potential Annual Per Acre Pesticide and Nutrient Movement Off-Field

Sediment (tons)	Organic N (lbs.)	NO_3 (lbs.)	P (lbs.)	Pendmethalin (lbs.)	Propanil (lbs.)	Flauzifop-P-butyl (lbs.)
1.08	3.79	26.20	1.41	0.00381	0.00198	0.00010

incentive to prevent sediment losses with irrigation reservoirs and tail water recovery systems. Further incentives are needed to produce benefits of reduced sedimentation to surface on from fields where strong-groundwater situations exist.

Under the assumed weak-groundwater supply conditions, reservoirs and tail water recovery systems may become a profitable way to manage scarce water conditions and control the amount of runoff that leaves the farm. When used in conjunction with other BMPs such as shorter season rice varieties, laser leveling, and underground pipe, profits may increase further while water needs are reduced. However, reductions in water needs may reduce the optimal reservoir sizes, which in turn increase the amount of available cropland and possibly the amount of sedimentation movement. However, the economic and water savings benefits provided from these practices likely offset any costs brought on by minimal increases in sediment movement off the farm.

Evidence from the present study supports the use of on-farm reservoirs and tail water recovery systems as an effective method of supplying needed irrigation water. In addition, these systems can provide an additional benefit by controlling the amount of sediment, nutrient, and pesticides that leaves the farm. Increased public awareness of these conservation benefits may further promote the use of on-farm reservoirs and tail water recovery systems in areas affected by sedimentation and other water-quality problems.

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