Using MARORA to Assess Economic and Environmental Impacts of On-Farm Reservoirs

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Introduction

Roughly 4 million of a total 7.7 million acres of harvested cropland are irrigated annually in Arkansas (USDA, NASS, 2002). More than 75 percent of the irrigated acres are in rice and soybean production; the remainder is in cotton. Irrigated agriculture in eastern Arkansas is heavily dependent upon ground water 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 rain water, ground water and surface water until water is needed on the field. Tail water recovery systems capture run off 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 sediment that leaves a farm. This is especially important as sedimentation is the number one problem affecting surface waters in Eastern Arkansas and is also the focus of the Total Maximum Daily Load (TMDL) 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., 2002). 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 this paper 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.

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 water Mississippi River Valley Alluvial aquifer. Ground water from the Mississippi River Alluvial Aquifer has been the primary source of irrigation water in Eastern Arkansas. Due to intensive pumping of ground water 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, 1996). The current irrigation system relies on ground water sources that are not sustainable in the long-run (Hays, Czarnecki and Terry, 2001). In addition to a quantity constraint, the cone of depression is altering the direction of ground water flow and causing salt water to migrate into fresh water zones (ASWCC, 1999). Excessive pumping has contributed to widespread problems of ground water salinity throughout the Arkansas delta, rendering the water unsuitable for sustainable irrigated agriculture (Baker et al., 1996; Gilmour, 2001).

Producers have responded to the depletion of the alluvial aquifer by drilling additional wells in the alluvial aquifer and drilling new wells to deeper aquifers such as the Sparta Sand and Memphis Sand. These deeper aquifers are confined aquifers with storage capacities that are less than that of the alluvial aquifer; hence, these sources are not predicted to sustain irrigated agriculture in the region due to aquifer characteristics and increased pumping costs. While the water quality from the Sparta Sands and Memphis Sands aquifer is excellent, municipalities in the region rely upon these aquifers and have priority over agricultural and industrial uses. Therefore, irrigated agriculture in eastern Arkansas is not sustainable at current levels in terms of quantity and quality of ground water sources.

To reduce the dependence on ground water use, some proposals such as the White River Diversion Project have called for large scale stream diversion of surface water for irrigation purposes (USACE, 1998). The White River Diversion Project has been challenged by environmentalists that are concerned about 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 while 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. In many parts of eastern Arkansas, the quality of the surface water is better than that of the ground water. While ground waters have had negative impacts on agricultural production, agricultural production has impacted the quality of surface waters. Water quality in the Delta Region is highly influenced by non-point source runoff generated from highly agriculturalized areas. Some research suggests that many of the Arkansas waterways do not support aquatic life due to elevated levels of siltation and sedimentation (turbidity) (FTN Associates, Ltd., 2001; ARDEQ, 2001).

Additionally the highest incidence of measurable pesticide residue in the water occurs in this region (FTN, Associates, Ltd., 2001). Some recommendations have suggested that in order to meet aquatic and human use criteria, turbidity levels must be reduced by nearly 50 percent in summer periods (FTN Associates, Ltd., 2001). It is likely that many of the suggested reductions will be imposed on agricultural producers. On-farm reservoir systems are designed to capture most farm runoff and thereby prevent sedimentation movement into surface waters.

Best Management Practices for Irrigated Rice and Soybean Production

Farms can decrease water needs for rice and soybean production by increasing irrigation efficiency with approved best management practices. Some of these practices 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 the amount of flooded time by 5 to 20 days. Irrigation pipelines can increase irrigation efficiency by roughly 10 percent compared to open canals by reducing evaporation and seepage losses (Tacker, 1999). 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 to 20 percent more efficient because less water is needed to flood the field (Tacker, 1999). Land leveling and underground pipe may produce an added benefit. On-farm reservoirs collect and store runoff to use for irrigation during the cropping season. Tail-water recovery systems collect runoff water from the farm and channel it to a storage pit where the runoff is pumped into the on-farm reservoir if present. Tail-water recovery systems usually are constructed with a reservoir, but can function separately if the tail-water irrigation storage pit is large. Water management and water quality are improved by tail-water recovery systems by recycling water throughout the farm (USACE, 1998).

The MARORA Model

Previous research has estimated the net economic benefits of supplementing ground water with surface water sources, on-farm reservoirs, and tail-water recovery systems to the current ground water irrigation management (Wailes et al., 1999, 2002). This research has been conducted using the MARORA model. 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, 1998). When run in Non-optimization 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 Suttgart, 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 present worth of annual net farm income over the projected period.

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. Two baseline models were developed. The Strong Ground Water scenario assumes a 50 ft saturated thickness and a 0.5 ft annual decline in the water level. The Weak Ground Water scenario assumes a 30 ft saturated thickness and a 1.0 ft 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 in the spring from surface water and field runoff and tail water is returned throughout the system. (4) As rice and soybeans are grown in a 1 to 1 rotation in Stuttgart, Arkansas, the model field is comprised of 50 percent rice and 50 percent soybeans in the first year of the simulation. The ability to maintain that rotation in future years can be impacted by weather and water availability. (5) The maximum annual soybean and rice yields are 50 bushels per acre and 160 bushels per acre, respectively. This is a conservative estimate based on 10 year averages in Stuttgart, Arkansas. (6)Water recovery efficiency is 80 percent, based on relift pump and temporary on field storage availability (Fooks, 2002). (7) Baseline irrigation efficiency with no water conservation improvements is 50 percent for rice and 45 percent for soybeans (Tacker, 1999). (8) Production costs reflect 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 is eight percent. (10) Crop prices are 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) The projection period is 30 years.

Using these assumptions, the two baseline models are run to determine if an on-farm reservoir is an economically efficient management practice for rice and soybean production on the 320 acre field under good and poor ground water situations. Economic returns, water use and sedimentation runoff are monitored for the baselines. Next, in the event that a reservoir is deemed profitable, impacts of on-farm reservoir and tail water recovery systems in conjunction with other BMPs are examined. These BMPs include 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 percent (such that rice/soybean irrigation efficiency increases from 50/45 to 50/55, respectively), whereas laser leveling can increase irrigation efficiency by 10 to 20 percent (Tacker, 1999).

Results

Baseline Scenarios

Rice and soybean production was first simulated using the Strong Ground Water and Weak Ground Water baseline characteristics. Results of these simulations are found in Table 1. The reservoir and tail water recovery system was not profitable in the Strong Ground Water scenario. Sensitivity analysis suggests that the reservoir does not become profitable until saturated thickness falls to 35 ft.

In this Strong Ground Water 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. While economic returns to this system are great, sediment losses are also large, averaging 382 tons annually or 14,460 tons over the full 30 year period. As reservoirs are not profitable in this

Strong Ground Water scenario, no further analyses of the impacts of reservoirs and BMPs were conducted.

Reservoir construction for the Weak Ground Water 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 utilizing 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 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 Ground Water scenario. Average annual returns were reduced from the Strong Ground Water situation to $49,280. 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. While economic returns may be less than in the Strong Ground Water scenario, environmental benefits with respect to sediment control are created in two ways. First, reservoir construction reduces the amount of surface area from which soil can move. Total (lost and recovered) soil movement in the Weak Ground Water scenario was less (9,828 tons) than in the Strong Ground Water Scenario (11,460 tons). Secondly, 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 thirty year period, less than 2000 tons of sediment escaped the field in the Weak Ground Water scenario whereas more than 5 times that left the field in that same time period in the Strong Ground Water scenario.

As reservoirs were found to be profitable in the case where a Weak Ground Water situation exists, impacts of reservoirs along with other BMPs were examined to determine whether the addition of other BMPs impacted the reservoir size, economic returns, water use and soil movement.

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 assuming a five, ten, fifteen and twenty day reduction in the needed growing season. Results are presented in Table 2. Results from the Weak Ground Water baseline scenario are also presented again for comparative purposes. This study found that compared to the baseline scenario, the reduction in the growing season by 5 to 20 days can increase average annual income by $2,393 to $6,606, reduce needed reservoir size by 40 to 100 acre feet, and reduce total annual water needs by roughly 2 to 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 as 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 percent from added underground pipe, 2) 10 percent from pipe and 10 percent from laser leveling and 3) 10 percent from pipe and 20 percent 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 and finally to only 440 acre feet when irrigation efficiency increased to 80/75 for rice/soybeans with underground pipe and laser leveling. While 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, when compared to the Weak Ground Water baseline scenario, the magnitude of the changes in soil lost off the field (6 tons annually or 10 percent increase) was minor compared to the changes in water use (24.7 inches or 38 percent reduction) and changes in annual returns ($5,528 or 11 percent increase).

Summary and Conclusion

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 movement along and off the field under two assumed ground water situations. A Strong Ground Water scenario was developed that assumed an initial saturated thickness of 50 ft and an annual decline rate of 0.5 ft. Results suggest that reservoir construction under these ground water 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 incentive to prevent sediment losses with irrigation reservoirs and tail water recovery systems. Further incentives are needed in order to produce benefits of reduced sedimentation to surface on from fields where strong ground water situations exist.

Under the assumed weak ground water 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 this 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 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 problems.

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Table 1 Results of Baseline Scenarios

Ground Water Situation	Optimal Reservoir Size	Average Annual Income	Average Annual Water Use Rice	Average Annual Water Use Soybeans	Average Annual Soil Loss	Average Annual Soil Recovered
	ac ft	$	in	in	tons	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

Table 2 Impacts of Short Season Varieties and On-farm Reservoirs and Tail Water Recovery Systems, for "Weak Ground Water" Situation

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

Table 3 Impacts of Various Irrigation Efficiencies and On-farm Reservoirs and Tail Water Recovery Systems, for “Weak Ground Water” Situation

Increase in Irrigation Efficiency (Improvements to rice yields)	Optimal Reservoir Size	Average Annual Income	Average Annual Water Use Rice	Average Annual Water Use Soybeans	Average Annual Soil Loss	Average Annual Soil Recovered
	ac ft	$	in	in	tons	tons
“Weak Situation” 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