Cost Analysis of Water Management Scenarios for the Mississippi Delta

Falconer, L.; Tewari, R.; Johnson, J.

The objective of this study is to provide the Mississippi Department of Environmental Quality with a report comparing the cost of reduced pumping or increase in recharge per acre-foot in the Mississippi River Valley Alluvial Aquifer as a result of 5 proposed groundwater management alternatives with scenarios. It is important to note that the cost data available for some of the alternatives are more detailed and current than the data for others. The cost data for the RISER and the Tailwater Recovery and Onfarm Storage scenarios are detailed, current, and based on recently implemented projects and practices. The cost estimates for the Enhanced Aquifer Recharge scenario are detailed and based on research on current materials and construction and ancillary costs for a project with similar components, but no comparable project has actually been built. The cost estimates for the Tallahatchie-Quiver Intra-basin Transfer scenarios are based on a U.S. Army Corps of Engineers (USACE) report issued in September, 2016. The cost estimates for the Instream Weir scenarios are based on itemized costs provided by USACE personnel.

Preliminary results indicate that at 33%, 66% and 100% adoption rates in the service area for the Instream Weir alternative scenarios, this alternative provides the lowest cost per acre foot per acre-foot in reduced pumping from the aquifer.

Introduction

For more than three decades, groundwater levels in the Mississippi River Valley Alluvial Aquifer (MRVA) have been declining. Although declines in water levels have been greatest in the central Delta, the problem is spreading. Because of declines in the MRVA, in 2014 Governor Phil Bryant issued Executive Order No. 1341, establishing the Governor's Delta Sustainable Water Resources Task Force (Task Force), thereby formally instituting a process begun by the Mississippi Department of Environmental Quality (MDEQ) in 2011 to assure that the Delta will have the water it needs to sustain its economy and environment. The Task Force members are MDEQ, Delta Council, Delta F.A.R.M., Mississippi Farm Bureau Federation, the Mississippi Soil and Water Conservation Commission, the Natural Resources Conservation Service (NRCS), the Vicksburg District of the U.S. Army Corps of Engineers (USACE), and the Yazoo-Mississippi Delta Joint Water Management District (YMD).

In 2014, MDEQ signed a multi-year agreement with the United States Geological Survey (USGS). Under the agreement, the USGS will cooperate with MDEQ to enhance the USGS regional groundwater model and then use the model to help MDEQ and the Task Force evaluate the effects on the aquifer of potential alternative actions and strategies. The first phase of USGS modeling compared the effects of various scenarios to the effects of a no-action base scenario. Some of the scenarios would reduce the amount of groundwater pumped relative to the base no-action scenario. One scenario would potentially enhance groundwater recharge.

Objective

The objective of this study is to provide MDEQ with a report comparing the cost of reduced pumping or increase in recharge per acre foot in the Mississippi River Valley Alluvial Aquifer as a result of 5 proposed groundwater management alternatives with scenarios.

Methodology

The USGS and MDEQ collaborated with the following organizations to develop scenarios that were modeled using the

USGS groundwater model:

1. Mississippi State University (MSU) Delta Research and Extension Center (DREC) for scenarios for implementation of water use efficiency practices to reduce groundwater pumping;
2. NRCS for scenarios for construction and operation of tail water recovery systems and on-farm water storage systems to reduce groundwater pumping;
3. USDA Agricultural Research Service (ARS) for scenarios for a proposed groundwater-to-groundwater transfer project to enhance aquifer recharge;
4. YMD for scenarios for the proposed Tallahatchie River-Quiver River intra-basin surface water transfer to reduce groundwater pumping;
5. USACE for scenarios for proposed in-stream weirs to provide additional surface water to reduce groundwater pumping.

After the alternatives were defined, the above organizations prepared preliminary cost estimates for implementation of the scenarios. For all alternatives to be modeled, the USGS provided DREC personnel with estimates of reduced groundwater pumping or enhanced aquifer recharge.

The calculations made by DREC personnel are based on construction, operation and maintenance cost estimates provided by each organization. These cost estimates were normalized using a consistent methodology, and the costs per acre-foot of groundwater saved or recharged by each scenario were compared using appropriate capital budgeting methods consistent with the planning horizon utilized in the USGS modeling. Where appropriate, opportunity costs were calculated for productive land that is designated for use in a water conservation scenario based on MSU Extension Service survey data (Parman, 2016). These costs were adjusted for future input price changes utilizing appropriate discount rates. The 3.125% discount rate used for net present value calculations in this study is the federal interest rate for USACE projects for fiscal year 2016 (U.S. Army Corps of Engineers, 2016).

The reduced pumping costs for each scenario were derived using the Calculating and Comparing Irrigation Pumping Costs Excel Spreadsheet (Tacker, 2005). It was assumed that all water pumped will use an electrical, vertical line shaft pump. The heights for water lift for the Delta and the Central Delta regions were assumed to be at 75 feet and 120 feet respectively. Irrigation well operating and maintenance costs derived using the Calculating and Comparing Irrigation Pumping Costs Excel Spreadsheet were estimated to be $1.23/ac-in Delta-wide and $1.90/ac-in for the central Delta.

Future electricity costs were adjusted based on projections made by the US Energy Information Administration (EIA, 2016). Future equipment costs, labor costs, and changes in land opportunity cost adjustments were based on projections made by the Food and Agricultural Policy Research Institute of the University Missouri (FAPRI, 2016).

Results and Discussion

Cash Flows: Riser (Irrigation Efficiency)

The cash flow estimates in the RISER (IRRIGATION EFFICIENCY) scenario are based on detailed information provided by MSU personnel for irrigation efficiency, capital equipment and supplies used in application of the RISER irrigation water conservation program. The initial costs of capital equipment and operating supplies were updated and verified by the authors.

RISER Scenario cash flows were calculated for two Sub-scenarios (Delta-wide and the Central Delta areas). The RISER Scenario is expected to increase irrigation efficiency and reduce the total water pumped by 4.38 ac-in/ac/year Delta wide and 4.80 ac-in/ac/year in the central Delta. The Sub-scenarios were assumed to be implemented on 1,453,074 acres across the entire Delta region, and on 91,590 acres in the Central Delta region. The amount of change in water withdrawals on account of the RISER Scenario is expected to be 530,647 acre-feet annually, or 0.37 acre-feet/acre of project area for the entire Delta region, and 36,710 acre-feet annually, or 0.40 acre-feet/acre of project area for the Central Delta region respectively.

Based on the above projections, costs per acre-foot of groundwater pumping reduced were calculated using capital budgeting for a planning horizon of 50 years. For the RISER Scenario, cost savings were calculated for reduced pumping costs for both scenarios. The reduced pumping costs were arrived at by multiplying the reduction in water

Table 1. RISER Scenario Investment Cost Estimate[1]

Depreciable Items	Quantity	Initial Cost (each)	Useful Life	Initial Investment
Surge Valve - 10"	2	$3,483.00	50	$6,966.00
Pipe Elbows	4	$127.00	50	$508.00
Soil Moisture Sensors	3	$39.00	3	$117.00
Irrometer Data-logger (package)	1	$450.00	10	$450.00
				$8,041.00

[1] The initial cost of implementation estimates of the depreciable items as part of the RISER Scenario for a 160 acre tract with 148 irrigated acres. This estimate includes two 10" surge valves at an initial investment of $6,966. The surge valves will be overhauled at 10-year intervals at a cost of $1,146 each. These overhauls will extend the life of the surge valve to the total length of the project. In addition, four pipe elbows at an initial purchase cost of $127 each (assumed to last the life of the project), 3 moisture sensors ($39 for each, and replaced every 3 years), and an Irrometer Datalogger (package) at $450 (replaced every 10 years), will be required. Total initial investment amounts to $8,041 for an average initial investment of $54.33 per irrigated acre.

Table 2. RISER Scenario Direct Cost Estimate[2]

Direct Expenses	Unit	Quantity	Price	Total Cost
Batteries	Each	4	$35.00	$140.00
Transfer Pipe - 15 mil	Ft	2640	$0.405	$1,069.20
				$1,209.20

[2] Table 2 presents the direct cost items associated with the RISER Scenario. 4 batteries for the controller costing $35 each amount to a total of $140, and last 2 years (personal communication with L. Jason Krutz, June 9, 2016). Transfer pipe priced at $0.405 per feet for a total of 4 at 660 feet (2,640 feet total) amount to $1,609.20 leading to total annual direct costs of $1,209.20. Assuming that out of a land parcel of 160 acres where 148 acres are irrigated, the annual direct costs per acre amount to $8.17. The reduction in water pumped by implementing the RISER Scenario is expected to be 4.38 ac-in/ac/year Delta wide and 4.80 ac-in/ac/year central Delta.

Table 3. Estimated Cost per Acre-Foot Not Pumped from the Aquifer for the RISER Sub-scenarios.

	Delta Wide RISER	Central Delta RISER
Acres in Project	1,453,074	91,590
Estimated Total NPV Cost of Project	$354,913,324.50	$9,295,469.10
Amount of Change (acre ft/year)	530,647	36,710
Total Amount of Change	26,532,350	1,835,500
Cost of Change per Acre Foot	$13.38	$5.06

pumped (4.38 ac-in/ac/year Delta wide and 4.80 ac-in/ac/year central Delta) by the number of irrigated acres, and the operating costs associated with pumping an acre-inch of water. This amounted to a reduction in water pumped costs of $5.39 per acre per year, and $9.12 per acre per year for the Delta and the Central Delta regions respectively.

Table 3 describes the costs per acre foot associated with the RISER Scenario in the project regions. The total discounted cash flow per acre for a 50 year planning horizon was estimated at $244.25 for the entire Delta region, and at $101.49 for the Central Delta region. The total reduction in water pumped over a 50 year planning horizon was found to be 26,532,350 acre-feet, and 1,835,500 acre-feet for the entire Delta region, and the Central Delta region respectively. The estimated total Net Present Value (NPV) cost of the project was found to be $354,913,325, and $9,295,469 for the entire Delta region, and the Central Delta region respectively. The cost per acre-foot for the RISER Scenario was estimated by multiplying the NPV of the costs by the acres in the project, and dividing by the total reduction achieved over the 50 years, which amounted to $13.38 and $5.06 for the entire Delta region, and the Central Delta region respectively.

Cash Flows: Tail Water Recovery (TWR) And Onfarm Storage (OFS)

The cash flow estimates in the Tail Water Recovery (TWR) and Onfarm Storage (TWR+OFS) scenario are based on detailed information provided by NRCS personnel for irrigation efficiency, capital equipment and operating supplies used in application of the Tail Water Recovery (TWR) and Onfarm Storage (TWR+OFS) program. The initial costs of capital equipment and operating supplies were updated and verified by the authors.

Table 4. TWR System Investment Cost Estimate[3]

TWR (160 Acre Project)	Unit	Amount	Cost/ Unit	Initial Cost
TWR Excavation	cuyds	22,000	$1.50	$33,000.00
Pumping Plant (30 HP)	each	1	$21,000.00	$21,000.00
Underground line - 12"	lnft	1,320	$7.00	$9,240.00
Stand (w/ flow meter)	lnft	8	$243.75	$1,950.00
2 acres lost for storage Annual	ac	2	$176.00	$352.00

[3]Table 4 describes the initial investment cost of implementation estimates for the TWR Scenario for a 160 acre tract. The excavation cost at $1.50 per cubic yard for 22,000 cubic yards amounts to $33,000. In addition, a 30 HP pumping plant will be installed at $21,000, and 12" underground lines at $7/lnft will cost $9,240 for a total length of 1,320 feet. One pump stand (including a flowmeter) costing $1,950 will also be required. The opportunity cost for the 2 acres lost for storage annually is calculated based on current Delta region average lease rate of irrigated land of $176/acre (Parman, 2016) at a total cost of $352 per year.

The TWR Scenario and the TWR+OFS Scenario cash flows were calculated for 3 Sub-scenarios: Delta-wide OFS+TWR (250 systems) leading to a 75% reduction in groundwater withdrawals from baseline, Delta-wide TWR (250 systems) leading to a 25% reduction in groundwater withdrawals from baseline and Delta-wide OFS+TWR and TWR mix (in a 50/50 ratio) leading to a 50% reduction in groundwater

Table 5. TWR+OFS System Investment Cost Estimate[4]

TWR + OFS (160 Acre Project)	Unit	Amount	Cost/ Unit	Initial Cost
TWR Excavation	cuyds	22,000	$1.50	$33,000.00
Reservoir Levees	cuyds	30,000	$1.50	$45,000.00
Pumping Plant (2-30hp)	each	2	$21,000.00	$42,000.00
Underground line - 12"	lnft	1,320	$7.00	$9,240.00
Stand (w/ flow meter)	lnft	8	$243.75	$1,950.00
14 (12+2) acres lost for storage Annual	ac	14	$176.00	$2,464.00

4 Table 5 presents the initial cost of implementation estimates for the TWR Scenario in combination with the on farm storage (OFS) for a 160 acre tract. The TWR pit excavation cost at $1.50 per cubic yard for 22,000 cubic yards amounts to $33,000.00. The project will also require the construction of reservoir levees at an excavation cost at $1.50 per cubic yard for 30,000 cubic yards amounting to $45,000.00 in total costs. In addition, two 30 HP pumping plants will be installed at $21,000.00 each leading to a total cost of $42,000.00, and 12" underground lines at $7/linear foot (installed) will cost $9,240.00 for a total length of 1,320 feet. One stand with flowmeter will also be required at a total cost of $1,950.00. Finally, the opportunity costs for the 14 acres lost for storage annually (2 acres for the TWR, and 12 acres for the OFS) are calculated at a current Delta region average lease rate of $176.00/acre for a total land opportunity cost of $2,464.00.

withdrawals from baseline.

The Sub-scenarios will be implemented on the acreages shown in Table 6, and will lead to the following respective changes in water withdrawals. Sub-scenario 1 (Delta-wide, OFS+TWR) will be implemented on 40,000 acres leading to an annual change in water withdrawals of 55,297 acre-feet or 1.38 acre-feet/acre of project area. Sub-scenario 2 (Delta-wide, TWR only) will be implemented on 40,000 acres leading to an annual change in water withdrawals of 18,432 acre-feet or 0.46 acre-feet/per acre of project area. Sub-scenario 3 (Delta-wide, OFS+TWR, and TWR mix) will be implemented on 40,000 acres leading to an annual change in water withdrawals of 36,865 acre-feet or 0.92 acre-feet/acre of project area.

Costs per acre-foot of change in water pumped from the aquifer were calculated using capital budgeting over a planning horizon of 50 years. For the TWR Scenario as well as for the TWR+OFS Scenario, cost savings were calculated in the form of reduced pumping costs for each Sub-scenario. It is assumed that 49 acre-feet of water will be pumped from the TWR ditch, and 145 acre-feet will be pumped from the TWR ditch into the OFS, and then from the OFS on to the field. It was assumed that all water pumped will use an electrical, vertical line shaft pump. The heights for water lift for pumping water from the TWR system into the OFS, and then from the OFS on to the field were both assumed to be 15 feet. Pump operating and maintenance costs to lift water from the aquifer were estimated to be $14.76/ac-ft for the Delta region. The operating and maintenance costs for pumping water from the TWR system into the OFS, and then from the OFS on to the field were both calculated at $2.76/ac-ft.

Table 6. Estimated Cost per Acre-Foot Not Pumped from the Aquifer for TWR and OFS Sub-scenarios

	Delta Wide TWR +OFS	Delta Wide TWR	Delta Wide 50% OFS +T WR / 50% TWR mix
Acres in Project	40,000	40,000	40,000
Annual Reduction (amount of change in ac-ft)	55,297	18,432	36,865
Total Reduction in acre-feet (50 years)	2,764,850	921,600	1,843,250
Cost per acre foot ($/ac-ft)	$19.76	$24.13	$20.85

The reduced pumping costs for each system were arrived at by multiplying the acre-feet of water pumped using the respective systems by the operating costs associated with pumping an acre-foot of water. This amounted to an annual reduction in water pumped costs of $723.24 for every TWR system for the Delta-wide region, and $2,140.20 for the TWR+OFS system for the Delta-wide region. The NPV of costs of each TWR System were calculated at $88,956 for the Delta-wide region, and the NPV of costs of each TWR+OFS system were calculated at $218,514 for the Delta-wide region.

Table 6 shows the comparisons in costs per acre-foot associated with the TWR, TWR+OFS, and the OFS+TWR and TWR mix Sub-scenarios. The total reduction in water pumped over a 50 year planning horizon was found to be 2,764,850 acre-feet for Delta-Wide TWR +OFS, 921,600 acre-feet for the Delta-Wide TWR, and 1,843,250 acre-feet for the Delta-Wide 50% OFS+TWR/50% TWR mix Sub-scenarios respectively. The annual cost per acre-foot for each Sub-scenario was estimated by dividing the NPV of the costs for the total number of systems installed for each scenario by the total reduction achieved over the 50 years. This amounted to $19.76, $24.13, and $20.85 per acre- foot of reduced pumping for the Delta-Wide TWR +OFS, Delta-Wide TWR, and the Delta-Wide 50% OFS+TWR/50% TWR mix scenarios respectively.

Cash Flows: Enhanced Aquifer Recharge

The cash flow estimates in the Enhanced Aquifer Recharge scenario are based on detailed information provided by ARS personnel for capital equipment and operating supplies used in application of the Enhanced Aquifer Recharge

Table 7. Enhanced Aquifer Recharge Scenario Investment and Maintenance Cost Estimate[5]	
Component	**Total cost**
Extraction / Injection Wells	$5,400,000.00
Booster Pumps	$10,034,000.00
Piping	$55,908,265.00
Miscellaneous	$15,268,453.00
Monitoring & Assessment	$1,000,000.00
Electricity	$2,744,683.00
Redevelopment	$46,394.60
Well Maintenance	$160,000.00
Pipeline Maintenance	$20,000.00
Monitoring & Assessment	$30,000.00

[5] Table 7 presents the cost of implementation estimates for the components required as part of the enhanced aquifer scenario. This estimate includes Extraction / Injection Well costs of $5,400,000, booster pump costs of $10,034,000 (replaced every 15years), and piping costs of $55,908,265. Extraction/ Injection wells will also require replacement of well pumps with electric motors (every 10 years), down-hole flow control valve (to be replaced every 25 years), and SCADA System (to be replaced every 25 years). Initial monitoring and assessment costs were estimated at $1,000,000, and annual monitoring costs for site visits and sample analysis were estimated at $30,000. Annual electricity expenditures were estimated at $2,744,683. Redevelopment charges were estimated at $46,395. Well maintenance is projected to cost $160,000, assuming total work hours at 3,200 for 2 employees working 2 days per well, and being paid $50/hour. Pipeline maintenance was estimated at $20,000 assuming the requirement of 400 work hours being paid at $50/hour.

program. The initial cost of capital equipment and operating supplies was provided by ARS personnel and Eley-Barkley Engineering and Architecture, Cleveland, MS.

The enhanced aquifer recharge Scenario will be implemented on 16,640 acres across the East-Central Delta region and the amount of change in water recharge on account of the Scenario is expected to be 120,976 acre-feet annually, or 7.27 acre-feet/acre of project area. Based on the above projections by the USGS, costs per acre-foot of groundwater recharge were calculated using capital budgeting for a planning horizon of 50 years.

Table 8 shows the costs per acre-foot associated with the enhanced aquifer recharge Scenario in the project region. The NPV for a 50 year planning horizon was estimated at $263,810,846, the annual change in aquifer was 120,976 acre-ft, and the total reduction in water pumped over a 50 year planning horizon was calculated to be 6,048,800 acre-feet. The cost per acre-foot for the scenario was estimated by dividing the NPV of the costs by the total reduction achieved over the 50 years, which amounted to $43.61 for the East-Central Delta region.

Cash Flows: Tallahatchie-Quiver Intra-Basin Transfer

The cash flow estimates in the Tallahatchie-Quiver Intra-basin Transfer scenario are based on data provided by USACE and YMD personnel. Detailed information for capital equipment and operating supplies is available in a USACE report titled "Big Sunflower River Watershed (Quiver River), Mississippi Draft Feasibility Report with Integrated Environmental Assessment", issued in September, 2016.

Net cash flow estimates were made for 6 Tallahatchie-Quiver Intra-basin Transfer Sub-scenarios in the East-Central Delta location. The Scenarios will be implemented on 51,933 acres assuming a ½ mile distribution area around the Quiver River in the East-Central Delta region, and the second scenario will be implemented on 95,893 acres assuming a 1 mile distribution area around the Quiver River across the East-Central Delta region. Three Sub-Scenarios will be calculated assuming 100% adoption, 66% adoption and 33% adoption rates for each Scenario. The amount of change in water withdrawals on account of the scenario implemented over a ½ mile distribution area is expected to be 36,289 acre-feet annually, or 0.70 acre-feet/acre of project area for a 100% adoption rate, 23,951 acre-feet annually, or 0.46 acre-feet/acre of project area for a 66% adoption rate, and 11,975 acre-feet annually, or 0.23 acre-feet/acre of project area for a 33% adoption rate respectively. Additionally, the amount of change in water withdrawals on account of the scenario implemented over a 1 mile distribution area is expected to be 71,917 acre-feet annually, or 0.75 acre-feet/acre of project area for a 100% adoption rate, 47,465 acre-feet annually, or 0.49 acre-feet/acre of project area for a 66% adoption rate, and 23,733 acre-feet annually or 0.25 acre-feet/acre of project area for a 33% adoption rate respectively.

Table 8. Estimated Cost per Acre-Foot of Increased Recharge to the Aquifer for the Enhanced Aquifer Recharge Scenario

	NPV of Total Cost	Annual Change in Aquifer (acre-ft)	Total Change in Aquifer (acre-ft)	Average Cost Change in Aquifer ($/acre-ft)
Enhanced Aquifer Recharge Scenario	$263,810,846	120,976	6,048,800	$43.61

Table 9. Tallahatchie-Quiver Intra-basin Transfer Scenario Construction Cost Estimate[6]

Construction Item	Cost/Unit
Lands and Damages	$489,000
Relocations	$13,750
Channels	$5,495,491
Pumping Plant	$6,249,012
Main Pump Motors & Pumps	$3,264,064
Engineering Design & Construction Management	$4,724,823
Total	$20,236,140

[6] Table 9 describes the initial investment cost estimates for the components required as part of the Tallahatchie-Quiver Intra-basin Transfer Scenario. The Pumping Plant is assumed to have a life of 25 years. Total annual operating costs are assumed to $550,000 per year.

Table 10. Tallahatchie-Quiver Intra-basin Transfer Scenario Relift Equipment Investment Cost Estimate (1/2 mile distribution area) [7]

		Adoption Rate		
Tallahatchie- Quiver Project 1/2 Mile Distribution Area	**Cost/Unit**	**100%**	**66%**	**33%**
Pumping Plant (30 HP)	$21,000.00	$6,489,000	$4,284,000	$2,142,000
Underground line - (12")	$7.00	$2,855,160	$1,884,960	$942,480
Stand (w/ flow meter)	$1,950.00	$602,550	$397,800	$198,900
Total Systems		309	204	102

[7] Relift equipment cost estimates required for the Tallahatchie-Quiver Intra-basin Transfer Scenario developed for ½ distribution area is shown above in Table 10 for the East-Central Delta region, for three specific adoption rates (100%, 66%, and 33%) based on Sub-scenario runs provided by the USGS. The number of systems to be used in a ½ mile distribution area assuming 100%, 66%, and 33% adoption rates were 309, 204, and 102 respectively. Initial investment costs associated with 30 HP relift pumping plants at a unit cost of $21,000 for a total of 309 systems was estimated at $6,489,000, $4,284,000, and $2,142,000 for 100%, 66%, and 33% adoption rates respectively. Relift pumps are projected to be replaced every 20 years. Total cost of underground lines at $7.00 per unit for 12" (installed) was estimated at $2,855,160, $1,884,960, and $942,480 for 100%, 66%, and 33% adoption rates respectively. The total costs for stands at $1,950 per unit were estimated at $602,550, $397,800, and $198,900 for 100%, 66%, and 33% adoption rates respectively.

Table 11. Tallahatchie-Quiver Intra-basin Transfer Scenario Relift Equipment and Right of Way Investment Cost Estimate (1 mile Distribution Area) [8]				
		Adoption Rate		
Tallahatchie- Quiver Project 1 Mile Distribution Area	Cost/Unit	100%	66%	33%
Pumping Plant (30 HP)	$21,000.00	$13,755,000	$9,072,000	$4,536,000
Underground line - (12"/15")	$7.00/$12.00	$19,297,080	$12,719,520	$6,359,760
Stand (w/ flow meter)	$1,950.00	$1,277,250	$842,400	$421,200
Right of Way	$10,460.00	$3,619,160	$2,384,880	$1,192,440
Total Systems		655	432	216

[8] Relift equipment cost estimates required for the Tallahatchie-Quiver Intra-basin Transfer Scenario for the 1 mile distribution area is shown above in Table 11 for the East-Central Delta region, for three specific adoption rates (100%, 66%, and 33%) based on Sub-scenario runs provided by the USGS. For a 1 mile distribution area, the number of systems to be used under 100%, 66%, and 33% adoption rates were 655, 432, and 216 respectively. Costs associated with 30 HP relift pumping plants at a unit cost of $21,000 for a total of 655 systems was estimated at $13,755,000, $9,072,000, and $4,536,000 for 100%, 66%, and 33% adoption rates respectively (to be replaced every 20 years). Total cost of underground lines at $7.00 per unit for 12" pipe (installed) for relift systems servicing the ½ mile distribution area and $12.00 per unit for 15" pipe (installed) for relift systems servicing the ½ mile to 1 mile distribution area was estimated at $19,297,080, $12,719,520, and $6,359,760 for 100%, 66%, and 33% adoption rates respectively. The total costs for stands at $1,950 per unit were estimated at $1,277,250, $842,400, and $421,200 for 100%, 66%, and 33% adoption rates respectively. Right of way costs are calculated for the number of systems outside the half-mile distribution area, based on a per system cost of $10,460 for a half mile of right of way (Eley, 2016). Right of way costs were estimated at $3,619,160, $2,384,880, and $1,192,440 for 100%, 66%, and 33% adoption rates respectively.

Table 12. Estimated Cost of Change per Acre-Foot in Reduced Pumping from the Aquifer for the Tallahatchie-Quiver Intra-basin Transfer Scenario (1/2 mile Distribution Area)

	NPV of Total Cost	Annual Change (acre-ft)	Total Change in Aquifer (acre-ft)	Average Cost of Change ($/acre-ft)
Tallahatchie/ Quiver- 100%	$40,369,190	36,289	1,814,450	$22.25
Tallahatchie/ Quiver - 66%	$42,559,883	23,951	1,197,550	$35.54
Tallahatchie/ Quiver - 33%	$44,680,714	11,975	598,750	$74.62

Table 13. Estimated Cost of Change per Acre-Foot of Reduced Pumping from the Aquifer for the Tallahatchie-Quiver Intra-basin Transfer Scenario (1 mile Distribution Area)

	NPV of Total Cost	Annual Change (acre-ft)	Total Change in Aquifer (acre-ft)	Average Cost of Change ($/acre-ft)
Tallahatchie/ Quiver- 100%	$53,868,434	71,917	3,595,850	$14.98
Tallahatchie/ Quiver - 66%	$51,427,291	47,465	2,373,250	$21.67
Tallahatchie/ Quiver - 33%	$49,113,657	23,733	1,186,650	$41.39

Transfer channel construction costs, initial costs of pumping plants installation (useful life of 25 years), engineering design and construction management costs, annual water lift cost to the field, annual operation and maintenance costs were combined to estimate total project cash flow. For the Tallahatchie-Quiver Intra-basin Transfer Scenario savings in pumping costs that result from relifting water from the river as opposed to pumping from the aquifer were calculated for the different adoption rates and distribution areas. The reduced pumping costs for different adoption rates and distribution areas were arrived at by multiplying the number of systems and the operating costs associated with pumping an acre-foot of water. Based on the above assumptions, estimated cost of change per acre-foot of reduced pumping from the aquifer was calculated using capital budgeting for a planning horizon of 50 years.

Table 12 describes the estimated cost of change per acre-foot in reduced pumping from the aquifer associated with the Tallahatchie-Quiver Intra-basin Transfer Sub-scenarios (1/2 mile distribution area). The NPV for a 50 year planning horizon was estimated at $40,369,910, $42,559,883, and $44,680,714 for 100%, 66% and 33% adoption rates respectively, and the corresponding total reduction in water pumped over a 50 year planning horizon was found to be 1,814,450 acre-feet, 1,197,550 acre-feet, and 598,750 acre-feet respectively. The cost per acre-foot for each Sub-scenario was estimated by dividing the NPV of the costs by the total reduction achieved over the 50 years, which amounted to $22.25, $35.54 and $74.62 under 100%, 66% and 33% adoption rates respectively.

Table 13 describes the estimated cost of change per acre-foot in the aquifer associated with the Tallahatchie-Quiver Intra-basin Transfer Sub-scenarios (1 mile distribution area). The NPV for a 50 year planning horizon was estimated at $53,868,434, $51,427,291, and $49,113,657 for 100%, 66% and 33% adoption rates respectively, and the corresponding total reduction in water pumped over a 50 year planning horizon was found to be 3,595,850 acre-feet, 2,373,250 acre-feet, and 1,186,650 acre-feet respectively. The cost per acre-foot for each Sub-scenario was estimated by dividing the NPV of the costs by the total reduction achieved over the 50 years, which amounted to $14.98, $21.67, and $41.39 under 100%, 66% and 33% adoption rates respectively.

Cash Flows: Instream Weirs For Surface-Water Availability

The cash flow estimates in the Instream Weirs for Surface-Water Availability scenario are based on detailed information provided by USACE personnel for capital equipment used in development of the Instream Weirs for Surface-Water Availability program. The relift cost estimates related to moving water from the weirs to the fields are based on estimates made by DREC personnel.

Cash flows were calculated for 2 Sub-scenarios for the Instream Weirs, one for a ½ mile distribution area and the second for a ¾ mile distribution area around select locations on the Big Sunflower River, Quiver River, Bogue Phalia and Clear Creek. The amount of change in water withdrawals on account of the three ½ Mile Distribution Area Sub-scenarios is expected to be 73,290 acre-feet annually for a 100% adoption rate, 48,372 acre-feet annually for a 66% adoption rate, and 24,186 acre-feet annually for a 33% adoption rate respectively. The amount of change in water withdrawals on account of the ¾ Mile Distribution Area Sub-scenarios is expected to be 108,859 acre-feet annually for 100% adoption, 71,847 acre-feet annually for a 66% adoption rate, and 35,923 acre-feet annually for a 33%

Table 14. Instream Weirs Scenario Construction Cost Estimates

Item	Total
Mobilization/Demobilization	$400,000
Filter Fabric	$247,806
R200	$1,053,000
R400	$4,613,752
Filter Stone	$1,648,272
42"/36"/30" Pipe	$214,480
Earth for Weir	$1,217,050
Earth for Cofferdam	$3,806,600
Erosion Control	$46,750
PZ22	$832,200
Mob/Demob Piling Crew	$150,000
Clearing and Grubbing	$98,000
Control of Water	$2,000,000
Total - All Weirs	$16,327,910

Table 15. Instream Weirs Sub-scenario Relift Equipment Investment Cost Estimate for the 1/2 mile Distribution Area[9]

In Stream Weir Project 1/2 Mile Distribution Area	Cost/Unit	Number of Systems - 100%	Number of Systems – 66%	Number of Systems - 33%
Pumping Plant (30 HP)	$21,000.00	$12,642,000.00	$8,337,000.00	$4,179,000.00
Underground line - 12"	$7.00	$5,562,480.00	$3,668,280.00	$1,838,760.00
Stand (w/ flow meter)	$1,950.00	$1,173,900.00	$774,150.00	$388,050.00
Total Systems		602	397	199

[9] Relift equipment cost estimates for the Instream Weirs Project for Surface-water Availability Scenario were developed for the ½ mile distribution area for three adoption rates (100%, 66%, and 33%) based on Sub-scenario runs provided by the USGS. The number of relift systems to be used in a 1/2 mile distribution area assumed for the 100%, 66%, and 33% adoption rates were 602, 397, and 199 respectively. Total relift equipment investment costs associated with 30 HP pumping plants respectively (to be replaced every 20 years) at a unit cost of $21,000 for a total of 602 relift systems was estimated at $12,642,00, $8,337,000, and $4,179,000 for 100%, 66%, and 33% adoption rates respectively. Total cost of underground lines at $7.00 per unit for 12" pipe (installed) was estimated at $5,562,480, $3,668,280, and $1,838,760 for 100%, 66%, and 33% adoption rates respectively. The total Stand costs were estimated at $1,173,900, $774,150.00, and $388,050 for 100%, 66%, and 33% adoption rates respectively.

Table 16. Instream Weirs Sub-scenario Relift Equipment Investment Cost Estimate for the 3/4 mile Distribution Area[10]

In Stream Weir Project 3/4 Mile Distribution Area	Cost/Unit	Number of Systems - 100%	Number of Systems – 66%	Number of Systems - 33%
Pumping Plant (30 HP)	$21,000.00	$19,698,000.00	$12,999,000.00	$6,510,000.00
Underground line - 12" & 15"	$7.00/$12.00	$16,206,960.00	$10,701,240.00	$5,355,240.00
Stand (w/ flow meter)	$1,950.00	$1,829,100.00	$1,207,050.00	$604,500.00
Right of Way	$10,460.00	$3,514,560.00	$2,322,120.00	$1,161,060.00
Total Systems		938	619	310

[10] Table 15 describes the total cost estimates for relift equipment needed for implementation in a ¾ mile distribution area under the Instream Weirs sub-scenario. For a total 3/4 mile distribution area, the number of systems to be used under 100%, 66%, and 33% adoption rates were 938, 619, and 310 respectively. Total relift equipment investment costs associated with 30 HP pumping plants at a unit cost of $21,000 for a total of 938 systems was estimated at $19,698,000, $12,999,000, and $6,510,000 for 100%, 66%, and 33% adoption rates respectively (to be replaced every 20 years). Total cost of underground lines at $7.00 per unit for 12" pipe (installed for ½ mile distribution area) and $12.00 per unit for 15" pipe (installed for systems past the ½ mile distribution area and in the ¾ mile distribution area) was estimated at $16,206,960, $10,701,240, and $5,355,240 for 100%, 66%, and 33% adoption rates respectively. The total Stand costs were estimated at $1,829,100, $1,207,050, and $604,500 for 100%, 66%, and 33% adoption rates respectively.

Table 17. Estimated Cost of Change per Acre-Foot Pumped from the Aquifer for Instream Weirs Sub-scenario (1/2 mile distribution area)

	NPV of Total Cost	Annual Change (acre/feet)	Total Change (acre/feet)	Average Cost of Change ($ per acre/feet)
In Stream Weir – 100%	$1,811,916	73,290	3,664,550	$0.49
In Stream Weir – 66%	$6,724,753	48,792	2,436,600	$2.76
In Stream Weir – 33%	$11,560,932	24,186	1,209,300	$9.56

adoption rate respectively.

Construction costs provided for the Instream Weirs Scenarios includes estimates for 10 weirs located at selected locations on the Big Sunflower River, Quiver River, Bogue Phalia and Clear Creek. The construction cost estimate used in the study was $16,327,910. Itemized construction costs provided by USACE are shown in Table 14.

Weir construction costs and annual water lift cost to the field costs were used to develop the cash flow estimates calculations. For the Instream Weirs Scenario savings in pumping costs that result from relifting water from the weir as opposed to pumping from the aquifer were calculated for the different adoption rates and distribution areas. The reduced pumping costs different adoption rates and distribution areas were arrived at by multiplying the number of systems and the operating costs associated with pumping an acre-foot of water.

Table 17 describes the cost of change per acre-foot in reduced pumping from the aquifer associated with the Instream Weirs Sub-scenario (1/2 mile distribution area). The NPV for a 50 year planning horizon was estimated to provide a savings across all adoption rates due to low initial investment and no specified maintenance costs for the weirs. The total reduction in water pumped over a 50 year planning horizon was found to be 3,664,500 ac-feet, 2,436,600 ac-feet, and 1,209,300 ac-feet respectively. The cost per acre-foot for the sub-scenario was estimated by dividing the NPV of the costs by the total reduction achieved over the 50 years, which amounted to costs of $0.49, $2.76 and $9.56 per acre foot under 100%, 66% and 33% adoption rates respectively.

Table 18 describes the cost of change per acre-foot in reduced pumping from the aquifer associated with the Instream Weirs Sub-scenario (3/4 mile distribution area). The total reduction in water pumped over a 50 year planning horizon was found to be 5,442,950 acre-feet, 3,592,350 acre-feet, and 1,796,150 acre-feet respectively. The cost of change per acre-foot in reduced pumping from the aquifer for each of the sub-scenarios was estimated by dividing the NPV of the costs by the total reduction achieved over the 50 years, which amounted to $1.63, $3.17and $7.74 under 100%, 66% and 33% adoption rates respectively.

Conclusion And Discussion

This study evaluated the costs of implementing five water management alternatives in the Mississippi Delta over a planning horizon of 50 years. Specifically, these were the RISER (Irrigation efficiency) Scenario, the Tail Water Recovery (TWR) and the Onfarm storage (OFS) Scenario, the Enhanced Aquifer Recharge Scenario, the Tallahatchie-Quiver Intra-basin Transfer Scenario, and the Instream Weirs for Surface-water Availability Scenario. In considering the study results, it should be noted that the cost data available for some of the alternatives are more detailed and current than the data for others. The cost data for the RISER and the Tail Water Recovery and Onfarm Storage scenarios are detailed, current, and based on recently implemented projects and practices. The cost estimates for components of the Enhanced Aquifer Recharge scenario are detailed and based on research of current materials and construction and ancillary costs for a project with similar components, but no comparable project has actually been built. Detailed information for capital equipment and operating supplies for the Tallahatchie-Quiver Intra-basin Transfer scenario is available in a USACE report titled “Big Sunflower River

Table 18. Estimated Cost of Change per Acre-Foot Pumped from the Aquifer for the Instream Weirs Sub-scenario (3/4 mile Distribution Area)

	NPV of Total Cost	Annual Change (acre/feet)	Total Change (acre/feet)	Average Cost of Change ($ per acre/feet)
In Stream Weir – 100%	$8,854,799	108,859	5,442,950	$1.63
In Stream Weir – 66%	$11,397,970	71,847	3,592,350	$3.17
In Stream Weir – 33%	$13,897,922	35,923	1,796,150	$7.74

Table 19. Cost of change per acre-foot in reduced pumping from the aquifer comparison of water management scenarios for the Mississippi Delta.

Water management Scenario	Type of change	Amount of change (ac-ft/ year)	Cost ($/ac-ft)
RISER (Irrigation efficiency)	Decrease groundwater withdrawal		
Delta-wide		530,647	13.38
Central Delta		36,710	5.06
Tail Water Recovery (TWR)	Decrease groundwater withdrawal		
TWR only			
Delta-wide		18,432	24.13
TWR + OFS			
Delta-wide		55,297	19.76
50% TWR-OFS/50% TWR			
Delta-wide		36,865	20.85
Enhanced Aquifer Recharge	Increase recharge to alluvial aquifer	120,976	43.61
Quiver/Tallahatchie Intra-basin	Decrease groundwater withdrawal		
1/2 mile distribution area			
100% adoption		36,289	22.25
66% adoption		23,951	35.54
33% adoption		11,975	74.62
1 mile distribution area			
100% adoption		71,917	14.98
66% adoption		47,465	21.67
33% adoption		23,733	41.39
Instream Weirs (Surface water)	Decrease groundwater withdrawal		
1/2 mile distribution area			
100% adoption		73,290	0.49
66% adoption		48,732	2.76
33% adoption		24,186	9.56
3/4 mile distribution area			
100% adoption		108,859	1.63
66% adoption		71,847	3.17
33% adoption		35,923	7.74

Watershed (Quiver River), Mississippi Draft Feasibility Report with Integrated Environmental Assessment", issued in September, 2016. The cost estimates for the instream weirs project was provided by the USACE, which has previously implemented weir construction in the Mississippi Delta region.

Overall results suggest that the instream weirs program resulted in the lowest costs of implementation measured as cost in dollar per-acre foot of reduced pumping from the aquifer among all scenarios, followed by the RISER program. The other alternatives resulted in various levels of implementation costs depending on the location of the project, and/or adoption rates by producers.

The results from this project provide an initial estimate of the costs associated with the different water management alternatives, and builds the groundwork for future in-depth studies addressing the feasibility of implementation, and the associated cost-benefit trade-offs for the proposed water management strategies in the Mississippi Delta.

Acknowlegements
The authors would like to thank USGS and MDEQ for their financial support of this project. Also, the authors would like to recognize Dr. Jeannie Barlow, Mr. Sam Mabry, Dr. Jason Krutz, Mr. Paul Rodrigue, Dr. J.R. Rigby, Mr. Mark Stiles and Mr. Dave Johnson for their assistance in this project.

References
Barlow, P. and S. Leake (2012). Streamflow Depletion by Wells—Understanding and Managing the Effects of Groundwater Pumping on Streamflow. United States Geological Survey Circular 1376. Available from: http://pubs.usgs.gov/circ/1376/pdf/circ1376_barlow_report_508.pdf. Accessed June 15, 2016.

Conservation Technology Information Center (2016). Conservation in the Mississippi DELTA. http://www.ctic.org/media/Conservation%20in%20the%20Mississippi%20DELTA.pdf. Accessed June 15, 2016.

EIA (2016). US Energy Information Administration. Electricity Supply, Disposition, Prices, and Emissions. http://www.eia.gov/forecasts/aeo/data/browser/#/?id=8-AEO2016&cases=ref2016~ref_no_cpp&sourcekey= 0 .Accessed August 17, 2016.

Eley, Bob (2016). Personal communication, August 31, 2016.
FAPRI (2016). U.S. Baseline Briefing Book Projections for Agricultural and Biofuel Markets. Food and Agricultural Policy Research Institute, University of Missouri. FAPRI-MU Report #02-16, March 2016.

Janes, L. and K. Breaux (2015). Quiver Tallahatchie Feasibility Study. YMD Joint Water Management district and U.S. Army Corps of Engineers (USACE). Presented at Delta Sustainable Water Resources Funding Committee Meeting. December 2, 2015.

Johnson, D. (2015). Instream Weirs for Water Supply. Presented at Delta Sustainable Water Resources Funding Committee Meeting. December 2, 2015.

Krutz, J., D. Dodds, T. Irby, and E. Larson (2014). The Mississippi State University RISER Program: Efficient Methods for Furrow Irrigation. Available from: http://www.mississippi-crops.com/2014/02/12/the-mississippi-state-university-riser-program-efficient-methods-for-furrow-irrigation/. Accessed June 15, 2016.

Parman, Bryon J. (2016). "Mississippi Land Values and Cash Rents Report: 2016 Survey of Lenders". MSU-ES Publication 2967 (POD-06-16).

Rigby, J.R. (2015). Tallahatchie Groundwater Transfer Option. USDA-ARS. Presented at Delta Sustainable Water Resources Funding Committee Meeting. December 2, 2015.

Tacker, Phil. Calculating and Comparing Irrigation Pumping Costs (Excel Spreadsheet), University of Arkansas, 2005.

The International Commission on Irrigation and Drainage (ICID) (2016). Diversion Weirs. Available from: http://www.icid.org/res_irri_weirs.html. Accessed June 15, 2016.

U.S. Army Corps of Engineers (2016). Economic Guidance Memorandum, 16–01, Federal Interest Rates for Corps of Engineers Projects for Fiscal Year 2016. October 14, 2015.