Mississippi Water Resources Research Institute
Annual Technical Report
FY 2013

Introduction

The Mississippi Water Resources Research Institute (MWRRI), established by the Mississippi legislature in1984, is a quasi-state agency located at Mississippi State University (MSU) created to provide a statewidecenter of expertise in water resources and associated land uses that incorporates all of Mississippi’sInstitutions of Higher Learning in its activities. MWRRI’s diverse statutory responsibilities are: 1) assist state agencies in developing and maintaining a state water management plan; 2) consult with stateand local agencies, water management districts, water user associations, the Mississippi legislature, and otherpotential users to identify and establish water research, planning, policy, and management priorities. 3) negotiate and administer contracts with local, regional, state and federal agencies and other Mississippi universities to mitigate priority water and related problems; 4) report to the appropriate state agencies each year on research projects’ progress and findings; 5) disseminate new information and facilitate transfer and application of new technologies as they are developed; 6) be a liaison between Mississippi and funding agencies as an advocate for Mississippi water research, planning, policy, and management needs; and 7) facilitate and stimulate planning and management that deals with water policy issues facing the state of Mississippi, supports state water agencies' missions with research on encountered and expected problems, and provides water planning and management organizations with tools to increase efficiency and effectiveness of water planning and management.

MWRRI staff work with departments and programs from Institutions of Higher Learning across Mississippi, state and federal agencies, and stakeholder organizations willing to participate in its collaborative approach in a team environment to develop approaches and projects to address the state’s water resources management and research priorities.

Research Program Introduction

Effective environmental planning and water resources management must first be informed and supported by scientifically-accepted research, the development of which is MWRRI's primary function. For over 30 years, MWRRI through its member Institutions of Higher Learning has worked with agencies and organizations in Mississippi and beyond to support and advance water resources research. Today, more than ever, research is vitally needed in Mississippi to advance our understanding of the science and dynamics of multiple interconnected and interdependent water-related issues and to inform our water resources planners, managers, users, and stakeholders. Since its creation and as part of its statutory responsibility, MWRRI has identified water resources research priorities through its Advisory Board and, supported by the U.S. Geological Survey through the 1984 Water Resources Research Act, has provided funding for selected research proposals that address these priorities.

Also established with the legislation that created MWRRI, the Advisory Board's role is to provide input on current and emerging priority state, regional and national water and water-related land research problems; identify opportunities to effectively collaborate with local and state governments and agencies, water user associations, other universities, federal government agencies, and the legislature in formulating MWRRI's research program; assist on the selection of research projects to be funded from USGS funds; and advise on disseminating and transferring information and technology produced by research. Designated Advisory Board members include representatives from the Mississippi Public Service Commission, Mississippi Department of Environmental Quality, Mississippi Department of Marine Resources, U.S. Army Corps of Engineers Engineering Research and Design Center, Mississippi/Alabama Sea Grant Consortium, University of Mississippi, University of Southern Mississippi, Jackson State University, Delta Council, USDA Natural Resources Conservation Service, Mississippi Soil & Water Conservation Commission, U.S. Geological Survey, USDA National Sedimentation Laboratory, and the Mississippi Water Resources Association. Five at large seats representing water stakeholders/users in private sector business and regional water management/waterway districts also serve three year staggered terms.

MWRRI's approach to integrated water resources research seeks to explore the linkages among natural science, engineering, and the dynamics of social and economic systems that underpin water management decisions. As one of its functions, MWRRI conducts an annual, statewide competitive grants program to solicit research proposals. Proposals are prioritized as they relate to the research priorities established by MWRRI's Advisory Board and by the ability of proposing parties to obtain letters of support or external cost share from non−federal sources in Mississippi. The Advisory Board then evaluates all proposals. Based on the most current list of research priorities, these would include: water quality, surface and groundwater management, water quality management and water resources development, contaminant transport mechanisms, wetlands and ecosystems, groundwater contamination, as well as other issues addressing coastal and marine issues linking water associations through the state, and institutional needs that include capacity building and graduate student training.

Three projects were funded this year that address priority water resources issues in Mississippi. These projects were: 1. Water quality and other ecosystem services in wetlands managed for waterfowl in Mississippi (2011MS135B - 11 publications to date);

2. Interdisciplinary Assessment of Mercury Transport, Fate and Risk in Enid Lake, Mississippi (2013MS182B - 3 publications to date); and

3. Non-linear downward flux of water in response to increasing wetland water depth and its influence on groundwater recharge, soil chemistry, and wetland tree growth (extension request granted - 2013MS183B).

It is anticipated that the final report for project 2013MS182B will be received by June 15, 2014. Project 2013MS183B has been granted an extension through December 31, 2014. Incremental reports submitted for research projects 2013MS182B and 2013MS183B are included in this document to provide background on these projects.

In addition, the final reports for projects 2011MS135B, 2012MS157B and 2012MS158B have been received and are included in this document as they received extensions that occurred after the previous year report.

Water quality and other ecosystem services in wetlands managed for waterfowl in Mississippi

Basic Information

Title:	Water quality and other ecosystem services in wetlands managed for waterfowl in Mississippi
Project Number:	2011MS135B
Start Date:	3/1/2011
End Date:	6/30/2013
Funding Source:	104B
Congressional District:	3rd
Research Category:	Water Quality
Focus Category:	Water Quality, Wetlands, Economics
Descriptors:	None
Principal Investigators:	Richard Kaminski, Amy B. Spencer

Publications

1. Quarterly reports 2011-2012 to Mississippi Water Resources Research Institute, Mississippi State University, Mississippi State, MS.
2. Alford, A.B., R.M. Kaminski, L.R. D’Abramo, and J. Avery. 2011. Characteristics of harvestable crayfish populations in managed wetlands of the Lower Mississippi Alluvial Valley. Poster presentation. American Fisheries Society, Seattle, WA. September 4-9, 2011.
3. Alford, A.B. 2011. Crawfish harvest as a wildlife enterprise. Natural Resources Enterprise and LSUAgCenter Paddling and Canoeing and Lease Opportunities for Landowners Workshop. Monroe, LA. September 28, 2011.
4. Alford, A.B., R.M. Kaminski, R. Kroger, L.R. D’Abramo, and J. Avery. 2011. Ecosystem services derived from moist-soil management. Poster presentation. Mississippi Chapter of the Wildlife Society. Louisville, MS, October 4-5, 2011.
5. Alford, A.B., R. Kroger and R.M. Kaminski, 2012, Nutrient characteristics of moist-soil wetlands in agricultural landscapes. Oral presentation, Mississippi Water Resources Conference, Jackson, MS, April 3-4, 2012, online at http://www.wrri.msstate.edu/pdf/2012_wrri_proceedings.pdf, p. 141.
6. Alford, A.B. and R. Kaminski, 2012, Duck hole 'dads' (dat's crawdads), Mossy Oak Gamekeeper: Farming for Wildlife, Spring 2012.
7. Final Technical Report, 2013, Water quality and other ecosystem services from wetlands managed for waterfowl in Mississippi, 17 pgs.
8. Alford, A.B., R.M. Kaminski, S. Grado, L. D'Abramo and J. Avery, 2013, Crayfish harvesting: alternative opportunities for landowners practicing moist-soil wetland management, Ecology and Conservation of North American Waterfowl, Memphis, TN, January 2013, Oral Presentation.
9. Alford, A.B., R. Kroger and R.M. Kaminski, 2013, Water quality from moist-soil wetlands in agriculture landscapes: a comparative approach, Ecology and Conservation of North American Waterfowl, Memphis, TN, January 2013, Poster Session.
10. Alford, A.B., S. Grado and R.M. Kaminski, 2013, Crayfish harvesting: alternative opportunities for landowners practicing moist-soil wetland management, Mississippi Water Resources Research Annual Conference, Jackson, MS, April 2-3, 2013.

11. Alford, A.B. and R.M. Kaminski, 2013, Crayfish harvesting in moist-soil wetlands, Louisiana Chapter of the American Fisheries Society, Baton Rouge, LA.

Project Title: Water quality and other ecosystem services from wetlands managed for waterfowl in Mississippi

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Focus Categories: WL, ECL, WQL

Keywords: aquatic invertebrates, crayfish, ecosystems, sedimentation, water quality, watershed management, wetlands

Federal Funds Spent: $14,150

Cost-Share Funds Spent: $36,365

Technical Abstract

A successful and increasingly applied conservation practice in the Lower Mississippi Alluvial Valley (MAV) to mitigate loss of wetland wildlife habitat and improve water quality has been development and management of "moist-soil wetlands." This conservation practice has the potential to provide ecosystem services critical to restoring wetland functions in the MAV such as reducing dispersal of sediments and nutrients into surrounding watersheds. Moreover, a significant potential exists for native crayfish (*Procambarus* spp.) harvest in moist-soil wetlands in the MAV. During spring 2011, we estimated average daily yield of crayfish from 18 moist-soil wetlands in Arkansas, Louisiana, Mississippi, and Missouri. Average daily yield in 2011 was 3.64 kg/ha (CV = 33%). This estimate was slightly greater and more variable than the estimated yield from Mississippi wetlands in 2009 (i.e., 1.75 kg ha^{-1}; CV = 16%, n = 9) and wetlands in Arkansas, Louisiana, and Mississippi in 2010 (i.e., 2.18 kg ha^{-1};CV = 30%, n = 15) . Our estimated daily yield of naturally occurring crayfish from moist-soil wetlands is lower than 10 kg ha^{-1} which is the average daily yield from commercially operated rice-crayfish ponds in Louisiana. However, our comparisons of operating budgets from the two harvest systems indicated that rice-crayfish systems incur $1455 in direct expenses per hectare whereas crayfish harvest operation in moist-soil wetlands incur $682 direct expenses per hectare. Although fixed expenses are lower in harvest operations from moist-soil wetlands, lower yields increased the break-even selling prices from $2.75 kg^{-1} in rice-crayfish systems to $6.38 kg^{-1} in moist-soil harvest systems. These prices, however, are still less than those observed in regions of the Southeastern United States outside of Louisiana. To determine if crayfish harvested from moist-soil wetlands are an acceptable seafood product relative to commercially harvested crayfish, we conducted a consumer acceptability panel in May 2011. We found that crayfish from both sources were well liked and did not differ significantly ($p > 0.05$) in overall consumer acceptability. In July 2010, we installed water quality monitoring stations at 5 wetlands and 5 agriculture fields. We monitored concentrations of nutrients and sediments exported from these habitats during storm events in December-March of 2010-2012. We determined that wetlands exported significantly less total suspended solids and NO_3 than agriculture fields in 2010-2011 whereas all parameters except for NH_3 were significantly lower in wetland effluent compared to agriculture fields in winter 2011-2012. We were able to calculate loads (kg ha^{-1}) from wetland habitats during the study years and determined that total annual loads of nutrients were slightly greater than currently assumed loading values of wetlands in Mississippi (i.e., 1 kg ha^{-1}). Quantifying these ancillary ecosystem services of moist-soil wetlands will encourage further establishment and management of these wetlands in the MAV and elsewhere for wildlife and associated environmental and human benefits.

INTRODUCTION

Loss of wetlands in the MAV has reduced surface water quality (e.g., Mitsch et al. 2005, Shields et al. 2009). To address loss of ecosystem services, ecologists and wildlife managers have encouraged best management practices (Maul and Cooper 2000, Stafford et al. 2006, Manley et al. 2009) and reestablishment of wetlands (Mitsch et al 2005, Kovacic et al. 2006, Kross et al. 2008) throughout the Mississippi River drainage. A successful management practice in the MAV to address loss of wetland wildlife habitat has been the establishment of moist-soil wetlands. Moist-soil wetlands are naturally vegetated basins, usually by herbaceous annuals (e.g., grasses, sedges), that are prolific producers of seeds and tubers. Because moist-soil wetlands can provide 4-10 times the carrying capacity of harvested agriculture fields in MAV (Kross et al. 2008), management of these habitats is encouraged to meet the goal of sustaining continental populations of waterfowl under the North American Waterfowl Management Plan (United States Fish and Wildlife Service 1986).

Additionally, within the MAV, strategic location of moist-soil wetlands amid farmed landscapes can reduce dispersal of sediments and other nutrients into surrounding watersheds. Predictions have been made regarding the environmental significance of this conservation practice relative to improving surface water quality in the MAV (Mitsch et al. 2005, Murray et al. 2009). However, to our knowledge, no effort has been made to quantify the success of this conservation practice to meet the goals of federal environmental quality mandates such as the Clean Water Act (CWA).

In addition to benefits provided by living plant material in moist-soil wetlands (e.g., carbon sequestration), seasonal flooding promotes decomposition of senescent vegetation (Magee 1993). Crayfish feed on the microbial consumers of detritus and other macroinvertebrates found in wetlands (Alcorlo et al. 2004). Thus, creating and managing moist-soil wetlands have propensity to provide significant habitat and forage for crayfish, opportunities for crayfish production and harvest, and additional economic gain for landowners (McClain et al. 1998). Harvest of crayfish for human consumption is significant, amounting to $115 million annually in the southern United States (Romaire et al. 2004). However, traditional crayfish-harvest operations incur considerable costs. Crayfish must be stocked annually into rice or other impounded fields. A sustainable crayfish-harvest from naturally occurring populations in moist-soil wetlands is a likely a cost-effective alternative.

OBJECTIVES

Our project was designed to identify additional ecosystem services provided by public- and private-sector management of naturally and artificially flooded moist-soil wetlands in the Mississippi Alluvial Valley (MAV). Specifically, the third year of our three-year study was designed to (1) estimate production of crayfish populations in moist-soil wetlands, (2) compare operating budgets of Louisiana rice-crayfish harvest systems with hypothetical budgets of moist-soil crayfish harvest systems in the MAV, (3), evaluate consumer acceptability of crayfish harvested from moist-soil wetlands, (4) quantify and compare nutrient and sediment concentrations discharged from moist-soil wetlands and adjacent agriculture fields, and (5) estimate loads of nutrients and sediments exported from moist-soil wetlands in north Mississippi.

METHODS

Study Sites

We identified 18 moist-soil wetlands on public and private lands in Arkansas, Louisiana, Mississippi, and Missouri that were appropriate for our crayfish harvest research. Locations of the wetlands were: Otter Slough Wildlife Management Area, Dexter, Missouri; Wappanocca National Wildlife Refuge, Turrell, Arkansas; Morgan Brake National Wildlife Refuge, Tchula, Mississippi; Panther Swamp National Wildlife Refuge, Yazoo City, Mississippi; Yazoo National Wildlife Refuge, Hollandale, Mississippi, Noxubee National Wildlife Refuge, Brooksville, Mississippi; the Property of Mr. C. Clark Young, West Point, Mississippi; Tensas National Wildlife Refuge, Tallulah, Louisiana; Catahoula National Wildlife Refuge, Jena, Louisiana; and Grand Cote National Wildlife Refuge, Marksville, Louisiana. Managed moist-soil wetlands varied in area, were fallowed cropland or idled ponds, and had functioning water control structures and levees.

To monitor water quality of effluents from moist-soil wetlands, in July 2010 we identified 5 wetlands in the north Delta region of Mississippi. The locations of these wetlands are: Tallahatchie National Wildlife Refuge, Macel, Mississippi; Property of Dr. Ronal Roberson, Tippo, Mississippi; Charleston Farms Wetland Complex, Charleston, Mississippi; Lone Cypress Wetland Complex, Oxberry, Mississippi; and Property of Mr. Robert Brittingham, Dwiggins, Mississippi.

Field and Analytical Methods

We estimated yield of crayfish in moist-soil wetlands from April to July 2011. We set baited pyramid-style crayfish traps at a density of 25 traps ha^{-1}. Traps were baited and checked for crayfish after 24 hours. All crayfish in traps were taken back to the lab where individuals were sexed, identified to species, weighed (g), and measured for carapace length (mm). Average daily yield was estimated as kg ha^{-1}. Our sampling efforts were limited to no more than 6 visits per site in 2011 because flooding of the Mississippi River limited access to many sites.

To create operating budgets and estimate break-even selling prices of crayfish, we estimated daily yield (kg ha^{-1}) of crayfish from moist-soil wetlands as the average of daily yield estimates from all sampled wetlands from 2009-2011. We modified 2012 enterprise budgets for rice production in Mississippi in the Mississippi State Budget Generator version 6.0 (Spurlock and Laughlin 2008) to reflect costs associated with moist-soil wetland management and harvest of crayfish. These operating budgets and break-even selling prices were then compared to current enterprise budgets for production of crayfish in planted rice-fields of Louisiana (Boucher and Gillespie 2012).

We recruited 149 volunteers from the Starkville community to evaluate the acceptability of cooked crayfish tail meat at the Garrison Sensory Laboratory with cooperation for Dr. Wes Schilling of the Department of Food Science, Nutrition and Health Promotion. Panelists evaluated crayfish harvested from moist-soil wetlands and crayfish harvested from commercial rice-crayfish production fields for taste, texture, appearance, aroma, and overall acceptability based on a nine-point hedonic scale. The values for the scale were: 1, dislike extremely; 2, dislike very much; 3, dislike moderately; 4, dislike slightly; 5, neither like nor dislike; 6, like slightly; 7, like moderately; 8, like very much; and 9 like extremely We used a randomized complete block design with panelists as blocks to evaluate differences ($\alpha = 0.05$) in overall consumer acceptability of the two crayfish tail meat samples.

We monitored nitrate (NO_3-N) nitrite (NO_2-N), ammonium (NH_3-N), soluble reactive phosphorus (SRP), particulate phosphorus (PP), total inorganic phosphorus (TP) and total suspended solid (TSS) concentrations (mg l^{-1}) within each wetland and in wetland effluent beginning July 2010. We installed storm water samplers at the water control structure of each wetland. These samplers are designed to take a effluent sample when precipitation was significant enough to produce wetland discharged. We monitored weather data and river gaging station data and retrieved storm samples within 48 hours. An agriculture field adjacent to each wetland was also sampled for effluent water quality and grab samples were taken when significant flooding occurred on the field to warrant a water sample. Within 24 hours of sampling, aliquots of each sample were filtered through a 0.45 µm cellulose filter and NO_3-N, NO_2-N, NH_3-N, and SRP concentrations were determined colorimetrically on a Hach DR 5000 spectrophotomer according to appropriate protocols (APHA 2005). We digested unfiltered aliquots of each sample and determined TP colorimetrically. We then estimated PP as the difference between TP and SRP. Beginning in December 2010, in cooperation with the Water Quality Laboratory in the Department of Wildlife, Fisheries, and Aquaculture, we also determined NO_3-N and NO_2-N concentrations with a Lachat QuickChem 8500 Flow Injection Analysis System. We estimated TSS concentrations by filtering a known volume of sample through a pre-washed and dried 1.5-µm glass fiber filter. We then dried the sample-washed filter to a constant weight at 120 C. The difference in weight between the clean filter and the sample-washed filter was used to estimate the concentration of suspended solids in the sample. To evaluate differences in concentrations of nutrients and sediments in runoff samples from wetlands and agriculture fields, we conducted a repeated measures analysis of variance ($\alpha = 0.05$).

We used barometric pressure referenced data loggers (In-Situ Troll 300) to estimate depth of water at water control structures at the study wetlands. We then used the logged data and standard weir equations to estimate discharge (m^3 sec^{-1}) from these wetlands during storm events. We created hydrographs for each sampling event, estimated total volume (L) of runoff for each peak storm event, and estimated the average wetland area (ha). We then calculated loads (kg ha^{-1}) of nutrients and sediments from the total volume of water discharged during the peak event and the measured nutrient and sediment concentrations as mentioned above.

RESULTS and DISCUSSION

Average daily yield of crayfish in 2011 was 3.64 kg ha^{-1} (n =18, CV = 32.8%). Average daily yields of crayfish from moist-soil wetlands for all three study years (2009-2011) ranged from 0.08 kg/ha to 23 kg/ha with an overall mean yield of 2.73 kg/ha (n = 42, CV = 21%). Wetlands located in Louisiana typically exhibited greater yields (Table 1).

In rice-crayfish commercial systems in Louisiana, farmers typically observe total yields of 600 kg during a 75 day season and therefore experience daily yields of 10 kg ha^{-1}. A typical harvest season in moist-soil wetlands will be shorter (i.e., 40 days) to ensure water management practices are followed that encourage optimal vegetation establishment. Our estimated average daily yield of crayfish harvested from moist-soil wetlands (2.73 kg ha^{-1}) is considerably lower than extensive culture practices in Louisiana. However, we determined that total fixed expenses associated with commercial systems (Table 2; Boucher and Gillespie 2012) were considerably higher compared to our estimates of fixed expenses associated with harvesting natural populations of crayfish from moist-soil wetlands (Table 3). Harvesting crayfish from moist-soil wetlands can potentially incur a cost of \$682 ha^{-1} (\$275 $acre^{-1}$) for a 40 season whereas commercial operations incur costs of \$1455 ha^{-1} (\$587 $acre^{-1}$) for a 75 season. Although the break-even selling price needed to recover fixed costs for harvesting crayfish from moist-soil wetlands (i.e., \$6.38 kg^{-1}) is considerably more than current break-even selling prices for Louisiana crayfish (\$2.75 kg^{-1}) these hypothetical break-even prices are still lower than those experienced by consumers in north Mississippi (e.g., >\$8 kg^{-1} at Brewski's and the Crawfish Hole, Starkville, MS; A. Alford, personal observation).

We did not detect a difference in mean overall acceptability of abdominal muscle samples between the two harvest practices (Table 4; F = 0.99, p > 0.05). Consumers on average rated overall acceptability of both abdominal muscle samples between 7.0-7.2 which corresponded to "like moderately" on the nine-point hedonic scale. Additionally, we did not detect differences in consumer scores for flavor (F = 0.04, p > 0.05) and texture (F = 1.85, p > 0.05) with both descriptors having scores characteristic of "like slightly" to "like moderately". We did detect statistically different mean scores for aroma (F = 5.77, p = 0.016) and appearance (F = 5.48, p = 0.019) with commercial crayfish samples receiving greater consumer scores for aroma and appearance compared to wild caught crayfish samples. However, the mean consumer scores for both descriptors across harvest practices were characteristic of 'like moderately' on the nine-point hedonic scale.

During the impounded period in fall-spring 2010-2011, we did not detect significant differences in average concentrations of total inorganic orthophosphorus (TP), soluble reactive phosphorus (SRP) and ammonia-nitrogen (NH_3) in effluent samples from the two field types (p > 0.05) although these nutrients exhibited a significant increase over time (Table 5). We did detect a significant difference (p = 0.002) in average concentrations of total suspended solids (TSS) between the field types with moist-soil wetlands exporting 80% less solids than agriculture fields. We did detect significant temporal differences (p = 0.03) in average concentrations of nitrate-nitrogen (NO_3) and between the two field types.

During fall-spring 2011-2012, we found concentrations of NH_3 were similar in effluent samples from the two field types and over time (Table 5). Similar to 2011, TSS concentrations were 90% greater in effluent samples from agriculture fields compared to moist-soil wetlands. Concentrations of TP, SRP, and NO_3 differed significantly between the two field types and TP and DIP also varied across the flooded period (p <0.005).

Our estimates of annual nutrient loads released by moist-soil wetlands during winter-spring (Figure 1) suggest that TP, SRP, and NO_3 loadings of >1 kg/ha/year exceed current assumed average total annual loads from wetlands in Mississippi (Shields et al. 2008).

We concluded that concentrations of most nutrients and sediments were significantly lower in runoff from moist-soil wetlands compared to runoff from agriculture fields in the surrounding landscape. Seasonally flooded plant communities concentrate nutrients and sediments from agricultural and other non-point sources of run-off (Maul and Cooper 2000, Manley et al. 2009). Agriculture fields have little crop cover after harvest and therefore little organic material is available for decomposition. Therefore, it is likely that strategic location of moist-soil wetlands amid farmed lands can reduce transport of sediments and other nutrients into surrounding watersheds and thus enhance water and environmental qualities. However, concentrations of TP in wetland effluent exceeded EPA recommendations of 0.128 mg/l under 303(c) of the Clean Water Act. Additionally, our estimates of nutrient loadings for TP, SRP and NO_3 exceed current assumed loading rates for wetlands in Mississippi (Shields et al. 2008). Because wetland soils have a finite capacity to store phosphorus and this nutrient is linked to environmental degradation such as the development of the hypoxic zone in the Gulf of Mexico (Rabalais et al. 2002), strategies such as periodical soil manipulations may need to be developed to increase the phosphorus storage capacity of these wetlands.

Quantifying ecosystem services provided by moist-soil management will facilitate fulfillment of proposed surface water quality regulations (i.e., total maximum daily loads). Finally, understanding the economic benefits of crayfish harvests from moist-soil wetlands will likely encourage establishment and management of these wetlands and therefore increase habitat for waterfowl and other wetland wildlife throughout the MAV.

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Table 1. Crayfish harvest statistics from 42 moist-soil wetlands in the Mississippi Alluvial Valley and Interior Flatwoods April-June 2009 – 2011..

Year	Site	State	kg ha^{-1}
2009	Coldwater NWR	MS	1.23
2009	York Woods #1	MS	3.62
2009	York Woods #2	MS	1.45
2009	Trim Cane WMA	MS	1.22
2009	Property of C. Clark Young	MS	1.13
2009	Noxubee NWR	MS	0.88
2009	Morgan Brake NWR	MS	2.69
2009	Yazoo NWR	MS	3.65
2009	Panther Swamp NWR	MS	2.20
2010	Cache River NWR #1	AR	0.26
2010	Cache River NWR #2	AR	0.85
2010	Wapanocca NWR #1	AR	0.05
2010	Wapanocca NWR #2	AR	7.28
2010	Coldwater NWR	MS	0.70
2010	Property of Ronal Roberson	MS	9.13
2010	Property of C. Clark Young	MS	2.00
2010	Noxubee NWR	MS	1.05
2010	Morgan Brake NWR	MS	0.47
2010	Yazoo NWR	MS	1.40
2010	Panther Swamp NWR	MS	1.22
2010	Tensas NWR	LA	2.30
2010	Catahoula NWR #1	LA	1.68
2010	Catahoula NWR #2	LA	1.95
2010	Grand Cote NWR	LA	2.36
2011	Otter Slough WMA #1	MO	7.17
2011	Otter Slough WMA #2	MO	0.68
2011	Wapanocca NWR #3	AR	0.65
2011	Wapanocca NWR #1	AR	3.40
2011	Wapanocca #2	AR	5.87
2011	Noxubee NWR #1	MS	0.45
2011	Noxubee NWR #2	MS	1.50
2011	Property of C. Clark Young #1	MS	0.63
2011	Property of C. Clark Young #2	MS	1.03
2011	Morgan Brake NWR #1	MS	4.21
2011	Morgan Brake NWR #2	MS	5.10
2011	Yazoo NWR #1	MS	0.33
2011	Yazoo NWR #2	MS	0.34
2011	Panther Swamp NWR	MS	0.49
2011	Tensas NWR	LA	1.38
2011	Catahoula NWR #2	LA	6.60
2011	Catahoula NWR #1	LA	23.02
2011	Grand Cote NWR	LA	2.68

Table 2. Estimated fixed costs associated with rice-crayfish commercial harvest systems in Louisiana. From Boucher and Gillespie 2012.

Table 3.A Estimated Costs and Returns per Acre, Single Crop Crawfish, Owner-Operator, Southwest Louisiana, 2012.

ITEM	UNIT	PRICE	QUANTITY	AMOUNT
		dollars		dollars
INCOME				
Crawfish (Dec - May)	lbs		600.0000	

TOTAL INCOME				
DIRECT EXPENSES				
CUSTOM				
Airplane seed	cwt	5.60	1.4000	7.84
Global pos. system	acre	0.35	2.0000	0.70
Airplane fert	cwt	6.25	0.7500	4.68
BAIT				
Crawfish bait (fish)	lbs	0.40	175.0000	70.00
Manuf. crawfish bait	lbs	0.26	180.0000	46.80
FERTILIZER				
Urea (45%)	lbs	0.19	75.0000	14.25
HIRED LABOR				
Irrigation labor	hour	9.60	1.8500	17.76
OTHER				
Hip boots	pair	74.95	0.0083	0.62
Sacks	each	0.40	18.1824	7.27
SEED				
Rice seed	lbs	0.45	120.0000	54.00
OPERATOR LABOR				
Tractors	hour	9.60	0.3491	3.35
Self-Propelled Eq.	hour	9.60	6.2605	60.10
IRRIGATION LABOR				
Crawf irrig single	hour	9.60	0.3960	3.80
DIESEL FUEL				
Tractors	gal	3.50	1.7397	6.08
Self-Propelled Eq.	gal	3.50	1.0075	3.52
Crawf irrig single	gal	3.50	71.2224	249.27
GASOLINE				
Self-Propelled Eq.	gal	3.50	1.5975	5.59
REPAIR & MAINTENANCE				
Implements	acre	1.71	1.0000	1.71
Tractors	acre	0.72	1.0000	0.72
Self-Propelled Eq.	acre	3.17	1.0000	3.17
Crawf irrig single	acin	0.15	33.0000	4.95
Crawf pond&eq single	acre	7.18	1.0000	7.18
INTEREST ON OP. CAP.	acre	14.46	1.0000	14.46

TOTAL DIRECT EXPENSES				587.87

Table 3. Estimated fixed costs associated with harvesting crayfish from moist-soil wetlands in the Mississippi Alluvial Valley and Interior Flatwoods.

Table 3.F Estimated costs per acre
Moist-soil Average yield owner operator labor
, Mississippi, 2012

ITEM	UNIT	PRICE	QUANTITY	AMOUNT
		dollars		dollars
DIRECT EXPENSES				
HARVEST AIDS				
TRAPS	each	8.25	12.0000	99.00
OTHER				
Waders	pair	69.99	0.2800	19.60
Ice Chest 48qt	each	22.88	0.0300	0.69
Sacks	each	0.30	2.0000	0.60
BAIT				
Manuf. crawfish bait	lbs	0.24	120.0000	28.80
OPERATOR LABOR				
Self-Propelled	hour	9.60	10.0875	96.84
GASOLINE				
Self-Propelled	gal	3.50	5.0437	17.64
REPAIR & MAINTENANCE				
Self-Propelled	acre	10.22	1.0000	10.22
INTEREST ON OP. CAP.	acre	2.20	1.0000	2.20
TOTAL DIRECT EXPENSES				275.59

Table 4. Mean scores (N=149) for consumer acceptability of cooked abdominal meat from commercially harvested crayfish and wild crayfish captured from moist-soil wetlands.

	Source	
	Commercial	Wild
Appearance	7.4[a*]	7.1[b]
Aroma	7.3[a]	7.0[b]
Flavor	6.9	6.8
Texture	7.5	7.3
Overall	7.2	7.0

[*] Means within rows followed by different letters are significantly different ($p < 0.05$).

Table 5. Mean (95% confidence interval) concentrations (mg/l) of nutrients and sediments in agriculture and wetland runoff samples for December-May 2011 and 2012. Estimates are untransformed $\log_e$ values for field types computed from least-squared means in a repeated measures model.

	Agriculture Fields	Moist-soil Wetlands
Variable[a]	2011	
TP*	0.30 (0.08, 0.43)	0.25 (0.07, 0.34)
SRP*	0.05 (0.02, 0.09)	0.06 (0.02, 0.11)
NO_3***	0.53 (0.27, 1.09)	0.08 (0.04, 0.17)
NH_3*	0.06 (0.02, 0.10)	0.06 (0.02, 0.09)
TSS**	78.2 (35.6, 143.6)	15.4(6.39, 26.35)
	2012	
TP***	0.46 (0.27, 0.77)	0.25 (0.16, 0.39)
SRP***	0.06 (0.03, 0.14)	0.06 (0.03, 0.13)
NO_3**	0.53 (0.34, 0.83)	0.17 (0.11, 0.27)
NH_3	0.09 (0.05, 0.15)	0.05 (0.03, 0.10)
TSS**	129 (66.1, 252)	12.3 (6.46, 23.3)

[a] * = Significant ($p<0.05$) across time, ** = significant between habitats, *** = significant across time and between habitats.

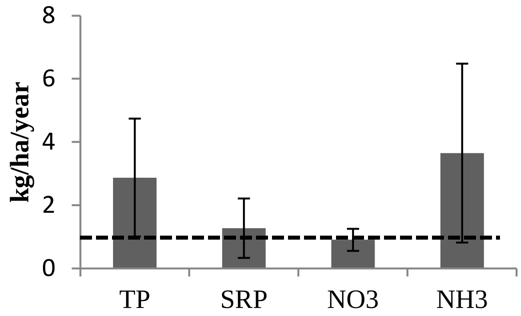

Figure 1. Average total annual loads (kg/ha/year ± SE) delivered by moist-soil wetlands in Mississippi during December 2010- May 2011. The dashed line represents 1 kg/ha/year, the current assumed total annual loads of TP and NO_3 delivered to the lower Mississippi River by wetlands in Mississippi.

SIGNIFICANT RESEARCH FINDINGS

During spring 2011, we estimated average daily yield of crayfish from 18 moist-soil wetlands in Arkansas, Louisiana, Mississippi, and Missouri. Average daily yield in 2011 was 3.64 kg/ha (CV = 33%). This estimate was slightly greater and more variable than the estimated yield from Mississippi wetlands in 2009 (i.e., 1.75 kg ha^{-1}; CV = 16%, $n = 9$) and wetlands in Arkansas, Louisiana, and Mississippi in 2010 (i.e., 2.18 kg ha^{-1};CV = 30%, $n = 15$) .

Our comparisons of operating budgets from the two harvest systems indicated that rice-crayfish systems incur $1455 in direct expenses per hectare whereas crayfish harvest operation in moist-soil wetlands incur $682 direct expenses per hectare. Although fixed expenses are lower in harvest operations from moist-soil wetlands, lower yields increased the break-even selling prices from $2.75 kg^{-1} in rice-crayfish systems to $6.38 kg^{-1} in moist-soil harvest systems. These prices, however, are still less than those observed in regions of the Southeastern United States outside of Louisiana.

To determine if crayfish harvested from moist-soil wetlands are an acceptable seafood product relative to commercially harvested crayfish, we conducted a consumer acceptability panel in May 2011. We found that crayfish from both sources were well liked and did not differ significantly ($p > 0.05$) in overall consumer acceptability.

In July 2010, we installed water quality monitoring stations at 5 wetlands and 5 agriculture fields. We monitored concentrations of nutrients and sediments exported from these habitats during storm events in December-March of 2010-2012. We determined that wetlands exported significantly less total suspended solids and NO_3 than agriculture fields in 2010-2011 whereas all parameters except for NH_3 were significantly lower in wetland effluent compared to agriculture fields in winter 2011-2012. We were able to calculate loads (kg ha^{-1}) from wetland habitats during the study years and determined that total annual loads of nutrients were slightly greater than currently assumed loading values of wetlands in Mississippi (i.e., 1 kg ha^{-1}).

PUBLICATIONS, PRESENTATIONS, and OUTREACH

Alford, A.B., R. Kaminski, J.L. Avery, L.R. D'Abramo. 2011. Characteristics of harvestable crayfish populations in managed wetlands of the Lower Mississippi Alluvial Valley. American Fisheries Society. Seattle, WA.

Alford, A.B. Paddling and Canoe Landowner Workshop. Louisiana State University AgCenter and Mississippi State University Natural Resources Enterprises. Monroe, LA. 2011.

Alford, A.B., R.M. Kaminski, R. Kroger, L.R. D'Abramo, and J. Avery. 2011. Ecosystem services derived from moist-soil management. Poster presentation. Mississippi Chapter of the Wildlife Society. Louisville, MS, October 4-5, 2011.

Alford, A.B. R. Kroger, and R.M. Kaminski. 2012. Nutrient characteristics of moist-soil wetlands in agricultural landscapes. Oral presentation. Mississippi Water Resources Conference. April 3-4, 2012. Jackson, MS.

Alford, A.B., R. Kaminski. 2012. Duck hole 'dads' (dat's crawdads). Mossy Oak Gamekeeper: Farming for Wildlife. Spring 2012.

Alford, A.B., S. Grado, and R. Kaminski. 2012. Crawfish: Another incentive to practice wetland conservation. Mississippi Ducks Unlimited Annual Convention. July 27, 2012. Natchez, MS.

AWARDS

Alford, A.B. John F. Skinner Memorial Award. 2011. American Fisheries Society.

Alford, A.B. James Kennedy Endowed Fellowship in Waterfowl and Wetlands Conservation. 2011. Mississippi State University.

TRAINING POTENTIAL AND INFORMATION TRANSFER

The proposed project provided necessary field and laboratory research for Amy Alford, a Ph.D. student in Department of Wildlife, Fisheries and Aquaculture (WFA), Mississippi State University. Mrs. Alford's field of interest is wetland ecology and aquatic ecosystem management. She also holds a M.S. degree in fisheries from the Department and her extensive aquatic ecology and population modeling background will aid in the successful implementation of the proposed research. The experience that Mrs. Alford gained through this research project has earned her a Research and Extension Associate appointment with the Louisiana Sea Grant College Program in Baton Rouge, LA.

We also encouraged landowners and land managers to observe water quality and crayfish sampling activities. We received field assistance from three landowners. We also involved high school students in crayfish harvest activities during the College of Forest Resources' sponsored summer camp. Mrs. Alford in a Natural Resources Enterprises sponsored workshop in Monroe, LA where she met with area landowners to discuss the potential for crayfish harvest from wetlands managed for wildlife habitat. We produced a popular article regarding crayfish harvests in moist-soil wetalnds for the Mossy Oak Gamekeeper monthly magazine. Mrs. Alford presented the economic analysis of crayfish harvest in moist-soil wetlands to members of the Mississippi Chapter of Ducks Unlimited at the annual convention in Natchez, MS. We believe that continuing our model of a combination of formal and informal training will increase the population of individuals aware of wetland conservation principles.

STUDENT TRAINING

Name	**Level**	**Major**
Amy B. Alford (Co-PI)	Ph.D.	Forest Resources
John Perron (Wage)	B.S.	WFA
Kelsey Brock (Wage)	B.S.	Speech Pathology
Candice Bogen	B.S.	WFA

FUTURE RESEARCH

This report summarizes the results of our three-year research project. Amy Alford, the PhD candidate and Co-PI on the project is currently preparing the dissertation from this research and plans on defending in spring 2013. We hope that through the extension and outreach activities that we have participated in and the future peer-reviewed manuscripts that will be produced from this research that innovative approaches similar to ours will be made to quantify additional ecosystem services from specific habitat management practices.

Acoustic Measurements for Monitoring Fine Suspended Sediment in Streams

Basic Information

Title:	Acoustic Measurements for Monitoring Fine Suspended Sediment in Streams
Project Number:	2012MS157B
Start Date:	3/1/2012
End Date:	5/31/2013
Funding Source:	104B
Congressional District:	1st
Research Category:	Water Quality
Focus Category:	Water Quality, Sediments, Surface Water
Descriptors:	None
Principal Investigators:	James P. Chambers, Wayne O Carpenter, Cristiane Queiroz Surbeck

Publications

1. Quarterly Reports 2012-2013 to Mississippi Water Resources Research Institute, Mississippi State University, Mississippi State, MS.
2. Chambers, J.P., Kleinert, D.E., Carpenter, W.O., Goodwiller, D.G. and Kuhnle, R.A., "Using Acoustic Measurements as a Surrogate Technique for Measuring Sediment Transport" In Proceedings of the 2013 MWRC, Jackson, MS, April 3-4, 2012, http://www.wrri.msstate.edu/pdf/2012_wrri_proceedings.pdf, pg. 231.
3. Chambers, J. "Ultrasonic Measurements of Clays and Silts Suspended in Water" submitted for presentation, Acoustical Society of America fall conference, October 2012.
4. Quarterly Reports 2012-2013 to Mississippi Water Resources Research Institute, Mississippi State University, Mississippi State, MS.
5. Chambers, J.P., Kleinert, D.E., Carpenter, W.O., Goodwiller, D.G. and Kuhnle, R.A., "Using Acoustic Measurements as a Surrogate Technique for Measuring Sediment Transport" In Proceedings of the 2013 MWRC, Jackson, MS, April 3-4, 2012, http://www.wrri.msstate.edu/pdf/2012_wrri_proceedings.pdf, pg. 231.
6. Chambers, J. "Ultrasonic Measurements of Clays and Silts Suspended in Water" submitted for presentation, Acoustical Society of America fall conference, October 2012.
7. Final Technical Report, 2013. Chambers, J.P., C.Q. Surbeck, and B. Carpenter, Acoustic Measurements for Monitoring Fine Suspended Sediment in Streams. Final technical report submitted to Mississippi Water Resources Research Institute, Mississippi State, MS., 16 pgs.

Acoustic Measurements for Monitoring Fine Suspended Sediment in Streams

A Final Project Report to the
Mississippi Water Resources Research Institute

Conducted by
James P. Chambers
Associate Professor
Department of Mechanical Engineering

Cristiane Q. Surbeck, P.E., Ph.D.
Assistant Professor
Department of Civil Engineering

Brian Carpenter
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National Center for Physical Acoustics

The University of Mississippi

June 30, 2013

1 *Abstract*

The use of ultrasonic acoustic technology to measure the concentration of fine suspended sediments has the potential to greatly increase the temporal and spatial resolution of sediment measurements while reducing the need for personnel to be present at gauging stations during storm events. The conversion of high-frequency acoustic attenuation data to suspended silt and clay concentration has received relatively little attention in the literature. In order to improve the state of knowledge, a laboratory investigation was undertaken by the University of Mississippi (National Center for Physical Acoustics and Depts. of Mechanical and Civil Engineering) in cooperation with the USDA-ARS National Sedimentation Laboratory. In Laboratory experiments, two immersion transducers were used to measure attenuation from 20 MHz acoustic signals propagated through known concentrations of suspended clay (smectite and kaolinite) and silt particles. The resulting data includes attenuation values for a wide range of concentrations (0.3 – 14 g/L) and particle sizes (0.011 – 20 micron diameter). The Lab data was then utilized with a field deployed system in USGS monitored sites to monitor unknown concentrations of suspended fine sediments under realistic flow conditions (after storm events).

2 *Budget*

2.1 Budget Requested

The budget requested from Federal funds, was $20,000 (direct costs) with an additional $20,000 requested from MWRRI, and the non-Federal matching was $20,000 by the University of Mississippi in the form of salary (both faculty release and direct contributions) as well as fringe benefits, and indirect costs.

2.2 Budget Expended

The budget expended from Federal funds, was $ 40,000 (direct costs), and the non-Federal matching was $ 21,978.07 by the University of Mississippi in the form of salary (Both direct and faculty release) as well as fringe benefits and indirect costs. The breakdown of expended funds is shown in Table 2.1.

Table 2-1. Summary of Budget Expended.

Cost Category	Federal - USGS ($)	Federal - MSU ($)	Non-federal (matching by UM) ($)	Total ($)
1. Salaries and wages	$13,440.99	$11,155.14	$8,118.71	$32,714.84
2. Fringe benefits	$763.01	$2,830.86	$2,885.93	$6,479.80
3. Supplies, Travel, Tuition	$5,796.00	$0	$93.51	$5,889.51
4. Total direct costs	$20,000.00	$13,986.00	$11,098.15	$45,084.15
5. Indirect costs	$0	$6,014.00	$10,880	$16,893.92
6. Total estimated costs	$20,000.00	$20,000.00	$21,978.07	$61,978.07

3 *Students Involved, Presentations, and Publications*

Two students were involved in this project. See Table 3.1 for a description.

Table 3-1. Students involved in project.

Student Name	Major	Class	Involvement
Alex Kajdan	Civil Engineering	Master's	Lab and Field data collection and
Sam Di	Electrical Engineering	Junior	Lab data collection

Student Alex Kajdan used this study as his thesis topic. He is expected to graduate in June 2014. Portions of his work was presented at the 2013 Mississippi Water Resources Conference. Portions of this work dealing with the lab work and development of inversion routines to convert acoustic data to sediment data have been submitted as an archival publication in a peer-reviewed journal. It is anticipated that additional portions of the work described in this report involving field data collection and analysis will be written as an additional manuscript for submission in a peer-reviewed journal.

4 *Motivation for Project*

In many streams, suspended sediment transport is dominated by a few significant storms each year (Nelson and Benedict, 1950). These flood events are hard to predict and frequently occur at night, making it difficult and expensive to collect physical sediment samples. Traditional sampling techniques, including manually deployed isokinetic samplers and automatic pumping samplers, yield samples that are widely spaced in time and small in number. Ultrasonic measurement systems have the potential to measure the concentration of particles with a high degree of both spatial and temporal resolution, making them ideal for addressing the needs of those who rely on sediment data (Shen and Lemmin, 1996; Thorne et. al, 1995; Moore et. al 2013).

There is a relatively small body of literature relevant to the measurement of fine sediments with an ultrasonic system. Urick (1948) measured attenuation with 1, 5, and 15 MHz frequencies pulsed in 1 μs bursts in an aqueous suspension of kaolinite and finely ground quartz and concluded that viscous interactions were largely responsible for the observed acoustic absorption. Flammer (1962) measured attenuation due to the scattering of 2.5-25 MHz signals propagated through a suspension of 44-1000 μm particles. Measuring kaolinite/water suspensions with near 40% solid-volume at 3.5 and 7 MHz, Green and Esquivel-Sirvent (1999) found that increasing frequency produced only a moderate increase in attenuation and a slight increase in the concentration of maximum absorption.

This report describes experiments aimed at the development and use of a device that uses measurements of acoustic signal attenuation from clay and silt particles to determine the concentration. In laboratory tests, Silt and two clays, smectite and kaolinite, were used to represent typical constituents of the fine sediment load for streams. Field measurements were made at USGS instrumented sites.

5 Assembly, calibration and use of a new field grade acoustic device

5.1 Objectives

The objective of the Part A was confirmation of previous lab studies of the use of acoustic attenuation to observe sediment concentration(Carpenter et al. (2009)). The idea behind the work is that sound waves that propagate between two opposing transducers experience signal loss that is proportional to the concentration of sediment in the volume of water between the transducers. In the size range considered (1-100 microns), the kinetic energy of the water is sufficient that the sediments can be considered well mixed and sampling at a spot in the water column is representative of sampling of the entire water column. This is similar to shining a flashlight in a fog. Without water vapor there is a direct pathway for the light to go between two points. As more water is added, more light is lost by scattering from the water droplets.

5.2 Materials, Methods & Results, Lab Experiments

The experiments were performed in a 110 gallon (416.9 L) elliptically shaped (126 cm long, 85 cm wide, and 51.5 cm deep) recirculation tank at the University of Mississippi National Center for Physical Acoustics (NCPA).

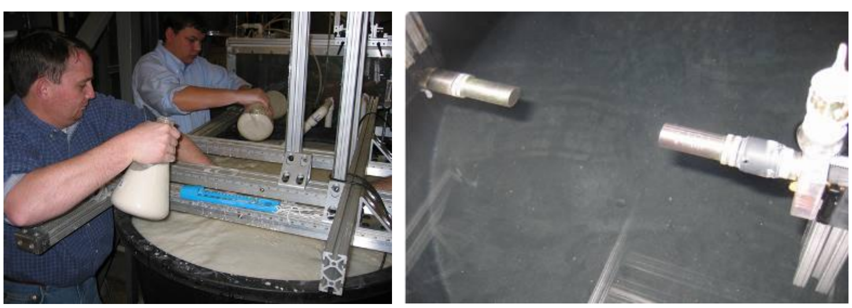

Figure 1: Laboratory measurement of acoustic attenuation.

The water was processed by an Aries HY-122B-DI Hydra deionizing system and treated with Sodium Hexametaphosphate (SH) to inhibit particle aggregation. The water and particles were re-circulated using a Weg ½ hp 220V centrifugal pump. Aluminum rails were mounted on top of the test tank to allow three-dimensional alignment of the transducers, and a point gauge was used to establish the water depth.

Two 20 MHz immersion transducers were aimed at each other to send and receive acoustic as shown in Figure 1. The transducers were placed 4.5 cm under the water surface and separated by 18 cm, which was determined by Carpenter et al. (2009) to be the distance that maximized the signal while allowing sufficient sensitivity at low concentrations. Statistical variations in backscattered signal due to the random relative motion of the particles were minimized by averaging 100 bursts per data set (Crawford and Hay, 1993). A Hewlett Packard 3314A function generator was used to generate a continuous 10 V_{peak} acoustic waveform. A Stanford Research Systems DS345 synthesized function generator created a modulated burst wave with a frequency of 200 kHz and amplitude of 1 V_{peak}. Both signals were sent to a Ritec GA 2500 gated RF amplifier to create a composite gated signal at 300 $V_{peak\text{-}peak}$. The resulting signal was sent and received with NDT Systems IBHG202 20 MHz immersion transducers with a ¼” (≈6mm) diameter. The near-field length, N, for the transducers was 13.6 cm and the half angle beam width was 0.365˚. With a separation of 18 cm, the transducers were in the far field and had no multipath effects from the water surface. The attenuated and backscattered acoustic signals were each amplified by an Olympus 5682 500 KHz - 25 MHz preamplifier and then captured with a National Instruments 2-channel, 8-bit, 1GS/s per channel oscilloscope card (NI PXI-PCI-5152). Using this knowledge a field grade acoustics prototype unit was designed and assembled as shown in Figure 2.

Figure 2: Field grade prototype acoustic attenuation system .

This unit was ultimately used to make measurements at bayous under surveillance by USGS. Before field tests commenced, however, the prototype unit was tested side by side with the laboratory grade equipment. That is, the transducers were mounted in a fixed bracket, shown in Figure 3 and the signal level between the two transducers were monitored as more and more sediment was added to a recirculation tank (Figure 4).

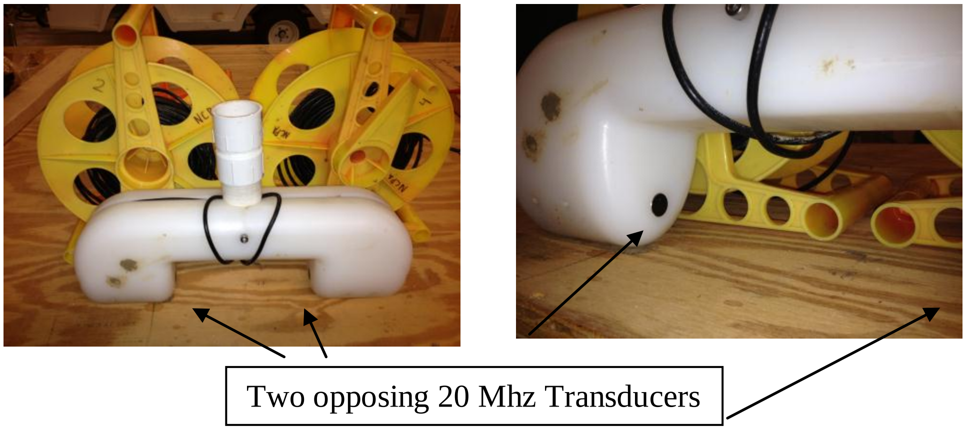

Figure 3: Transducer mount for field prototype system showing opposing transducers.

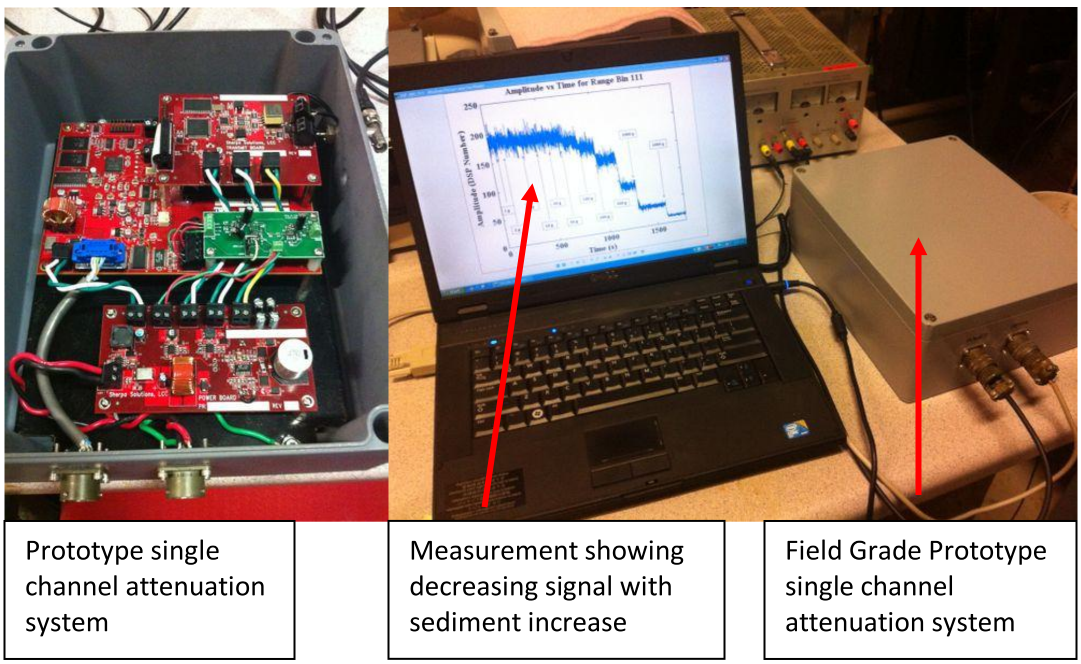

Figure 4: Field prototype system showing decreasing signal with increasing concentration.

Figure 5 shows detailed repeated measurements of signal level decrease (relative to clear water) with increasing concentration between laboratory grade equipment and the new field prototype system. Measurements also show the repeatability of measurements.

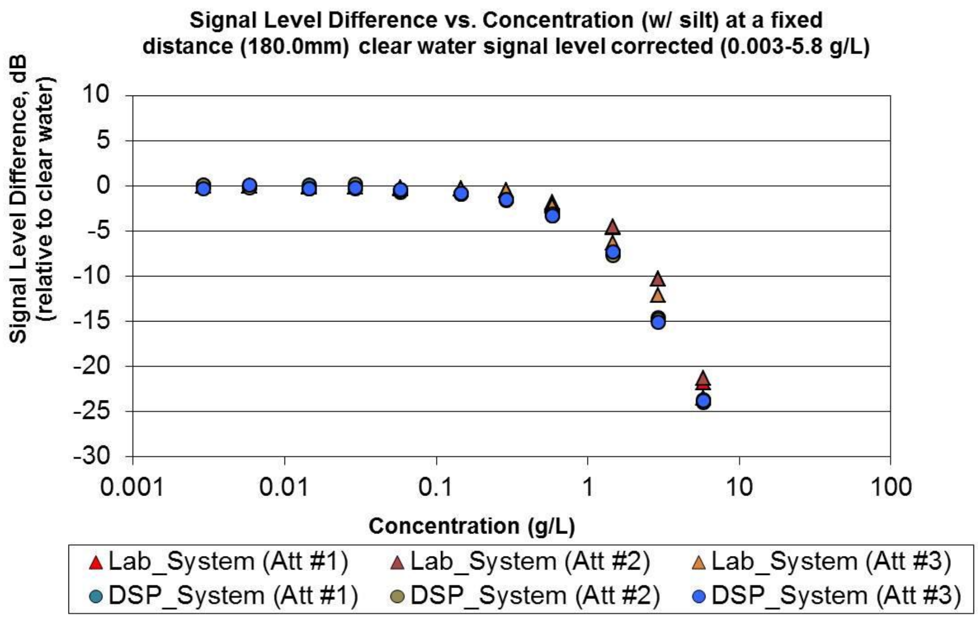

Figure 5: Comparison of Lab system and Field prototype (DSP) system showing decreasing signal with increasing concentration.

5.3 Materials, Methods & Results Field Experiments

After laboratory confirmation and calibration, the system was used in the field at USGS monitored sites as shown in Figure 6. Grab samples as well as data from a USGS automated sampler are being used as the standard to compare against acoustic predictions.

Figure 6: USGS instrumented field site at Harris Bayou near Aligator, Mississippi.

5.3.1 Field Locations

Site: 07288068 HARRIS BAYOU AT PALMER RD EAST OF ALLIGATOR, MS

Location: Lat 34°04'29.1", long 90°37'29.8" referenced to North American Datum of 1983, in SW ¼ SW ¼ SW ¼ sec.33, T.26 N., R.4 W., Coahoma County, MS, Hydrologic Unit 08030207.

Description of Site: This site is one of three that is continuously gauged by the United States Geological Survey (USGS). This is the largest of the three gauged sites on this particular bayou. This gauging station is located in the Yazoo Basin more closely known as the Big Sunflower Sub-basin. This station is used to monitor the stage height of the bayou as well as providing a place to obtain water samples during a storm event. There are two Isco samplers that are currently being used at this site, that allow the USGS to analyze water samples for nutrients, turbidity, and dissolved oxygen in the water. This Harris Bayou site is well maintained and is easily accessible. This particular bayou has relatively steady base flow, which is ideal for the acoustic device. The steady base flow of this bayou ensures that the signal produced by the transducer will not reflect off of the surface of the water causing inaccurate attenuation data.

- This picture shows the housing that is used by the USGS to store the Isco samplers along with the transmitting devices. The 20 MHz transmitting device will be housed in the facility during data collection.
- The USGS has allowed access to the facility throughout the duration of the project.

- The piping shown in this picture is used as a conduit for cables and tubing. The ends of the pipes are submerged. At the end of each pipe are the velocity meter and the tubing to collect water samples.
- There are roughly 50 feet of piping between the outfall location and the gage housing which could be used to co-locate the acoustic cabling.
- This point is roughly 6 feet downstream of the location of the 20 MHz acoustic device.

- This picture shows the structure that is located just upstream of the outfall point of the instrumentation that is already in place.
- Ideally, the 20 MHz transducers are placed at the same depth as the USGS's sampling devices.
- The 20 MHz system can be set to run in correspondence with the Isco samplers. This will allow us to obtain attenuation data at the same time that the water samples are being collected.

Associated Links:

- Water-Data Report 2011 (Harris Bayou 07288068) http://wdr.water.usgs.gov/wy2011/pdfs/07288068.2011.pdf
- Daily Stream Flow Conditions (Harris Bayou 07288068) http://waterdata.usgs.gov/ms/nwis/uv?site_no=07288068
- Water Quality Samples (Harris Bayou 07288068) http://nwis.waterdata.usgs.gov/usa/nwis/qwdata/?site_no=07288068

5.3.2 Field data collection

Figures 7 and 8 show acoustic and estimated concentration data from the field site after a storm event on March 5, 2013. One can note that the acoustic signal is increasing, indicating a decrease in sediment concentration with time. Bottle samples taken 10 min before this data set indicated concentrations of 0.8 g/L.

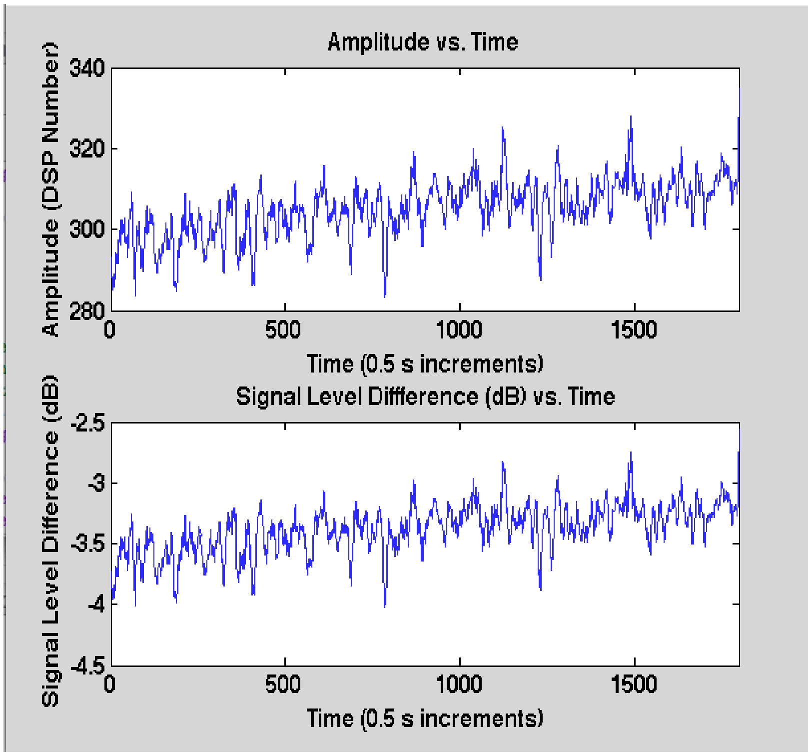

Figure 7: Raw data from acoustic signal (top) and conversion (bottom) to decibels (signal relative to clear water from 15-minute data run in field.

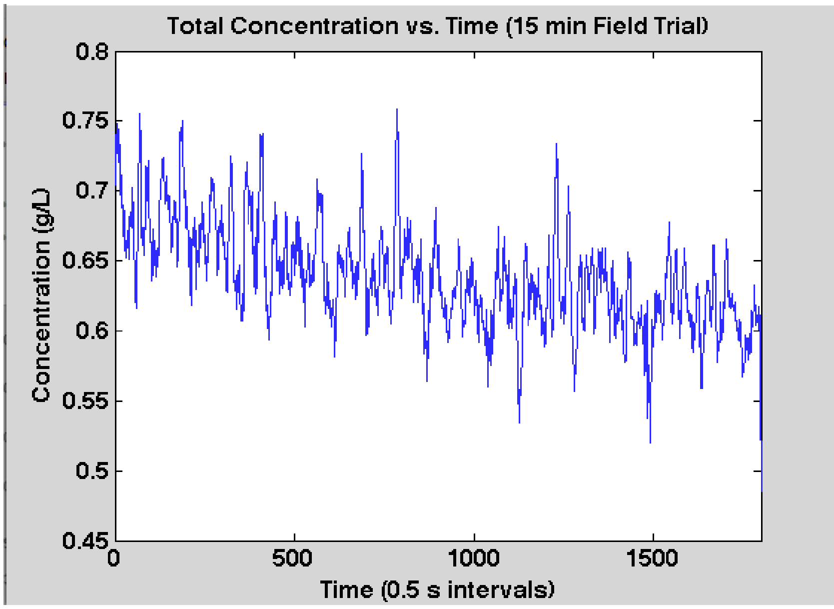

Figure 8: Concentration of sediment estimated from inversion of acoustic data using empirically derived inversion (Figure 5).

If one were predict the sediment concentration 10 min previous to the acoustic data one might expect a range of 0.74- 0.84 g/L based on the trend in the data. Comparison to USGS data on actual concentrations continued through the Spring. Figures 8 through 11 show additional data from field exercises along with grab samples. It should be noted that due to problems with hardware affecting source levels (now fixed), the system was calibrated against these grab samples for each data run. So it is not entirely surprising that there is good agreement between the acoustic and sediment data. However, what is extremely encouraging is that the data is self-consistent. That is, the acoustic system was calibrated with the grab samples but the grab samples and acoustic data remained fairly constant throughout the data set. The acoustic data tracked the sediment. Detailed comparisons between sediment concentration estimated from the acoustic data and bottle samples are ongoing and now that the hardware problems are fixed a lab based permanent calibration can be made.

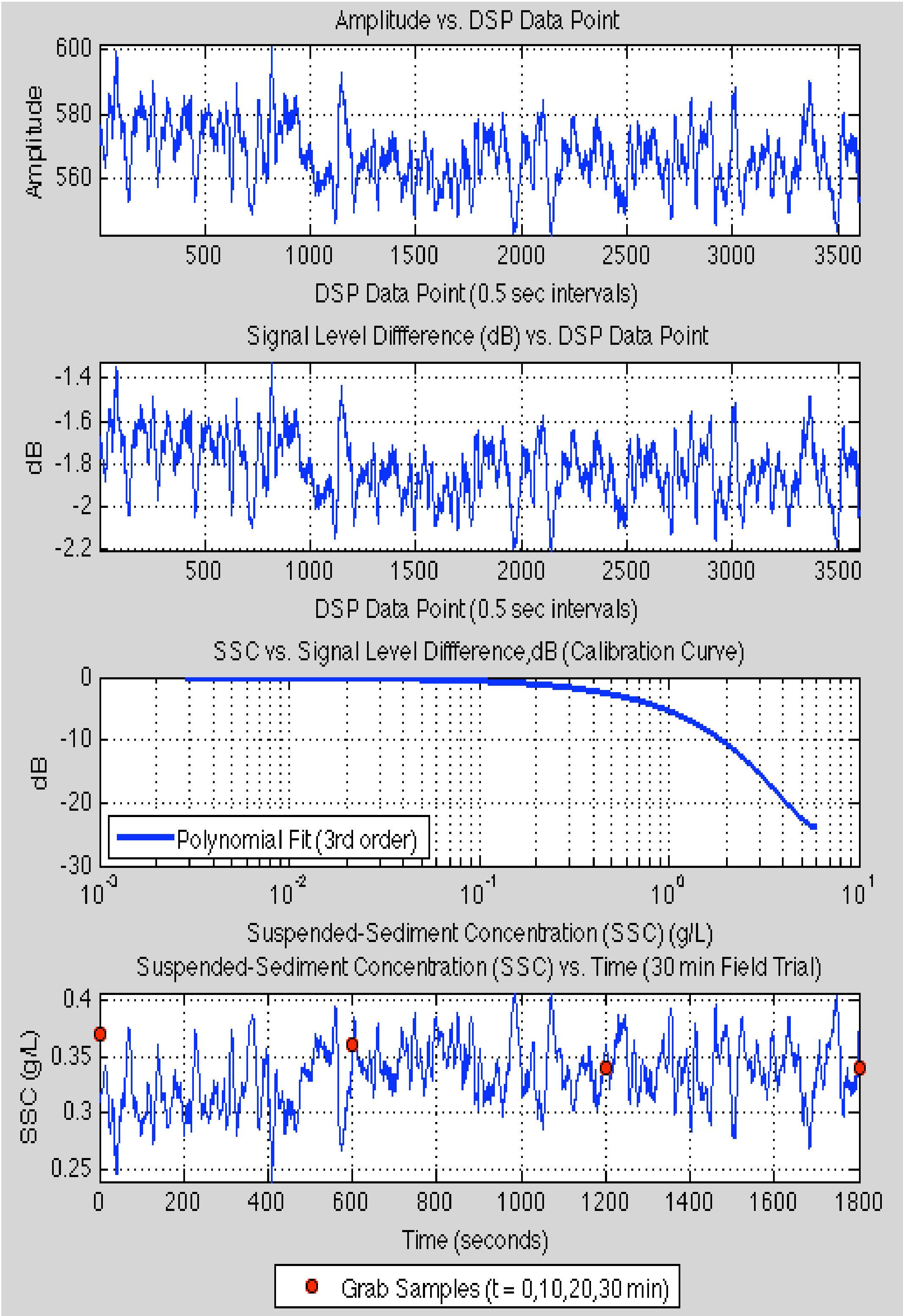

Figure 8: 1st (raw acoustic data) 2nd (conversion to dB reduction re to clear water) 3rd (calibration wrt concentration) 4th estimated concentration of sediment vs. time).

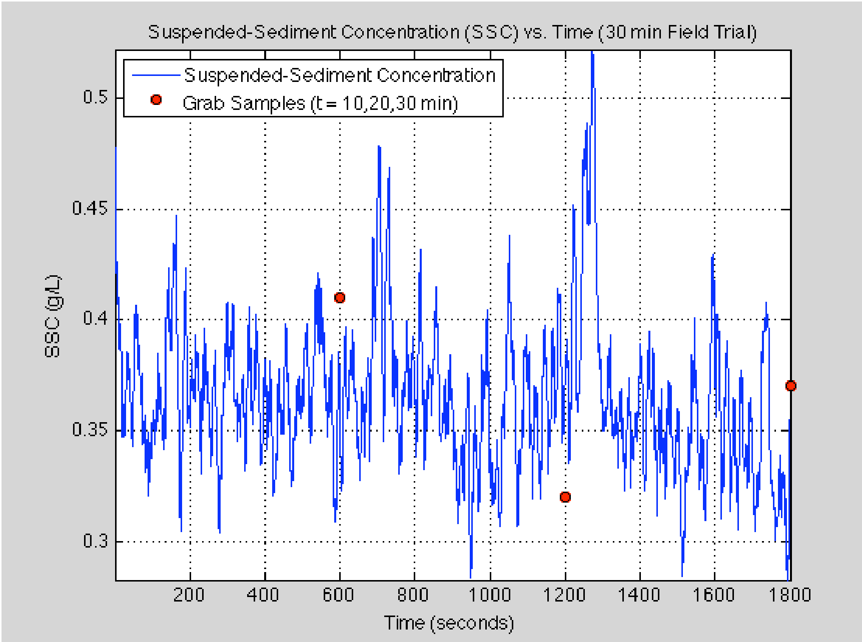

Figure 9: Estimated concentration of sediment over 30 minutes from inversion using empirically derived inversion.

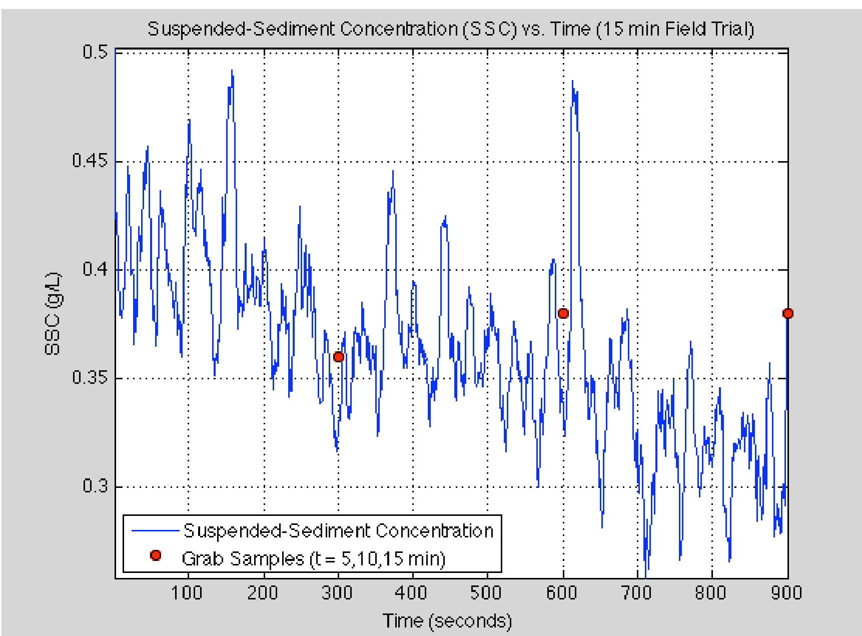

Figure 10: Estimated concentration of sediment over 15 minutes from inversion using empirically derived inversion.

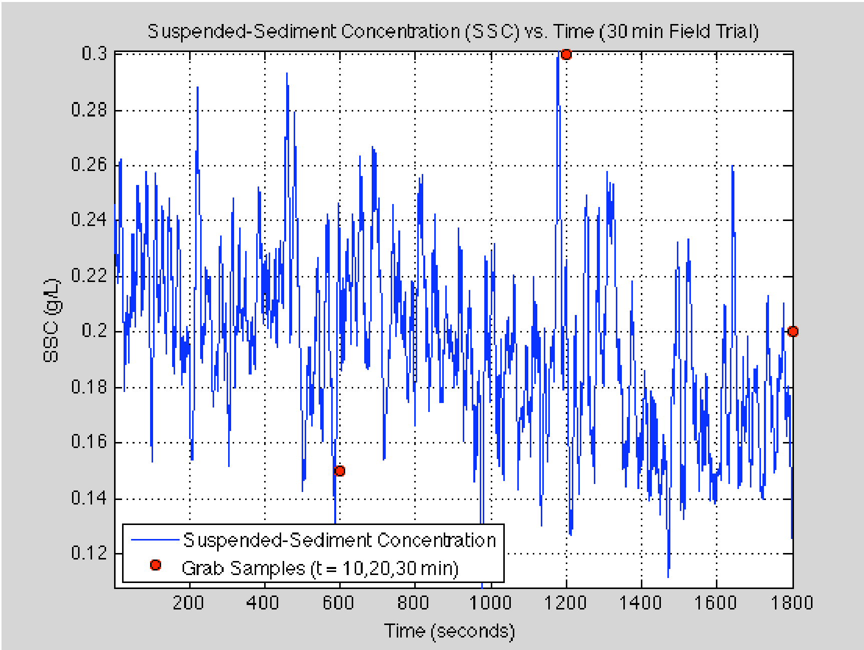

Figure 11: Estimated concentration of sediment over 30 minutes from inversion using empirically derived inversion.

While the MWRRI grant that funded this field work is now ending, the work (as well as Alex Kajdan's thesis) continues under a USDA grant to monitor sediment transport for erosion studies. The project resulted in three conference presentations, and an archival publication should follow from Alex Kajdan's thesis, which should be finished in Fall 2013 or Spring 2014.

6 *Conclusions*

A field grade acoustic system has been developed and used to monitor fine (1-100 micron) suspended sediments. The system was initially calibrated alongside laboratory grade equipment and then used at USGS monitored sites in the MS Delta. Preliminary measurements indicated quite good agreement between concentrations estimated from the acoustic system and more traditional bottle samples. Data collection and analysis is continuing as part of an ongoing Masters thesis and an allied USDA grant. This technology holds the promise of providing better temporal and spatial resolution of sediment flux.

6.1 Recommendations for Further Analysis and Future Research

The technology should continue to be used in the field and exposed to a wider audience of non-experts in acoustics. That is, engineers and managers tasked with monitoring sediment flux for agencies such as CoE, USGS, EPA, USDA, BoR, and others could benefit from this technology. As part of future work, the use of acoustics to simultaneously estimate concentration and particle size would be of value and steps toward that goal have been made in laboratory tests with a publication submitted. The inclusion of that work into a field prototype would expand the value of the technology even more.

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Analysis of Precipitation Variability and Related Groundwater Patterns over the Lower Mississippi River Alluvial Valley

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Mississippi Water Resources Research Institute (MWRRI) / US Geological Survey

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Analysis of Precipitation Variability and Related Groundwater Patterns Over the Lower Mississippi River Alluvial Valley

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Abstract

The lower Mississippi River alluvial valley (LMRAV) is characterized by a humid sub-tropical climate, with agriculture playing a major role in land cover, economic, and hydrologic processes. A large portion of the agricultural land relies on rainfall for crop sustainability, leading to an increased sensitivity of crop production to atmospheric processes; therefore, it is critical to quantify the frequency and distribution of precipitation over the LMRAV. Due to the unknown specifics of meteorological modifications in the region, along with continually changing anthropogenic needs on the groundwater system, it is difficult for water resource managers to make sound decisions for future water sustainability. This project will address water availability over the LMRAV through an assessment of historical precipitation variability, including quantification of rainfall patterns using both radar-derived and surface measured rainfall data. This information will be used to estimate current and future precipitation availability over the region, which will be compared with regional groundwater observations to determine the level of interaction between rainfall and sub-surface water levels. Results of this project will aid in determining the natural limits to water resource availability, as well as the relationship between regional precipitation and groundwater variability.

1. Project Overview

The lower Mississippi River alluvial valley (LMRAV is well recognized as a major agricultural center of the US. The area is characterized by extremely fertile soils deposited through repeated flooding of the Mississippi River; therefore, farming plays a critical role in regional economic sustainability. In Mississippi alone, the alluvial valley boasts 80% of the states total agricultural production (YMD, 2006), which is substantial given that Mississippi is the fourth largest producer of cotton and rice in the United States (USDA, 2008).

Agriculture is highly dependent on climatological variables related to the surface energy and water budgets (i.e., rainfall, evaporation, etc.); however, studies have shown that agriculture can have an influence on regional weather variability through land use and vegetation patterns (Brown and Arnold, 1998). Specifically, variations in soil and vegetation type can influence energy and moisture transport into the atmospheric boundary layer through evapotranspiration, albedo, surface roughness, and heat and moisture fluxes (Hong et al., 1995; Segal et al., 1988; Ookouchi et al., 1984; Rabin et al., 1990; Mahfouf et al., 1987; Boyles et al., 2007; Dyer, 2011). These energy and moisture fluxes all have strong influences on the generation and strength of mesoscale circulations, and therefore precipitation; therefore, variations in land use and/or soil type can lead to modifications to regional rainfall patterns (Anthes, 1984; Koch and Ray, 1997; Boyles et al., 2007; Dyer, 2011).

Substantial soil and vegetation contrasts exist within the lower Mississippi River alluvial valley due to extensive deforestation before 1940 (MacDonald et al., 1979), and Dyer (2011) has shown that these regional soil and vegetation boundaries can influence local rainfall patterns. These rainfall patterns are modified due to variations in the sensible and latent heat fluxes, especially at the end of the growing season, leading to abnormal temperature variations in the floodplain (Raymond et al., 1994; Brown and Wax, 2007). The agricultural nature of the LMRAV makes it extremely sensitive to water resources; therefore, precipitation variability is of key concern to sustainable crop production. This is especially true in the warm season when biomass growth and water requirements are maximized while rainfall patterns are determined primarily by high intensity convective storms with limited duration and extent. As a result of these precipitation patterns, irrigation from surface and groundwater sources is often necessary to maintain a suitable level of soil moisture for crop production. This irrigation is costly in terms of both equipment and natural resources, and studies have shown that current irrigation practices are not sustainable (YMD, 2008). In fact, given current levels of groundwater extraction for agricultural irrigation, many areas of Mississippi and Arkansas will soon run out of viable groundwater sources, requiring other measures to be taken (i.e., surface water transport).

Although there is a push towards more efficient irrigation technologies and practices, the driving factor in water resources management remains precipitation. In a very real sense, rainfall is the only renewable source of water to the LMRAV, providing recharge to both surface and subsurface systems through surface runoff and infiltration processes. Climate predictions show that the LMRAV will likely experience a general decrease in warm-season precipitation over the coming decades, which will place additional stress on already limited regional surface and groundwater resources during the growing season (IPCC, 2007). However, other studies indicate that extreme precipitation events have increased in frequency in recent decades (Karl, 1998; Milly et al., 2002), resulting in flash flooding and crop losses (Chagnon et al., 1997; Pielke and Downtown, 2000).

Although these findings seem contradictory, both scenarios can occur simultaneously depending on the level of modification of local rainfall variability and the timing of these modifications (warm vs. cold season); therefore, in terms of rainfall changes, of greater importance to agriculture are the potential spatial and temporal changes in precipitation variability and depth due to small-scale climatic forcings and land cover influences. Even if precipitation trends showed no significant temporal changes, a variation in spatial rainfall patterns could drastically alter the availability of water. For example, if patterns change such that rainfall does not fall over an aquifer recharge zone, that water will not be available for irrigation but will instead run off into the surface hydrologic system. Additionally, local-scale increases or decreases in precipitation intensity and/or duration could play a large role in erosional or biological processes, especially if those changes coincide with harvesting or critical growing phases of crops (Rosenzweig et al., 2002).

Based on the concerns related to water resources management and precipitation, OBJECTIVE 1 of this project is to quantify the historical spatial and temporal trends and variability of rainfall over the LMRAV. This information is critical to the generation of water resource planning and mitigation strategies since it will provide details regarding potential near-future water availability and warm-season rainfall probabilities. Due to the complicated feedback processes between surface and atmospheric energy and moisture fluxes, it is critical to define historical small-scale precipitation patterns over the LMRAV to better identify specific areas where variability is highest. By finding these areas and quantifying the variability, water resource managers will be better able to define and predict water availability in the near future.

Despite abundant precipitation in the lower Mississippi River alluvial valley, local agriculture is under considerable strain due to diminishing groundwater availability and the non-sustainable trend in irrigation draws from the lower Mississippi River alluvial aquifer (LMRAA). Current estimates show that roughly two billion gallons day^{-1} of water are being drawn from the shallow unconfined alluvial aquifer in northwest Mississippi (Stiles and Pennington, 2007), which has led to substantial drawdowns in aquifer levels across the region. It is logical to assume that the abundant and relatively evenly distributed cool-season rainfall over the area could potentially mitigate aquifer drawdown if appropriate conservation practices are put into place; however, since the alluvial aquifer is overlain with an impermeable clay layer over much of the Mississippi Delta (Arthur, 1994), there are limited areas where recharge through meteoric water is possible.

Researchers and water resource managers speculate that recharge into the shallow alluvial aquifer could come from a variety of sources, including surface hydrologic features (rivers and lakes; Bordonne et al., 2009), direct infiltration from rainfall, as well as inflow from the underlying tertiary aquifer (Mason, 2010). However, determining the exact magnitude of the recharge from these various sources is extremely difficult due to the influence of aquifer drawdown on recharge rates through variations in piezometric head. Although research has been done to define recharge zones of the LMRAA over northwest Mississippi (Mason, 2010; Ackerman, 1996), the exact areas have yet to be clearly outlined.

There are a number of different approaches that can be used to define areas of recharge and/or quantify recharge rate in unconfined aquifers, many of which are based on empirical estimates of water balance and water level fluctuations within the aquifer (Sophocleous, 1991; Tan and O'Connor, 1996; Carling et al., 2012). These approaches rely on measurements of groundwater level and precipitation, with estimates or empirical functions often used to define infiltration rate within the aquifer. These methods can be augmented using statistical or analytical techniques to account for measurement uncertainty and/or spatial variability of the observations (Moon et al., 2004; Fazal et al., 2005; Mandal and Singh, 2010; Ghayoumian et al., 2007); however, each method remains sensitive to local vegetation, topographic, geologic, and climatic influences that make it difficult to apply methods across different landscapes. As such, many approaches for determining areas and rates of recharge in unconfined aquifers rely on assessment of geologic maps to determine the depth, extent, and orientation of low-permeability clay layers, or are based on hydrologic assessment of stream discharge levels in relation to measured rainfall.

In general, unconfined phreatic aquifers are replenished directly from precipitation, although the rate of recharge is dependent on the characteristics of the precipitation (i.e., phase, intensity, distribution, etc.), antecedent soil conditions, topography, vegetation, and depth to groundwater (Bear, 1979). As a result, since natural recharge is normally related to precipitation, it can be concluded that a detailed investigation of rainfall patterns in relation to groundwater levels should allow for an assessment of potential recharge zones. It should be noted, though, that rainfall-recharge relationships are dependent on soil conditions related to infiltration, such that the depth of the water table influences the projected intensity and duration of the recharge event through the inherent time lag between rainfall and aquifer response (Wu et al., 1995; Jan et al., 2007).

To this end, Wax et al. (2008) attempted to define recharge zones by correlating groundwater patterns with precipitation records from regional surface gauges; however, the poor spatial resolution of the existing gauge network led to inconclusive results. Given the current period of record of radar-derived multi-sensor precipitation estimates from the NEXRAD network (1996 – present), it is now possible to utilize the high-resolution (nominal 4-km x 4-km) rainfall data to provide an improved assessment of recharge zones to the LMRAA using a similar methodology. Dyer and Mercer (2013) established the variability of spatial rainfall patterns over the Mississippi Delta and surrounding regions using the NEXRAD multi-sensor estimates and found that there are substantial and quantifiable differences in rainfall amount and distribution over space and time. The next logical step, then, is to correlate local rainfall patterns with available water table measurements over the LMRAV to determine the spatial and temporal influence of precipitation on regional groundwater levels more conclusively.

OBJECTIVE 2 of this project is to determine the spatial and temporal relationships between precipitation and groundwater patterns over the LMRAA to isolate areas of possible recharge. This will involve a statistical comparison of gridded monthly rainfall totals with seasonal groundwater level measurements from the Yazoo Water Management District (YMD) to define the spatial extent of surface recharge zones over the LMRAA. It is expected that the rainfall and groundwater data will show the highest correlation near the alluvial aquifer recharge zones; however, variables such as temporal lag, irrigation, and evapotranspiration will complicate this assessment, as well as increase the difficulty in determining local-scale groundwater flow direction. As a result, the correlations will be used to isolate patterns within the data to try and account for these variables using both spatial and temporal adjustments.

2. Data and Methods

2.1 Objective 1 – Quantifying Precipitation Variability

The study area for this project is centered on the Mississippi Delta; however, to incorporate regional precipitation patterns, especially downstream of the Mississippi Delta with respect to prevailing westerly winds, surrounding areas in Tennessee, Arkansas, Louisiana, and Alabama were included (Figure 1). To most effectively define and quantify the local-scale patterns of rainfall over the LMRAV, multi-sensor precipitation estimates derived from hourly WSR-88D data (Weather Surveillance Radar – 1988 Doppler; details of the methods and limitations of the products can be found in Fulton et al. [1998]) were used due to their high spatial (4x4 km) resolution. The NEXRAD Stage III/MPE dataset has been used over the Mississippi Delta to quantify average rainfall depth (Dyer, 2008), and Dyer (2009) verified that the high resolution multi-sensor estimates over the region generally agree with existing surface observations from various networks. To minimize temporal changes in bias associated with the multi-sensor data while maintaining spatial resolution, the hourly radar-estimated precipitation data were used to generate lower temporal resolution monthly and seasonal rainfall totals on the same 4x4 km grid as the initial data. It should be noted that missing data during December 1999 and August 2000 prevented those months from being included in the analysis.

The dominant spatial precipitation patterns were identified by performing an *S-mode* (Richman, 1986) Varimax-rotated principal component analysis (RPCA; Wilks, 2011) on monthly and seasonal rainfall values. A RPCA is a data transformation procedure that identifies leading modes of variability embedded within a dataset. The RPCA method proceeds as follows:

1) Formulate a similarity matrix (correlation matrix). The 4x4 evenly-spaced gridding of the MPE dataset is ideal for such a formulation, as irregularly spaced data (e.g. gauge data) will have variability in their correlation structure based on the proximity of the stations (e.g. closer stations will be more highly correlated due to their proximity, not their statistical characteristics).

2) Eigenanalyze the similarity matrix (Richman, 1986; Wilks, 2011)

3) Compute the Varimax rotated PC loading matrix and PC score matrix. In this step, it is necessary to determine the correct number of RPCs to retain. Numerous methods have been devised to determine this (e.g. North et al., 1982; Richman and Lamb, 1985; Richman 1986). We used the method of congruence, which matches the

rotated PCs against the underlying correlation matrix and determines which PCs have a strong match with the correlation matrix. Values of 0.81 or higher for the congruence coefficient (Richman and Lamb, 1985) suggested a good match with the correlation matrix and thus were retained. Note that both Promax (oblique) and Varimax (orthogonal) rotations were attempted with no appreciable difference.

The RPCA method provides generalized patterns of precipitation that represent the most common rainfall patterns at the different time scales considered (monthly and seasonal). Time series of the RPC scores provide insight into how each pattern has changed with time, allowing the investigators to determine if the phasing of each pattern is undergoing observable changes. The result of these RPC analyses are a series of maps that reveal regions where precipitation amount and variability has been changing over the period of record of the MPE dataset, identifying regions of additional concern for water resource managers.

2.2 Objective 2 – Defining Groundwater Recharge Zones

The Yazoo Mississippi Delta Joint Water Management District (YMD), which is tasked with recording and maintaining groundwater data over the Mississippi Delta, measures water table depth within the unconfined alluvial aquifer twice annually (early April and October). As such, seasonal variations in groundwater levels can be found by calculating the difference between subsequent measurements; however, due to the high levels of irrigation during the warm season for agricultural purposes, this study only utilized the changes in water levels from October to April (a.k.a., the cool season). By following this approach, the influence of irrigation on groundwater levels is minimized; therefore, any fluctuations in the unconfined aquifer water table can be accounted for through natural recharge/discharge processes.

It should be noted that cool-season irrigation still exists within the Mississippi Delta, primarily over approximately 50,000 acres of aquaculture (i.e., catfish farms). However, even though the actual volume of water being pulled from the LMRAA for this purpose cannot be easily quantified, the relative amount of water being used is negligible compared to that used in the warm season, and more importantly, is negligible compared to the water added over the region through precipitation during the cool season.

Local-scale rainfall patterns were quantified using multi-sensor precipitation estimates from the NEXRAD MPE product (described in Section 2.1). However, to minimize seasonal bias in the data associated with warm vs. cool season atmospheric patterns (i.e., convective vs. stratiform precipitation, respectively), monthly cumulative rainfall totals were compared with groundwater fluctuations. This also addresses time-lag issues associated with rainfall-recharge relationships (Wu et al., 1995).

For direct statistical comparison of measured groundwater levels and estimated precipitation, the 4x4-km Hydrologic Rainfall Analysis Project (HRAP) grid was cropped to cover the maximum extent of the groundwater sampling sites, while the groundwater data obtained from the YMD were interpolated to the resulting HRAP grid (Figure 2) using a Barnes objective analysis (Barnes 1964). Since the multi-sensor precipitation data were only available since April 1996, a total of 16 years' worth of cool-season data were available for analysis (defined as the difference between the October and subsequent April groundwater readings). Although the aquifer level measurements were not all taken at precisely April 1 and October 1, monthly mean precipitation from October through March were used for comparison purposes.

Once the groundwater and precipitation data were fixed to the same grid and grid extent, an *S-mode* (Richman, 1986) varimax-rotated principal component analysis (RPCA; Wilks, 2011) was applied on monthly and seasonal rainfall values and seasonal groundwater change. A RPCA is a data transformation procedure that identifies leading modes of variability embedded within a dataset. The same RPCA method used in Objective 1 was applied here; therefore, details of the method can be found in Section 2.1.

The RPCA method provides generalized patterns of precipitation and groundwater change that represent the most common patterns at the different time scales considered (monthly and seasonal). Time series of the RPC scores provide insight into how each pattern has changed with time, allowing the investigators to determine if the phasing of each pattern is undergoing observable changes. Previous research has shown that RPCA is useful in defining water table hydrograph patterns that could be interpreted in terms of groundwater recharge characteristics, such that the areal distribution of different hydrograph patterns can be used to determine the areal characteristics of recharge over an area (Winter et al., 2000). Although this project utilizes annual groundwater level changes and precipitation to define potential areas of recharge using a PCA methodology instead of hydrographs, the inherent usefulness of the resulting PCs in spatial interpretation of recharge patterns is still present.

The result of the RPC analyses will be a series of maps that reveal regions where precipitation amount and/or groundwater levels have been changing most appreciably over the 1996-2011 study period. It should be noted that the rotation of the loading matrix in the RPCA methodology means the associated loadings are no longer ranked in terms of explained variance, though variance explained is still useful for determining the most common patterns within the dataset.

To assess the statistical association between the RPC scores of the groundwater data and the precipitation data, stepwise multivariate linear regression analysis (Wilks, 2011) was applied using RPCs from the monthly, three-monthly (Oct. – Dec. and Jan. – Mar.), and seasonal (Oct. – Mar.) precipitation analysis. The primary goal of the stepwise regression is to identify the precipitation patterns that correlate most strongly with specific groundwater patterns (in this case the most dominant groundwater pattern) and to isolate any temporal lags associated with these relationships. This allowed for the determination of (1) when groundwater fluctuations are most sensitive to precipitation, and (2) locations within the study area where precipitation and groundwater show the highest correlation. Since increases in the water table within the unconfined aquifer during the cool-season should be primarily associated with recharge, locations where water levels respond most rapidly to rainfall will outline potential surface recharge zones.

3. Project Results

3.1 Objective 1 - Quantifying Precipitation Variability

3.1.1 *Seasonal Precipitation Patterns*

To better understand the spatial patterns and variations of precipitation over the lower Mississippi River alluvial valley, it is first necessary to define the baseline precipitation depth defined over the NEXRAD period of record. This will provide a point of comparison for interpretation of subsequent RPCA results over the region.

There are four distinct seasons over the study area based on general precipitation patterns, centered on consistent cool-season (January – March; JFM) and warm-season (July – September; JAS) precipitation depth and distribution (Figure 3a and 3c, respectively). The spring and fall seasonal periods of April – June (AMJ) and October – December (OND), respectively, exhibit lower inter-annual consistency over the period of record than the JAS and JFM seasons (in terms of annual precipitation depth) due to the varying influence of warm and/or cold season patterns during the transition months. Although the precipitation patterns in the selected seasons may shift outside the specified months, the three-month periods were chosen to normalize the season length and minimize the influence of transitional processes on rainfall distribution.

The precipitation pattern during the cool season (JFM) over the study area is characterized by lower overall precipitation amounts (< 375 mm) in southeast Arkansas and areas in and to the southwest of the Mississippi Delta (Figure 3a). This area of lower precipitation increases in extent and magnitude from November through March, at which point the lowest mean precipitation depth in the Mississippi Delta decreases from roughly 85 mm month^{-1} to 60 mm month^{-1} (not shown). However, there is a narrow band of increased rainfall (~360 mm) along a line roughly parallel to the eastern edge of the Mississippi Delta through central Mississippi. Although apparent during the fall transition season (OND; Figure 3d), this region of high mean precipitation depths along the eastern edge of the Mississippi Delta becomes more prominent through the cool season, and expands during JFM from the eastern edge of the Mississippi Delta to central Alabama and southeast Mississippi, where it increases from around 125 mm month^{-1} in November to a maximum of 160 mm month^{-1} in some areas in March (not shown).

The AMJ precipitation pattern deviates from this cool-season setup into a more defined latitudinal gradient of higher precipitation to the north and lower precipitation to the south (Figure 3b). This is likely a result of the shift of mid-latitude cyclone tracks to the north with the transition between the cold and warm season, such that passing storm systems produce precipitation in the northern parts of the study region before surface temperatures are warm enough to sustain a consistent sea breeze along the coast. Although lumped together with April and May rainfall patterns, June produces another sharp change in precipitation distribution as the rainfall patterns now exhibit a more “warm-season” characteristic with higher precipitation depths along the coast and less consistent rainfall depths to the north (not shown).

Although the relative magnitude of precipitation over the study region changes through the JAS period, the same general zonal pattern as the AMJ season is maintained. Besides the maximum in coastal rainfall, a notable pattern during this period is a relative minimum in precipitation within and to the west of the Mississippi Delta, extending into eastern Arkansas (Figure 3c). Along with this minimum, there is a corresponding increase in mean rainfall depths east of the Mississippi Delta. This increase to the east produces a relatively narrow band of higher rainfall amounts along a line slightly east of the Mississippi – Alabama border, at which point rainfall amounts again begin to decrease.

It is difficult to precisely define the exact causes for the warm-season precipitation patterns across central and northern Mississippi; however, Dyer (2011) suggests that soil and vegetation characteristics across the area may lead to substantial sensible and latent heat flux gradients that effectively generate and drive mesoscale circulations. These circulations produce convective instability along the eastern border of the Mississippi Delta, which eventually advect to the east before producing rainfall. This could explain the roughly north-south line of precipitation depths in east-central and north-central Mississippi during JAS, as well as the general lack of precipitation over the more agricultural areas of the Mississippi Delta and southeast Arkansas.

3.1.2 *RPCA of Monthly Precipitation*

To identify trends in the spatial variability of precipitation associated with the warm and cool season, maps of RPC loadings and their associated RPC score time series are provided. Note that the product of an RPC score time series value and the RPC loading map yields units of standard anomalies. For interpretation purposes, a positive RPC score means that positive/negative anomalies are related to higher/lower precipitation, while a negative RPC score means that negative/positive anomalies are related to higher/lower precipitation. Thus, interpreting RPC loading maps without knowledge of the associated RPC score values provides no insight about local maxima or minima. It is important to note that trends associated with RPC scores are not associated with the robustness of the associated RPC loading map; they simply demonstrate changes to the RPC loading maps over time. That is, a non-significant RPC score time-series does not suggest a meaningless RPC loading map, but instead that the RPC pattern is stable over time.

A congruence test of the RPC loadings for the monthly summed multi-sensor precipitation data over the study area revealed that the primary modes of variability within the precipitation signal are encompassed by the first four RPCs, which constituted a total of 37.6% of the total variance in precipitation (Figure 4). The relatively low explained variance is likely a result of large changes in precipitation patterns between seasons and years, producing noise in the data that cannot be differentiated by monthly rainfall aggregations. Subsequent seasonal analysis should minimize this by focusing the RPCs on time periods with similar precipitation variability; however, the monthly analysis is necessary to provide a baseline for comparison to the seasonal analyses.

RPC 1 (Figure 4a) shows a defined positive anomaly in precipitation in south-central Mississippi with a negative anomaly in Arkansas, while RPC 2 (Figure 4b) shows a general negative anomaly in precipitation over much of the western and southern extent of the study area, with an area of positive anomaly over north-central Alabama and east-central Mississippi. The RPC score time series for RPC 2 indicates a significant increase ($p < 0.10$) throughout the study period, despite the relatively short period of record used for analysis, suggesting an increase of precipitation over time in central and northern Alabama; however, the large variation in the score time series around a zero value indicates that although the positive anomaly may be increasing in magnitude (i.e., higher rainfall), there is still a high level of variability in the overall pattern.

The third and fourth RPCs (Figure 4c-d, respectively) show distinct areas of negative precipitation anomalies over west-central Mississippi and northeast Mississippi, respectively, extending into neighboring states, with the strongest positive anomalies in southern Alabama and Mississippi. However, the high variability in the score time series indicates that these patterns are not consistent, with substantial changes in anomaly magnitude and direction between seasons. Based on the roughly southwest to northeast orientation of the anomalies shown in RPCs 1, 3, and 4, it is likely that the RPC patterns are a result of changes in location and intensity of regional moisture convergence associated with synoptic-scale frontal systems, which would influence precipitation distribution and intensity. Due to the inherent spatial and temporal variability in synoptic-scale storm tracks and the associated mesoscale convective precipitation patterns over the southeast US, especially during the spring and autumn transition seasons, the high variability in the score time series seems logical.

To further investigate the influence of possible seasonal storm track variability on the RPCA anomalies, the frequency of occurrence of anomalies greater than or less than one and negative one, respectively, was calculated for each RPC score time series (Figure 5). RPC score values of ± 1 represent the actual pattern displayed on the RPC loading maps, although values of -1 represent the opposite to the anomaly patterns. Results show that the greatest frequency of positive anomalies for RPC 1 (Figure 5a) and RPC 3 (Figure 5c) was during the summer, while high magnitude negative anomalies occurred primarily during the winter. This would indicate that the positive precipitation anomalies are associated with summertime convection, while negative anomalies are associated with synoptic-scale frontal systems, as mentioned above. The frequency of high magnitude anomalies for RPC 2 (Figure 5b) is actually opposite this pattern, such that positive anomalies are most frequency in the cool season and vice versa. However, the overall monthly frequencies are generally less than those for RPCs 1 and 3, indicating a more stable and consistent pattern. The frequency of high magnitude events for RPC 4 (Figure 5d) is also low, although there is a distinct peak of negative anomalies during the spring. Due to the influence of frontal precipitation in the southeast US during this time of year, it is reasonable to suspect that synoptic-scale patterns play a large role in the rainfall patterns. Based on the anomaly map associated with RPC 4 (Figure 4d) it seems that higher rainfall is more likely in the northern reaches of the study area during the spring, which could be related to the occurrence of stationary frontal systems.

3.1.3 *RPCA of Seasonal Precipitation*

To more effectively differentiate the seasonal patterns from one another within the RPCA, the winter (JFM) and summer (JAS) seasons were investigated independently. Also, since these seasons had more well-defined precipitation patterns than the fall (OND) and spring (AMJ) transition seasons, it is reasonable to figure that the associated RPCAs will produce the most stable results. In a physical sense, focusing on the summer allows for an interpretation of precipitation trends during the late growing season over the study area, which is when irrigation is usually applied to crops due to the hydrologic stress on the land surface, while a focus on winter is warranted because of the importance of rainfall during this time period on aquifer recharge.

The RPCA of cool-season precipitation revealed four dominant RPCs that explained 61.3% of the total precipitation variability. The first cool-season RPC (Figure 6a) indicates a region of positive anomalies through northwest Mississippi and lower anomalies along the Gulf Coast and southern Alabama, while RPC2 (Figure 6b) shows a similar overall pattern except the dominant feature is a strong negative anomaly in central Alabama and east-central Mississippi. This agrees with the observed seasonal rainfall patterns for the cool-season (Figure 3a). Based on these spatial patterns and the fact that the score time series for both RPCs follow the same significantly decreasing trend ($p < 0.10$), the two RPCs show a strong gradient of precipitation depth from northwest Mississippi through central Alabama. This indicates that rainfall over the Mississippi Delta and areas to the west in Arkansas and Louisiana is persistently lower than areas to the east, and that the negative precipitation anomalies are increasing in magnitude over the period of record.

The lower rainfall over the Mississippi Delta is of particular importance since this area receives the least amount of precipitation based on monthly totals (Figure 3a), meaning that the region could potentially be sensitive to cool-season precipitation deficits and subsequent hydrologic stress during the early growing season. Since this area has a strong dependence on agriculture for economic sustainability, the lack of water resources early in the warm-season through decreased aquifer levels could be a potentially critical situation.

RPC3, which explains 13.4% of the total variance in winter precipitation patterns, shows a positive anomaly in the southern reaches of the study area, especially along the Alabama and Mississippi Gulf Coast, while the northern half of the study area is generally characterized with a negative anomaly (Figure 6c). Based on the precipitation pattern shown it is likely that this RPC is describing rainfall resulting from coastal influences to the south, such as convective rainfall produced by southeast flow during warmer wintertime conditions.

The fourth RPC (Figure 6d) is similar to RPC1 in that the greatest positive anomalies in precipitation depth are in the northwest area of the study period, through central Arkansas. However, the magnitudes of the anomalies are generally lower than RPC1 and RPC2. Due to the roughly northwest to southeast orientation of the gradient in precipitation anomaly over the study region, along with a dominant region of positive anomalies in Arkansas and a score time series with no significant slope, this RPC is indicative of normal cool-season synoptic-scale rainfall associated with mid-latitude cyclones passing to the north of the study area.

A RPCA of warm-season precipitation yielded four viable RPCs explaining a total of 71.0% of the variability in precipitation over the study area. RPC1 (Figure 7a) is characterized by an area of negative anomalies through northern Mississippi and Alabama and into western Tennessee, while RPC2 (Figure 7b) shows a large area with a positive anomaly over southeast Arkansas and northern Louisiana. The score time series' for RPCs 1 and 2 oscillate around a zero value and show no significant trend ($p < 0.10$), which means that the spatial precipitation anomalies are relatively consistent, and in the case of RPC 1, generally of a low magnitude. The exception is 2007, which was characterized by extremely high rainfall during July (3-5 times the climatological average) in northern Louisiana, southern Arkansas, and west-central Mississippi (not shown).

Since most of the precipitation in this region during the warm-season is convective, it is logical that mechanisms related to convective initiation and precipitation generation (i.e., moisture convergence, isentropic forcing, etc.) should be the primary drivers for variations in rainfall patterns. Additionally, given the fact that the anomalies for RPCs 1 and 2 cover a relatively large area, the underlying mechanisms are likely based on synoptic-scale mechanisms. Due to the proximity of the region to the Gulf of Mexico, it is reasonable to speculate that the anomalies in rainfall in RPCs 1 and 2 are related to a shift in the moisture flux, such that a westward shift of the low-level moisture would lead to a decrease in rainfall over north Mississippi and an increase in Arkansas, and vice-versa. RPC3 shows a high magnitude negative anomaly in southwest Mississippi (Figure 7c), which is more indicative of the spring transition rainfall pattern (Figure 3b) than of summertime rainfall patterns (Figure 3c). Since frontal systems associated with extra-tropical cyclones produce a large percentage of the precipitation in this region during the early and late part of the season, especially along the northern reaches of the study area that are closer to the jet stream, a northward shift in the respective storm tracks could lead to a decrease in rainfall in the northern regions of the study area, as shown by this anomaly pattern

RPC4 (Figure 7d), which explains 12.9% of the variance in precipitation over the region, is most notable due to the close agreement between the anomalies and the mean warm-season precipitation depth (Figure 3c). Based on this pattern, there is a general area of negative precipitation anomalies over western Mississippi, centered on the Mississippi Delta, with a line of positive anomalies just west of the Mississippi – Alabama border. The rainfall distribution given by this RPC agrees with the summertime precipitation pattern described in Dyer (2011), whereby convection along the eastern boundary of the Mississippi Delta resulting from vegetation contrasts between cultivated land to the west and forested land to the east generates a surface-based mesoscale convective boundary. Since this only occurs during synoptically benign conditions, it is reasonable that this pattern would only explain a limited percentage of the total variability in rainfall over the region. However, the fact that this pattern is driven by anthropogenic modification of the land surface warrants further research, especially considering the stability of the pattern over time as seen by the lack of a slope in the associated score time series with generally positive (although low) magnitude values in most years.

An important aspect of the data that must be addressed with respect to the seasonal precipitation analysis is the apparent increase in variability after 2003 in nearly all of the retained RPC score time series. As mentioned previously, there was a transition in 2003 from the Stage III algorithm to the MPE algorithm that included, among other modifications, a change in the weighting factor associated with each gauge; therefore, it is expected that the rainfall totals would be influenced as well, although there isn't a long enough data record to fully quantify the associated bias. However, as shown by the various score time series, the spatial variability in the data seems to be suppressed prior to 2003, after which there are several high magnitude jumps in the RPC scores. Despite the change in variability in the time series, though, in most cases the overall slope remains consistent. This indicates that the spatial rainfall patterns given by the RPCs remain valid.

To address more fully the potential physical atmospheric mechanisms driving the precipitation anomalies described by the RPCAs for the warm and cool season, the meteorological characteristics associated with the seasons with the highest magnitude anomalies were studied. This was done by calculating the difference in atmospheric features related to precipitation generation (mean sea level pressure, 700 hPa specific humidity, and 850-500 hPa temperature difference) between the seasons with the highest and the lowest anomalies. For example, for the cool-season RPC1 (Figure 6a), the difference between the 2006 and 2009 seasons was calculated to diagnose the primary differences in atmospheric patterns between positive and negative anomalies. Although there are a number of additional variables that could be analyzed, these values reflect pressure patterns, lower atmospheric moisture content, and mid-level lapse rates, respectively, which provide an overview of the major dynamic and thermodynamic features related to rainfall generation over the study region. Only the first two RPCs for the warm and cold season were analyzed since they had the most explained variance.

The difference in atmospheric characteristics between the greatest positive and negative anomalies for the cool season RPCs (Figure 8a-b) show that the difference in mid-level temperature lapse rates are small (less than 0.5K), indicating that thermal instability is not a strong factor in precipitation generation. This is reasonable considering the important of synoptic-scale frontal systems during this period, which is shown by the relatively large differences in mean sea level pressure over the study region (greater than 1.5 hPa). However, the greater influence in precipitation patterns seems to focus on differences in low level moisture, which shows relatively well-defined differences that relate to the spatial location of the precipitation anomalies.

For cool-season RPC1 (Figure 8a), there is generally more moisture through central Mississippi and areas to the west during the highest magnitude positive anomaly, associated with increased precipitation in northwest Mississippi. This, along with lower mean sea level pressure relative to the highest magnitude negative anomaly, suggests that lower pressure and increased moisture from the west lead to higher precipitation over the lower Mississippi River valley, while higher pressure and increased moisture through central Alabama leads to an eastward shift of precipitation maxima. Cool-season RPC2 (Figure 8b), which shows a maximum negative precipitation anomaly through central Alabama, also seems to be influenced by a change in low-level moisture as seen be a smaller difference in specific humidity from the Gulf Coast along the Mississippi-Alabama border northeast through Alabama. The relatively large differences in mean sea level pressure further indicate that the change in moisture flux may be a result of variations in synoptic-scale features.

The atmospheric characteristics associated with differences in the warm-season precipitation anomalies tend to focus on thermal and moisture characteristics, such that differences in mean sea level pressure over the study region are generally less than 1 hPa while differences in 700 hPa specific humidity and 850-500 hPa temperatures show a noticeably larger range than during the cool season (Figure 8c-d). For warm-season RPC1, the highest magnitude positive anomaly is associated with a distinct area of increased low-level moisture from the Mississippi Gulf Coast northwards, which means that the highest magnitude negative anomaly has less moisture for precipitation generation over the area (Figure 8c). For the negative precipitation anomaly, the greatest low-level moisture is shown to be in eastern Texas and the southern Appalachians through North Carolina and Virginia. Additionally, 850-500 hPa temperature differences indicate that mid-level lapse rates are lower during the negative anomaly period, suggesting less thermal instability and a possible decrease in convection through northern Alabama and Mississippi.

Atmospheric patterns associated with warm-season RPC2 show a strong zonal gradient of low-level moisture and mid-level lapse rates through the study area, with the highest magnitude negative anomaly having more moisture and higher lapse rates through northern Louisiana and southern Arkansas (Figure 8d). This seems counterintuitive considering the negative precipitation anomaly is associated with decrease rainfall over this area; however, the increased moisture flux through Alabama associated with the highest magnitude positive anomaly, along with higher pressure through the northern study area, suggests that variations in the moisture flux from the Gulf of Mexico play a key role in convective development and associated rainfall for this pattern.

3.2 Objective 2 - Defining Groundwater Recharge Zones

3.2.1 *General Precipitation and Groundwater Patterns*

Before investigating the variations in precipitation and groundwater levels over the LMRAA, it is advantageous to define the underlying mean patterns for comparison. To that end, Figure 3 shows the average gridded multi-sensor precipitation estimates and changes in groundwater levels for the October – March time period (a.k.a., cool season). The precipitation patterns indicate an area of maximum rainfall to the south and east of the Mississippi Delta (> 700 mm year^{-1}; Figure 9a) and a minimum in the central Delta near the Mississippi River (< 500 mm year^{-1}). The seasonal changes in groundwater levels show a similar pattern with respect to the rainfall minima, with the smallest change (< 0.5 m year^{-1}; Figure 9b) in the central Mississippi Delta. The greatest average change in groundwater levels from 1996-2011 occurs in the southern and north-eastern periphery of the Mississippi Delta (> 1.5 m year^{-1}). The agreement in the spatial location of the rainfall and groundwater minimum through the central Delta is of particular importance since it may help define the association between the data sets; however, relating the areas with the greatest change in groundwater with the maximum rainfall depth is the primary focus since this will define the areas of potential aquifer recharge.

Although the mean rainfall and groundwater patterns show some association, based on initial assessment of the spatial location of maxima and minima, the variability in the data sources shows less agreement (Figure 10). Figure 4b indicates that the areas with the greatest change in groundwater depth match with the areas of greatest variability, with a minimum in variability in the central Mississippi Delta. The same is not true with the precipitation estimates, however. Although the highest average precipitation occurs along the southern and eastern portions of the Mississippi Delta, the greatest precipitation variability is seen in the northern areas of the study region and into southwest Tennessee (Figure 10a).

These results indicate that changes in groundwater depth show stable spatial and seasonal patterns over the 1996-2011 period of record, although the magnitude of the changes over the region may vary based on external conditions such as rainfall, which does not exhibit the same consistency. As such, the areas with the greatest change in groundwater depth can be associated with areas of recharge since they consistently show a positive change in groundwater levels despite the magnitude of rainfall present over the region.

3.2.2 *PCA of Precipitation and Groundwater Data*

A rotated principal components analysis (RPCA) of the NEXRAD precipitation data over the Mississippi Delta study region yielded three precipitation-based RPCs (hereafter referred to as P-RPCs) with a total explained variance of 0.58 (only the first three P-RPCs were retained based on a congruence test). The first P-RPC (r^2 = 0.27) indicates an area of positive anomalies in the southern third of the Mississippi Delta study region and an area of negative anomalies running roughly zonally through the north-central Mississippi Delta (Figure 11). The associated score time series shows positive scores during most of the study period, with the exception of 2001 and 2002 when the pattern was effectively reversed. P-RPC2 (r^2 = 0.18) shows the area of greatest positive anomalies running east-west through the south-central Mississippi Delta with negative anomalies to the north and south. However, the related score time series shows considerable oscillation around a value of zero, which can be interpreted as an unstable and weak signal. The same is true for the score time series associated with P-RPC3 (r^2 = 0.13), which also has a noisier spatial signal with smaller areas of positive and negative anomalies throughout the study area.

The first three retained RPCs on changes in groundwater levels (hereafter referred to as GW-RPCs) yielded a total explained variance of 0.52. The first GW-RPC (r^2 = 0.25; Figure 12) shows an area of negative anomalies throughout the central Mississippi Delta and along the extreme periphery of the northeast border of the study region, with positive anomalies along the western periphery and eastern edge of the region. The score time series for this GW-RPC shows a consistent positive value through 2010 before dropping to near zero, indicating that this pattern was stable over the 1996-2010 study period before disappearing in 2011. The reason for this change cannot be determined without further data; therefore, further investigation is left for future research. GW-RPC2 (r^2 = 0.15) and GW-RPC3 (r^2 = 0.12) both have score time series with considerably less magnitude and more variability around zero, which means they are less stable and generally weaker than GW-RPC1. Regarding the spatial anomaly patterns given be these GW-RPCs, they both show negative anomalies along the western periphery of the Mississippi Delta and smaller areas of positive anomalies over the rest of the study area.

3.2.3 *Regression Analysis*

Since GW-RPC1 represents the greatest variability in seasonal changes in water levels in the LMRAA (25%), it is important to isolate the P-RPC patterns that are most strongly correlated with the GW-RPC1. To determine this, the P-RPC score patterns were correlated with the GW-RPC1 scores at monthly, three-monthly, and six-monthly time scales. The regressions were calculated by comparing GW-RPC1 at each grid point with the associated precipitation anomalies at the various time scales, assuming a linear relationship.

Results show that precipitation during November was most highly correlated with GW-RPC1 (r^2 = 0.45, Table 1), followed by December and the January – March three-month period (both with r^2 = 0.27). A correlation between groundwater and precipitation anomalies over the full six-month time period resulted in an r^2 of 0.26. The strong relationship between seasonal groundwater changes and precipitation in November is likely due to the cessation of heavy irrigation in late September through early October, such that rainfall in November leads to a rapid response in the depleted LMRAA. As the aquifer recharges, the association between rainfall and changes in groundwater levels should then weaken due to the higher water levels and lower absolute change in depth to the water table. This is supported by the gradual decrease in r^2 values from November through March (Table 1).

It should be noted that the weak correlation between groundwater changes and October precipitation is most likely due to the sensitivity of aquifer levels to irrigation through early October, when water table fluctuations are still highly sensitive to withdrawals from the aquifer along with strong residual gradients in piezometric head resulting from intense warm-season irrigation.

These results provide evidence that recharge into the LMRAA through meteoric water leads to a relatively quick rebound in groundwater levels, meaning that average cool-season precipitation patterns can maintain adequate aquifer levels given sustainable irrigation practices. Even if the necessary precipitation needed for recharge does not occur early in the cool-season, rainfall at any time during the six-month period from October – March can help to recharge the LMRAA, especially if it falls over the defined recharge zones.

To support the correlation results presented in Table 1 more fully, a stepwise regression for the nine P-RPCs from the rainfall data (one for each of the one-month, three-month, and six-month time periods) was used to isolate the months/seasons that provide the best responses to changes in groundwater level (e.g., recharge) as characterized by GW-RPC1. A stepwise regression considers a step-by-step approach, such that the variables are added sequentially based on correlation strength until all variables are included. This method is advantageous since it takes into account cross-correlation between variables, which is likely the case with monthly precipitation data due to the relatively consistent climatic features leading to rainfall generation during the cool season in the southeast US (i.e., frontal passages). By removing variables with high cross-correlation, a regression model with better generalization will be possible. The variables retained from the stepwise regression are determined by calculating the cumulative r^2

and mean squared error values to see where no appreciable new variability is added and/or error begins to increase with the addition of variables.

The stepwise regression results (Table 2) reveal that adding the entire cool season and February P-RPCs to November only provides a modest increase in variance explained by the model (r^2=0.45 to r^2=0.66). The addition of a fourth predictor, the P-RPC for March, yields a slight increase in r^2 but no decrease in MSE. A comparison of the spatial patterns of groundwater change anomalies given by GW-RPC1 and precipitation anomalies given by the P-RPCs associated with November and all cool-season rainfall show that despite regional variations in precipitation, recharge still occurs over defined locations over the Mississippi Delta study region. The P-RPC associated with November rainfall shows generally positive precipitation anomalies across much of the study region, with a small area of negative anomalies along the southeast edge of the area. The associated score time series indicates that these anomalies are generally weak, such that despite variations in rainfall patterns, the greatest increases in groundwater levels (e.g., aquifer recharge) still occur around the periphery of the Mississippi Delta and along the Tallahatchie River in the eastern Mississippi Delta (Figure 12; GW-RPC 1).

The six-month (a.k.a., full cool-season) precipitation anomalies show a strong positive anomaly in the south of the Mississippi Delta, with negative anomalies through the central and north-central areas. The score time series associated with these patterns shows considerable oscillations around a zero anomaly, meaning that this pattern is relatively unstable. However, changes in intensity of the precipitation anomalies associated with this P-RPC would still lead to rainfall occurring over the areas with the greatest recharge, especially if the anomalies remained positive such that precipitation was heaviest through the southern Mississippi Delta where groundwater levels also show a large area of positive anomalies (Figure 12; GW-RPC1).

4. Conclusions

4.1 Objective 1 - Quantifying Precipitation Variability

The lower Mississippi River alluvial valley is characterized by widespread agriculture due to fertile soils, a relatively long growing season, and abundant rainfall; however, unequal distribution of rainfall throughout the year, especially in the warm season due to the convective nature of precipitation, can lead to substantial water stress on crops. As a result, irrigation from the regional alluvial aquifer is common, leading to additional stress on groundwater resources and increasing the importance of aquifer recharge. Since local-scale precipitation variability can lead to drastic changes in water availability in surface and sub-surface hydrologic systems over the region, this paper works to quantify the spatial patterns of rainfall over the lower Mississippi River alluvial valley to better understand current and future water resource issues and needs.

Mean seasonal precipitation values indicate that there is a clear differentiation between rainfall patterns within the alluvial valley and areas to the east and south, although the causes of these patterns likely change by season. During the warm-season (July – September), surface features such as land cover could play a role in determining the location and magnitude of rainfall since air mass convection is the dominant forcing mechanism for precipitation generation. As a result, thermodynamically-driven boundaries such as the sea breeze along the Gulf Coast and circulations resulting from discontinuities in vegetation and soils along the alluvial valley boundary in northwest Mississippi (Dyer, 2011) cause rainfall to have a regional minimum within the alluvial valley (Figure 3c). During the cool-season (January – March) there is also a minimum in precipitation over the alluvial valley, although there is more spatial variability than during the warm-season (Figure 3a). This is likely a combination of thermodynamically-driven processes and dynamic mid-latitude processes (i.e., frontal passages), although the latter may be the dominant precipitation generation mechanism due to the proximity of the jet stream to the study area during this time.

The rotated principal component analysis (RPCA) of monthly precipitation over the study area shows several dominant modes of variability, most of which are likely related to variations in the location and intensity of synoptic-scale frontal systems due to the general southwest to northeast orientation of the anomalies (Figure 4). The high variability and general mean of zero of the associated score times series' indicates substantial inconsistency in the spatial rainfall patterns, which further justifies the influence of synoptic-scale systems on rainfall patterns. In general, the spatial patterns given by the RPCs show positive rainfall anomalies in northeastern Mississippi and northern Alabama and negative anomalies over southern Arkansas, northern Louisiana, and west-central Mississippi. The only score time series with a significant trend ($p < 0.10$; Figure 4b) indicates an increase in magnitude of a positive precipitation anomaly in north-central Alabama and a decrease in areas to the east and along the Gulf Coast. Despite the positive trend, there remains substantial variability around a zero anomaly.

A RPCA of seasonal rainfall shows that cool-season (January – March) rainfall is increasing through central Alabama and decreasing in northwestern Mississippi, based on the first two RPCs that explain 38.7% of the total cool-season rainfall variability (Figure 6a-b). The score time series' associated with these RPCs have significant trends ($p < 0.10$), indicating that the magnitude of the precipitation anomalies is increasing over the 1996-2012 study period. The remaining two RPCs from the cool-season RPCA show positive rainfall anomalies along the Gulf Coast and central Arkansas, although the related score time series show a consistent oscillation around a value of zero that suggests relatively weak and stable anomaly patterns (Figure 6c-d).

The RPCA results for the warm-season (July – September) show considerable spatial variability, with no significant trend in any of the associated score time series (Figure 7). The spatial variability is likely associated with the predominately convective nature of rainfall during the warm months, which is often driven by surface boundaries such as the sea breeze along the Gulf Coast or land cover changes near urban areas and forest-agriculture transitions. However, high-magnitude anomalies in the RPC score time series' are usually associated with increased moisture convergence related to synoptic-scale flow; therefore, the overall spatial patterns still contain a general northwest-to-southeast gradient indicative of frontal passages through the region.

Analysis of the general atmospheric characteristics associated with the highest magnitude positive and negative anomalies for the warm and cool-season RPCs show that variations in precipitation patterns during the cool season are more closely associated with synoptic-scale flow (as indicated by differences in mean sea level pressure), while variations during the warm season are influenced primarily by moisture flux and mid-level lapse rates (Figure 8). This result is reasonable, and does allow for some conjecture regarding the general conditions necessary for the precipitation anomalies to be realized; however, it should be noted that these results can only be used in a general sense due to the smoothed nature of the seasonal data and the inability to completely isolate the patterns related to a single RPC. Due to the importance of recognizing the meteorological characteristics associated with anomalously high and low precipitation, especially for seasonal climate assessments, future work will include a more detailed analysis of the mechanisms related to the rainfall patterns shown by the RPCA over the southeast US.

4.2 Objective 2 - Defining Groundwater Recharge Zones

A rotated principal component analysis (RPCA) of seasonal groundwater changes from October through April over the Mississippi Delta indicates spatially consistent recharge zones throughout the region. These zones include an area along the western periphery of the Mississippi Delta, as well as in the southeast and northeast edges of the region. The area in the northeast is associated with the Tallahatchie River, which is a sandy-bottomed river channel that intersects the shallow alluvial aquifer. The river levels are maintained by the Army Corp of Engineers (USACE) through a series of engineering structures; therefore, it is expected that aquifer recharge in this specific area will be directly associated with the volume of water released from upstream control structures. However, given the strong positive signal associated with GW-RPC1 over this region, precipitation falling over the Tallahatchie River watershed plays a critical role in aquifer recharge. As such, even with varying river levels associated with water releases determined by the USACE, recharge to the shallow aquifer can still be maintained through seasonal precipitation.

During the October – April cool season, precipitation patterns show a higher depth and spatial consistency than during the warm season. The association between groundwater recharge and precipitation indicates that rainfall during the late fall and early winter is most important for recharge, which was quantified using both a linear and stepwise regression between GW-RPC1 and the nine P-RPCs based on different temporal means.

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Tables

Table 1. Regression table showing correlations between RPC1 of the groundwater dataset and RPCs from the multi-sensor precipitation dataset at various time periods and intervals. JFM = January – March; OND = October – December; ALL = October – March.

Variable	MSE	R-sq	F-stat
Nov	0.067	0.45	9.95
ALL	0.047	0.62	8.82
Feb	0.045	0.66	6.51
Mar	0.045	0.70	5.15
OND	0.048	0.70	3.80
Oct	0.054	0.71	2.83
JFM	0.061	0.71	2.11
Jan	0.071	0.71	1.55
Dec	0.085	0.71	1.10

Table 2. Results of stepwise regression between RPC1 of the groundwater dataset and RPCs from the multi-sensor precipitation dataset at various time periods and intervals. JFM = January – March; OND = October – December; ALL = October – March.

Variable	**MSE**	**R-sq**	**F-stat**
Nov	0.067	0.45	9.95
ALL	0.047	0.62	8.82
Feb	0.045	0.66	6.51
Mar	0.045	0.70	5.15
OND	0.048	0.70	3.80
Oct	0.054	0.71	2.83
JFM	0.061	0.71	2.11
Jan	0.071	0.71	1.55
Dec	0.085	0.71	1.10

Figures

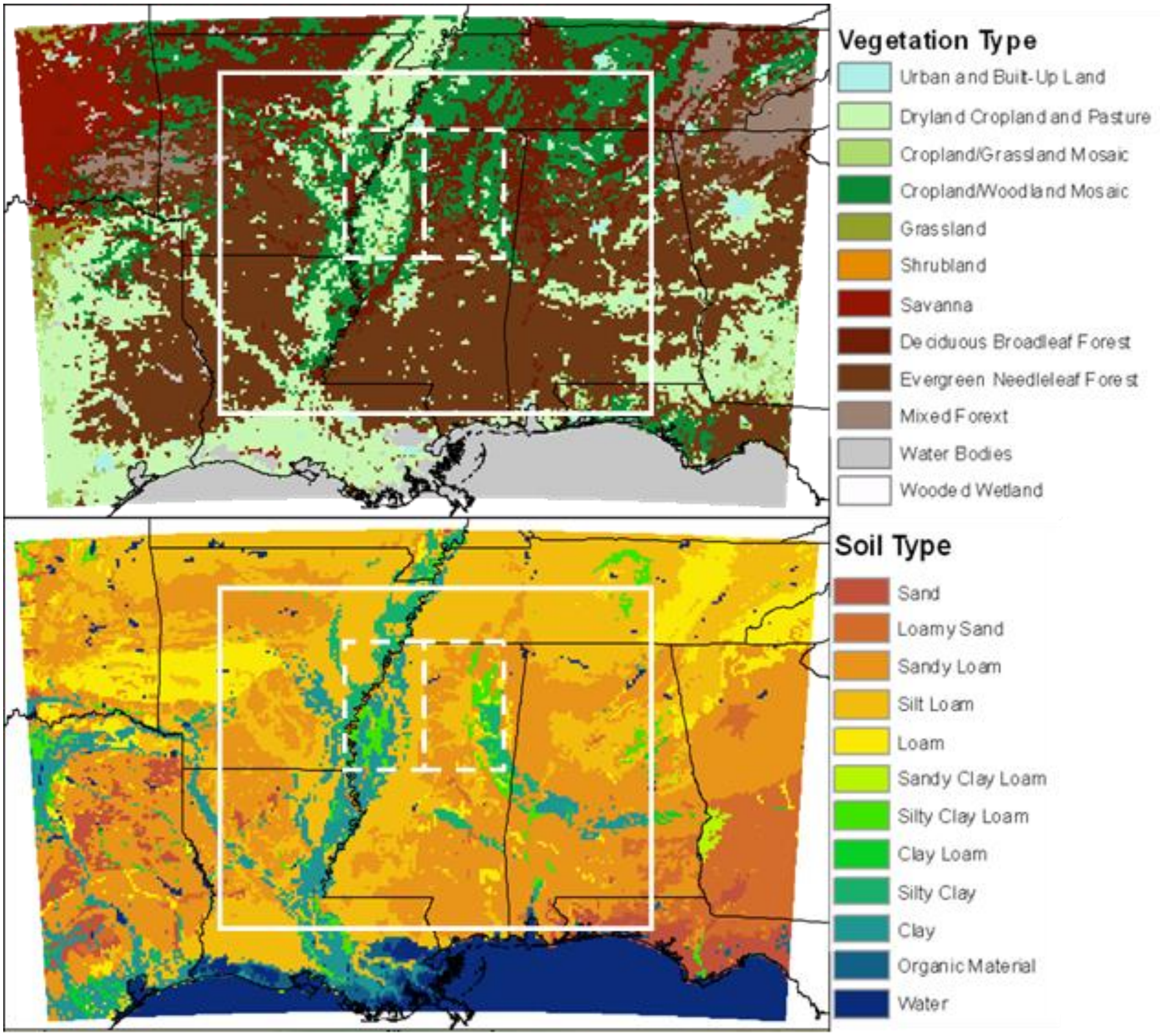

Figure 1. Map of vegetation and soil type over the southeastern US. The study area is denoted by the solid white box.

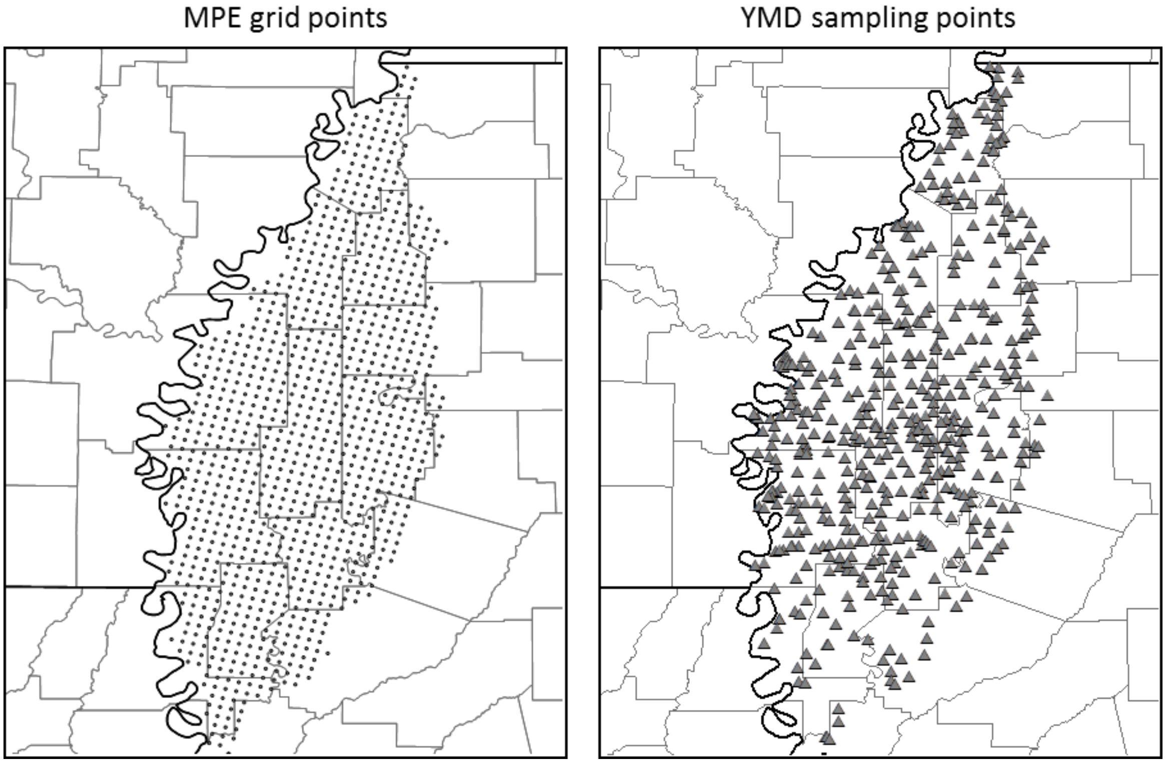

Figure 2. Location of multi-sensor precipitation estimation points (extracted from HRAP grid) and YMD groundwater sampling points within the defined Mississippi Delta study region.

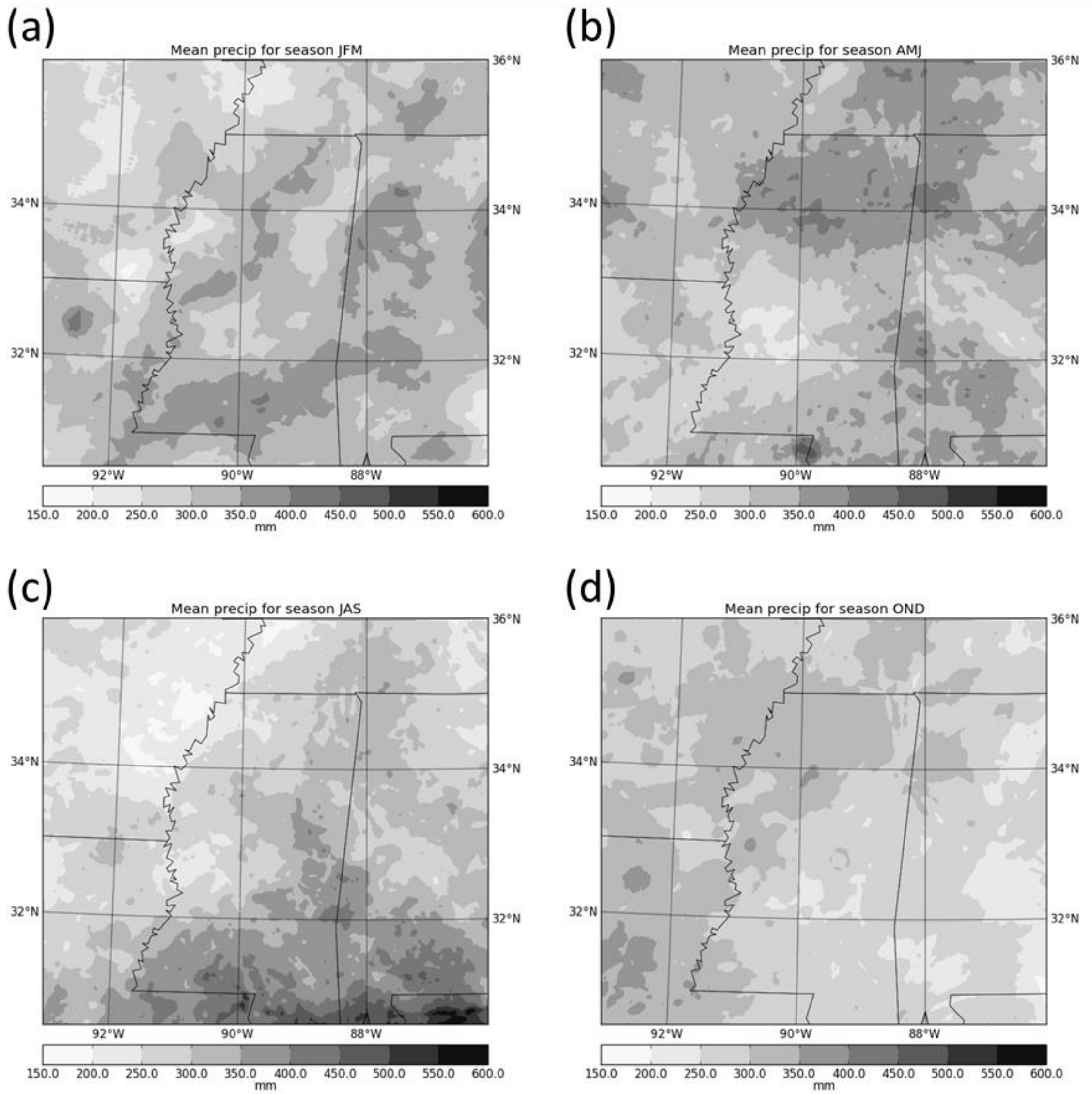

Figure 3. Mean seasonal NEXRAD-estimated precipitation for (a) January – March (cool season), (b) April – June (spring transition), (c) July – September (warm season), and (d) October – December (fall transition).

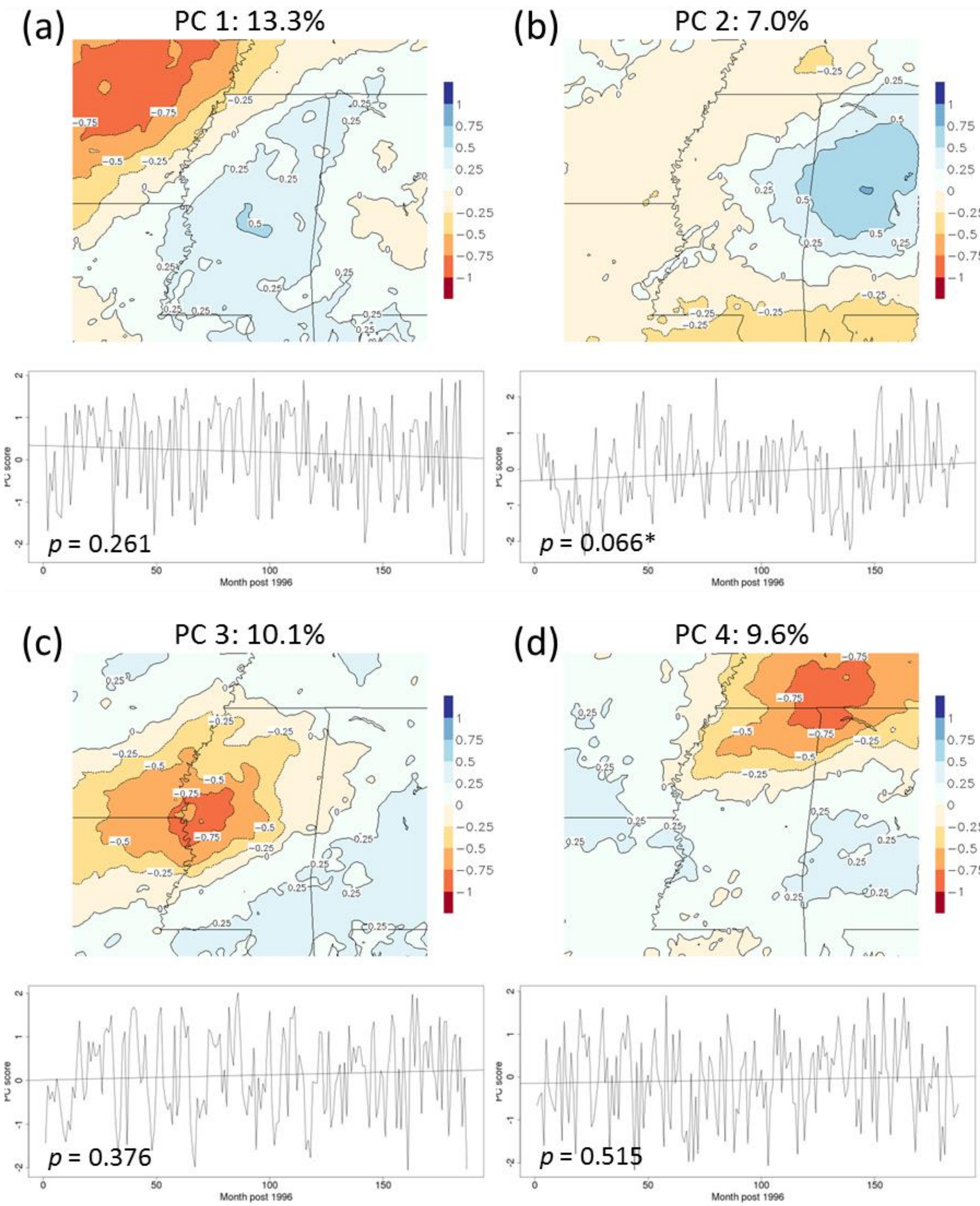

Figure 4. Monthly principal components and related score time series for RPCs 1–4 (panels a–d, respectively). Percent explained variance for each RPC is given above the respective map, and the *p* value for each score trend is given in the associated time series (trends significant at the 90% level are denoted by an asterisk).

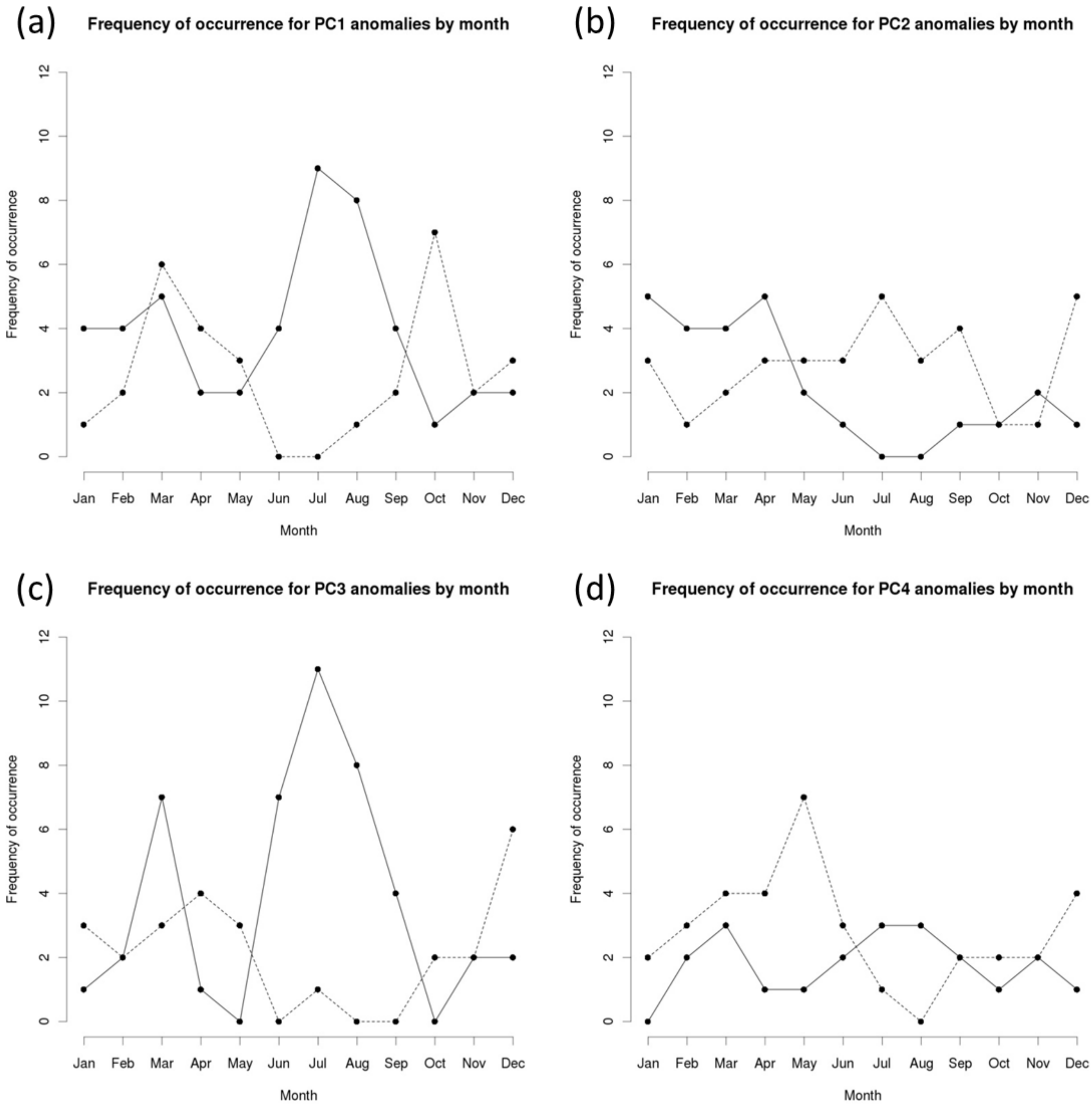

Figure 5. Frequency of occurrence of months with precipitation anomalies greater than one (solid lines) or less than negative one (dashed lines) for (a) RPC1, (b) RPC2, (c) RPC3, and (4) RPC4.

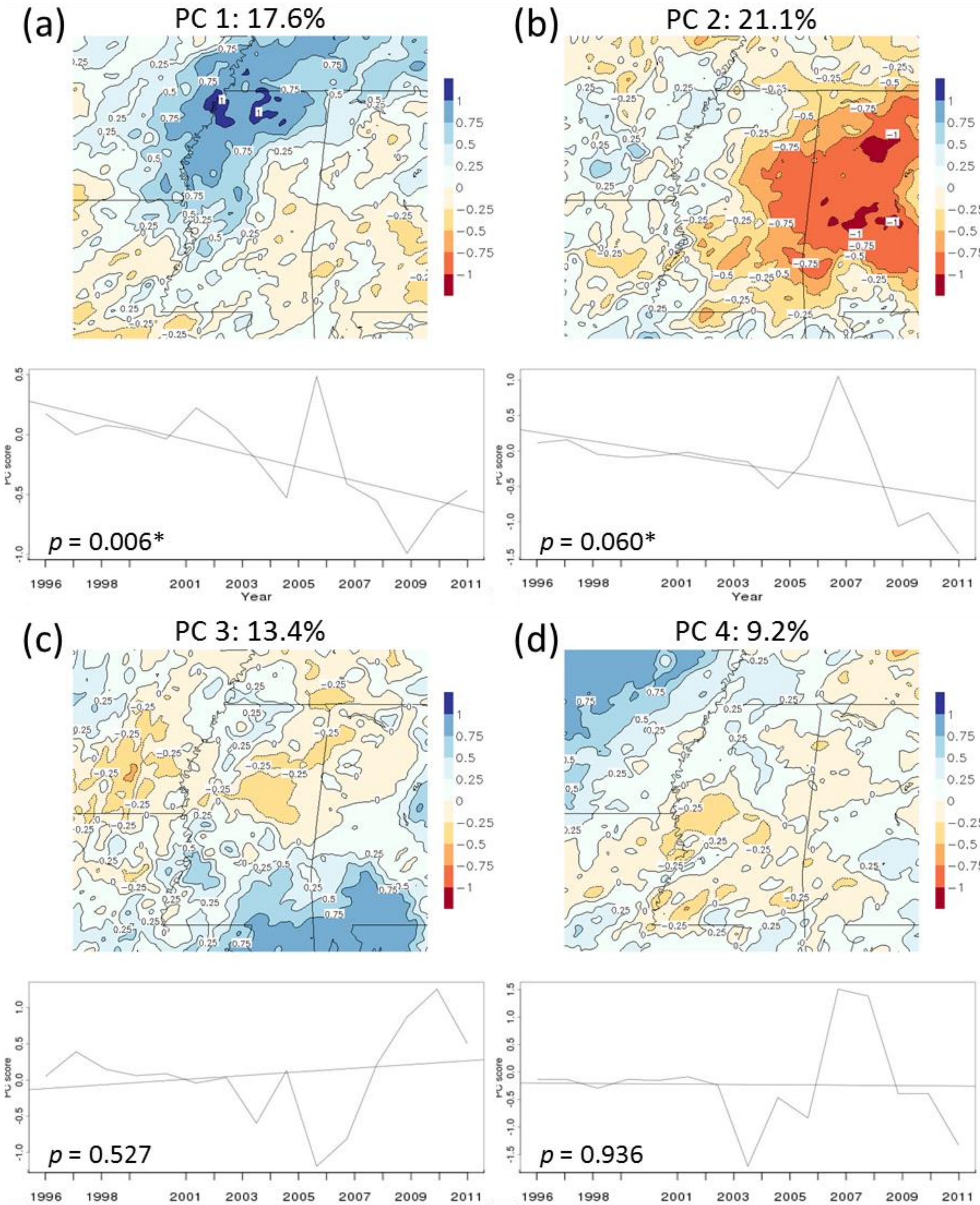

Figure 6. Cool-season (January – March) principal components and related score time series for RPCs 1–4 (panels a–d, respectively). Percent explained variance for each RPC is given above the respective map, and the *p* value for each score trend is given in the associated time series (trends significant at the 90% level are denoted by an asterisk).

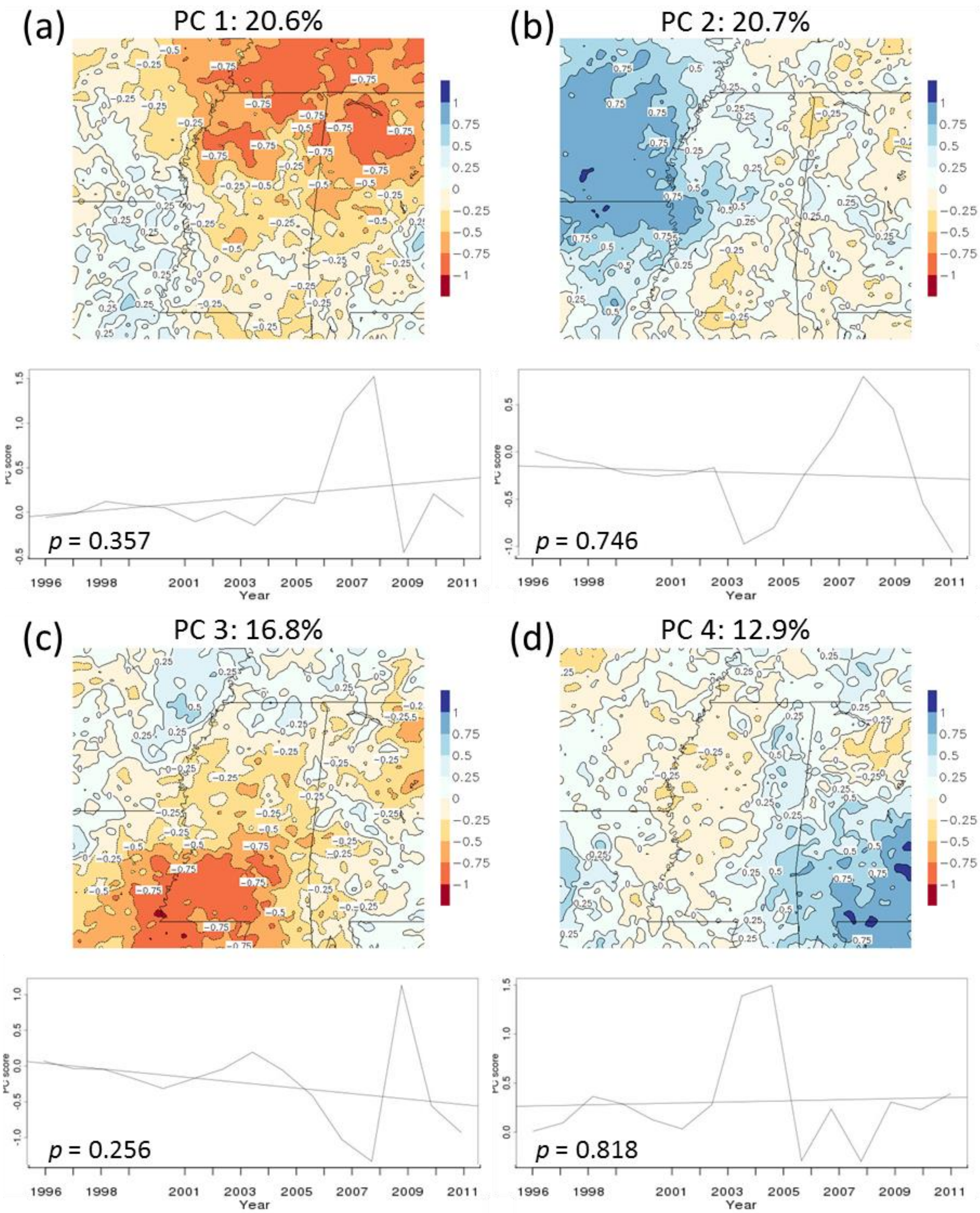

Figure 7. Warm-season (July – September) principal components and related score time series for RPCs 1–4 (panels a–d, respectively). Percent explained variance for each RPC is given above the respective map, and the *p* value for each score trend is given in the associated time series.

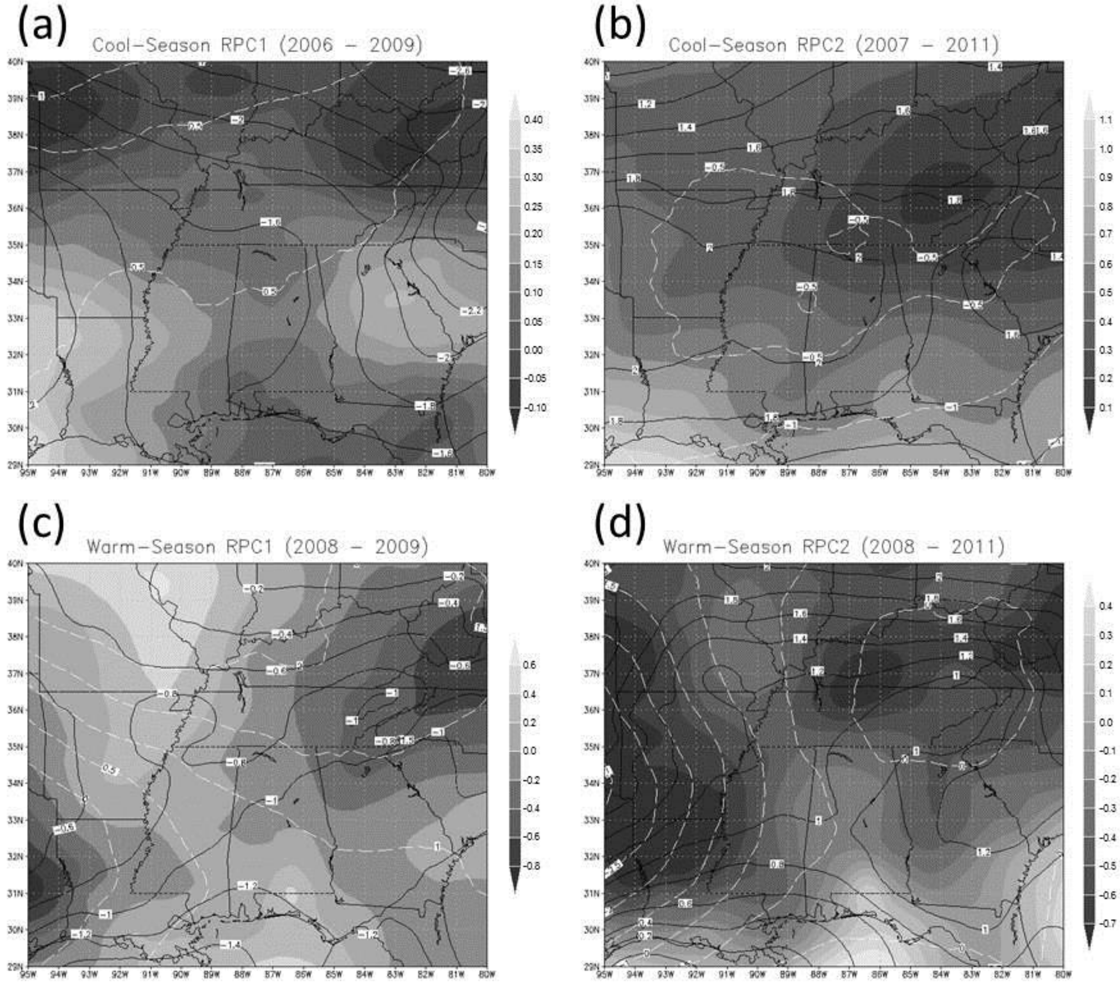

Figure 8. Difference in seasonal 700 hPa specific humidity (g/kg; shaded), mean sea level pressure (hPa; solid black lines), and 850–500 hPa temperature (K; dashed white lines) between seasons with maximum and minimum anomalies for (a) cool-season RPC1, (b) cool-season RPC2, (c) warm-season RPC1, and (d) warm-season RPC2. Note that mean sea level pressure and 850-500 hPa temperature have consistent contour intervals between figures while the 700 hPa specific humidity shaded contours change for each figure.

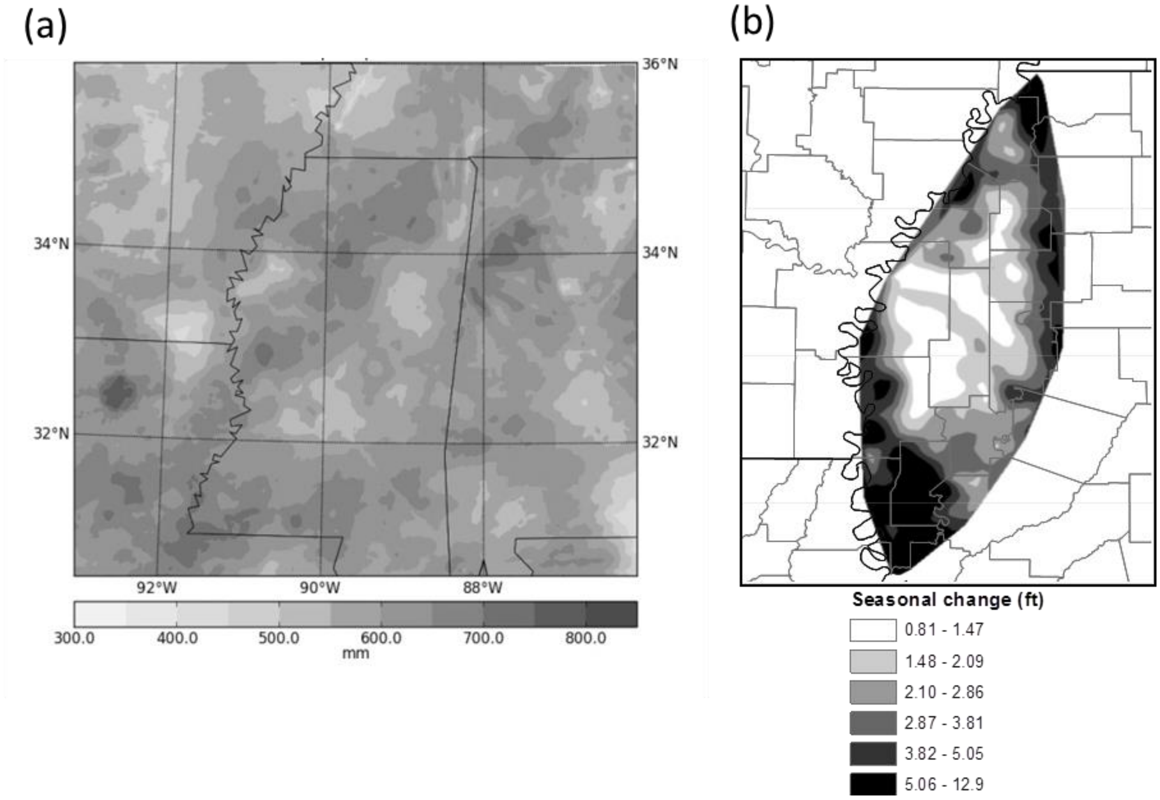

Figure 9. Mean of cool-season (October – April) (a) multi-sensor estimated precipitation depth and (b) changes in LMRAA water levels for the period 1996 – 2011.

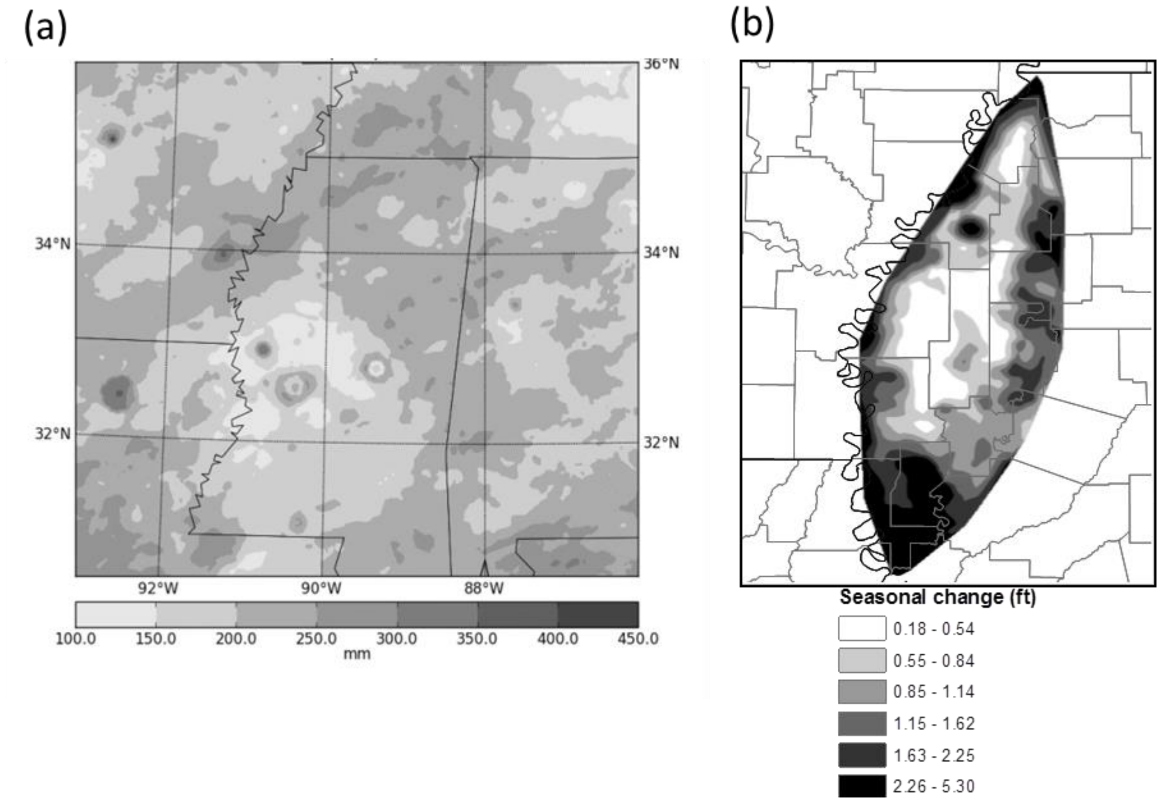

Figure 10. Standard deviation of cool-season (October – April) (a) multi-sensor estimated precipitation depth and (b) changes in LMRAA water levels for the period 1996 – 2011.

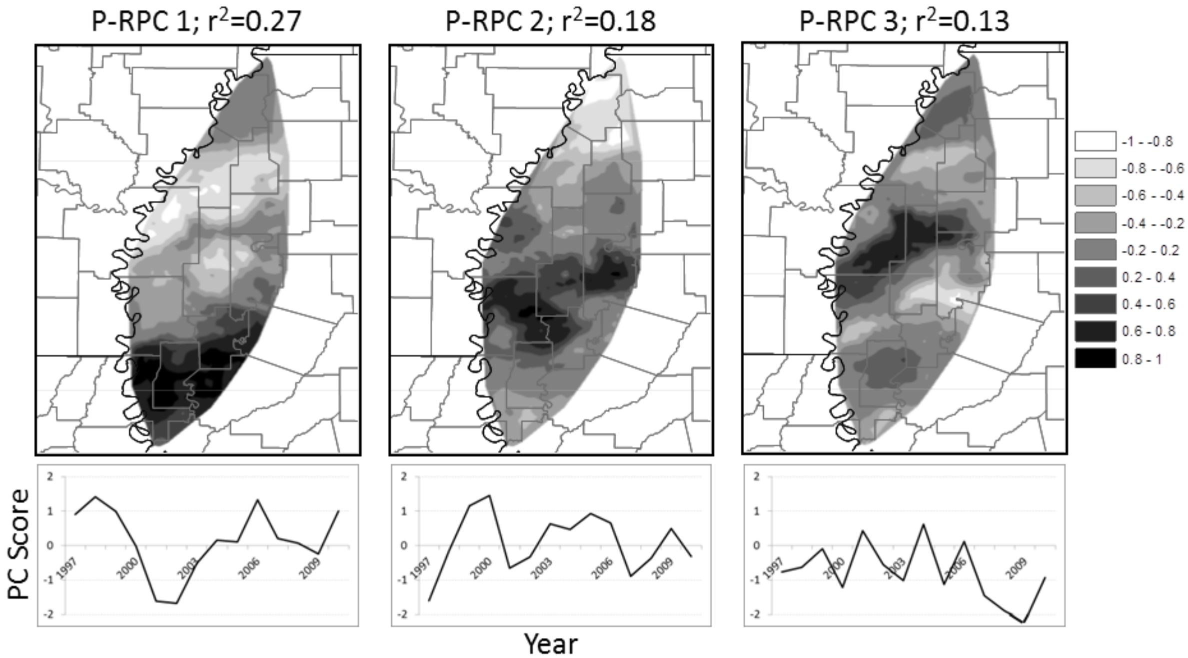

Figure 11. First three RPCs of 1996-2011 cool-season (October – April) multi-sensor precipitation depths over the Mississippi Delta study area. The score time series associated with each RPC is below the respective anomaly map.

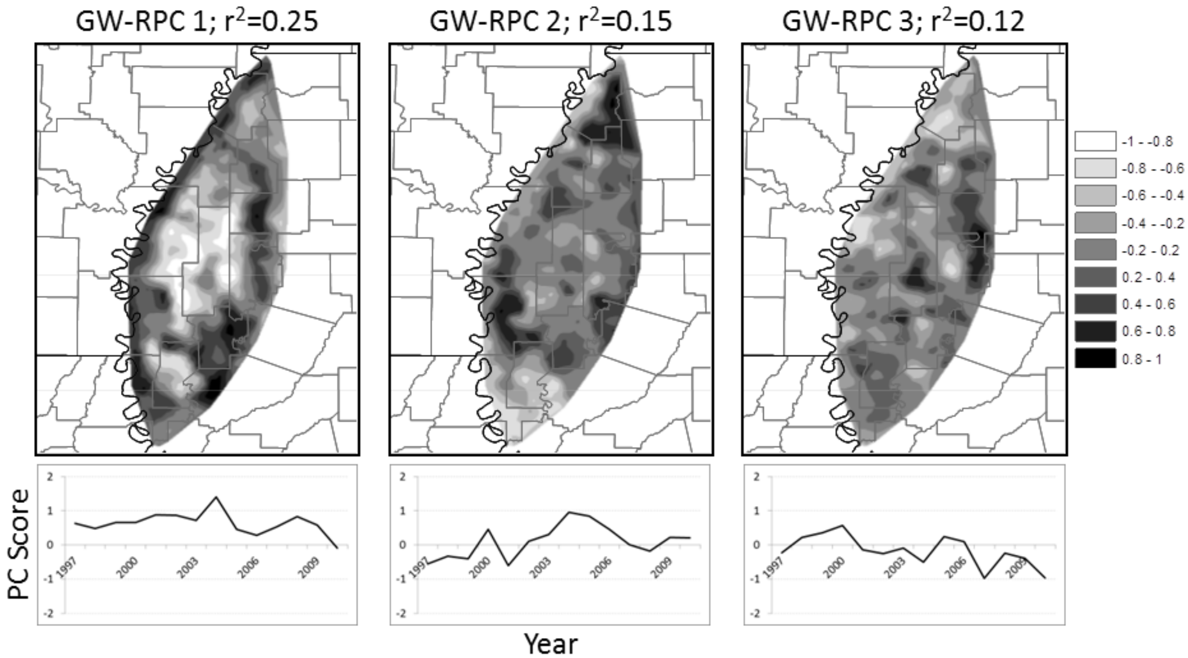

Figure 12. First three RPCs of 1996-2011 cool-season (October – April) changes in groundwater depths over the Mississippi Delta study area, as measured in the shallow LMRAA. The score time series associated with each RPC is below the respective anomaly map.

5. Significant Findings

This project utilized gridded multi-sensor (radar and surface) precipitation estimates to define local-scale precipitation patterns over the lower Mississippi River alluvial valley; specifically, the Mississippi Delta region. Utilizing a rotated principal components analysis (RPCA), the primary modes of variability of the precipitation over the area were examined to determine how and where precipitation is highest and lowest on an annual basis, as well as the stability of these patterns over the 1996-2012 period.

Results indicated that there was a clear differentiation of rainfall depth within the Mississippi Delta and areas to the east and south, likely a result of thermal boundaries generated through surface heat and moisture fluxes. This agrees with findings by Dyer (2011) that there is a noticeable and substantial change in rainfall amount and distribution over the area as a result of land use practices. Additionally, the RPCA of monthly and seasonal precipitation shows that overall rainfall patterns in the cool season (Oct. – Apr.) are dominated by synoptic-scale frontal systems, with considerable variation between the northern and southern extent of the study area; however, rainfall is shown to be increasing through central Alabama and decreasing in northwestern Mississippi, indicating a shift in moisture patterns and rainfall generation areas.

Analysis of warm-season precipitation shows no significant trend in spatial rainfall patterns and a high degree of spatial variability. Given the convective nature of rainfall generation during this period, it is likely that land cover variations play a larger role than atmospheric flow patterns in determining the location and intensity of rainfall at any given location. As a result, prediction of rainfall occurrence and depth is extremely difficult during the warm season and cannot be relied upon for accurate water resources decisions.

The investigation of groundwater recharge zones utilizing gridded multi-sensor rainfall estimates and RPCA methods yielded two primary results. First, the primary recharge zone in which meteoric water is introduced into the LMRAA is along the Tallahatchie River basin, with additional recharge zones along the eastern periphery of the Mississippi Delta. Second, the primary season for recharge of the shallow alluvial aquifer is the fall and early winter, which is when regional precipitation increases and the overall water budget (input minus output) becomes positive.

This positive water budget continues throughout the cool season, and precipitation variability during this time is relatively low. As a result, it can be concluded that intelligent dissemination of available groundwater resources during the growing season can lead to consistent water availability; however, given current extraction rates, recharge into the shallow aquifer through natural precipitation cannot sustain groundwater levels.

6. Future Research

The results of the first part of this project provide a good baseline for precipitation patterns and variability over the lower Mississippi River alluvial valley, which can be used for further investigation into the potential future changes in rainfall over the region. Although a much longer period of record of precipitation data is necessary to perform a robust statistical evaluation of future rainfall trends, this information can be used in conjunction with estimates of climate variability from global climate models (GCM) to predict regional-scale water resource availability and related management strategies in the near future (< 20 years).

Regarding research related to groundwater levels in the LMRAA, although this project showed the relative locations of recharge zones given by the correlation of groundwater fluctuations and precipitation, it is important to verify potential recharge zones through quantification of physical controls. This includes assessment of the role of precipitation in aquifer levels, determination of aquifer flow velocity and direction, and the influence of recharge in the LMRAA through non-atmospheric water (i.e., cross-aquifer flow). One approach that can address these questions includes an assessment of the connection between rainfall and groundwater using isotopic composition of oxygen and hydrogen (a.k.a., the "rain-out" effect). The method describes the progressive change in isotopic composition of precipitation (from heavier to lighter) through storm cycles. Combined with a diagnosis of prevailing weather patterns, this will results in a stable spatial dependence of mean isotopic composition of atmospheric water reaching the surface.

7. Information Transfer and Dissemination

The results of the research conducted during the course of this project have been disseminated through peer-reviewed publications and conference presentations. The results from the first part of this project have been published in the *Journal of Hydrometeorology*, while the second set of results has been submitted to the *Journal of Hydrology*. Additionally, findings were presented at the 2013 Mississippi Water Resources Conference in Jackson, Mississippi and the 2013 American Meteorological Society (AMS) annual meeting in Austin, Texas.

References to the two articles are as follows:

Dyer, J. L., A. Mercer, and A. Grimes, 2013: Identification of surface recharge zones in the lower Mississippi River alluvial aquifer utilizing high-resolution precipitation estimates. *J. Hydrology*, submitted.

Dyer, J. L. and A. Mercer, 2013: Assessment of rainfall variability and trends over the lower Mississippi River alluvial valley using NEXRAD precipitation estimates. *Journal of Hydrometeorology*, doi:10.1175/JHM-D-12-0163.1, in press.

8. Student Training

A portion of the research associated with this project was done by Alexandria Grimes, a MS student in the Department of Geosciences at MSU. Although her current research is not directly associated with objectives related to this project, she is conducting research related to atmospheric prediction utilizing rotated PCAs. Experience while working on this project has helped Ms. Grimes in the development of the objectives and methodology for her thesis; therefore, the training provided to her has been beneficial.

9. Financial Summary

Initial budget for funded project:

Cost Category		Percent Time Devoted to Project	Total Salary	Federal Contribution	State Contribution	Matching Contribution	Total
1. Salaries and Wages	PI	15.0%	$58,732	$4,695	$4,115	$0	$8,810
	co-PI	5.0%	$53,656	$1,341	$1,341	$0	$2,682
	GRA	50%	$12,000	$3,000	$3,000	$0	$6,000
	Total			$9,036	$8,456	$0	$17,492
2. Fringe Benefits	33.18% of faculty salaries			$2,003	$1,810	$0	$3,813
	0.76% of GRA salary			$23	$23	$0	$46
	GRA tuition for Fall 2012			$1,307	$871	$0	$2,178
3. Materials and Supplies				$750	$250	$0	$1,000
4. Permanent Equipment				$0	$0	$0	$0
5. Travel				$2,000	$500	$0	$2,500
6. Other Direct Costs				$2,500	$500	$20,000	$23,000
Total Direct Costs				$17,618	$12,410	$20,000	$50,029
8. Indirect Costs				$0	$5,135	$7,259	$12,394
9. Total Estimated Costs				$17,618	$17,545	$27,259	$62,422

Expenditures during quarterly reporting periods:

1st quarter [3/1/2012 – 6/30/2012]:
Federal:$0.00, Non-Federal:$0.00, Cost Share: $0.00

2nd quarter [7/1/2012 – 9/30/2012]:
Federal:$11,156.00, Non-Federal:$0.00, Cost Share:$0.00

3rd quarter [10/1/2012 – 12/31/2012]:
Federal:$5,627.63, Non-Federal:$465.00, Cost Share: $20,000.00

4th quarter [1/1/2013 – 2/28/2013]:
Federal:$0.00,Non-Federal:$6,644.03, Cost Share: $7,259.00

A request for an extension was submitted and approved, leading to expenditures from 3/1/2013 through 12/31/2013 as follows:

Federal:$2515.31,Non-Federal:$3026.86, Cost Share: $0.00

Interdisciplinary Assessment of Mercury Transport, Fate and Risk in Enid Lake, Mississippi

Basic Information

Title:	Interdisciplinary Assessment of Mercury Transport, Fate and Risk in Enid Lake, Mississippi
Project Number:	2013MS182B
Start Date:	3/1/2013
End Date:	5/1/2014
Funding Source:	104B
Congressional District:	1st
Research Category:	Water Quality
Focus Category:	Water Quality, Sediments, Surface Water
Descriptors:	
Principal Investigators:	Xiaobo Chao, James Cizdziel, AKM Azad Hossain, Kristine L. Willett

Publications

1. Quarterly reports to MWRRI.
2. Chao, X., Y. Jia, A.K.M. A. Hossain and J. Cizdziel, 2013, Numerical Modeling of Flow and Sediment transport in Enid Lake, Mississippi, presented at Mid-South Annual Engineering and Science Conference (MAESC 2013), Oxford, MS, October 28-29.
3. Hossain, A.K.M. A., Y. Jia, X. Chao, M.S. Altinaker, Y. Ding and S.S.Y. Wang, 2013, Application of Remote Sensing Techniques in Modeling Flow, Sediment and Pollutant Transport in Surface Water, Mid-South Annual Engineering and Science Conference (MAESC 2013), Oxford, MS, October 28-29.

Mississippi Water Resources Research Institute (MWRRI)

Quarterly Report – (From) MM/DD/YY – (To) MM/DD/YY

Reports due: 1st (March 31); 2nd (June 30); 3rd (Sept. 30); 4th (Dec. 31)

Note: Please complete form in 11 point font and do not exceed two pages. You may reference and append additional material to the report.

SECTION I: Contact Information

Project Title: Interdisciplinary Assessment of Mercury Transport, Fate and Risk in Enid Lake, Mississippi
Principal Investigator: Xiaobo Chao
Institution: University of Mississippi
Address: 322 Brevard Hall, NCCHE, School of Engineering
Phone/Fax: 662-915-8964
E-Mail: chao@ncche.olemiss.edu

SECTION II: Programmatic Information

Approximate expenditures during reporting period:

Federal:_$991.71_, Non-Federal (MWRRI):_$0.00_, Non-Federal (Dept.):_$1,233.50_, In-Kind:________, Total Cost Share:_$1,233.50_

Equipment (and cost) purchased during reporting period:

Progress Report (Where are you at in your work plan):

Quarterly report ending 6-30-13
1. Samples of water, sediment and fish were collected from Enid Lake.
2. The samples were analyzed for total-mercury concentrations using combustion-atomic absorption spectrometry and cold vapor atomic fluorescence spectrometry.
3. The digital bathymetric data of the Enid Lake was generated based on the lake fish map.
4. The computational domain of the lake was generated based on satellite imagery.
5. A three-dimensional numerical model was developed to simulate the flow fields of a storm event occurred on March 10, 2013.
6. Near-real time MODIS reflectance imagery was collected on the corresponding water sample collection dates.

Quarterly report ending 9-30-13
1. Sediment and total mercury concentrations in Enid Lake were analyzed from the samples collected in Quarter 1.
2. A three-dimensional numerical model has been developed to simulate the flow fields and sediment transport in Enid Lake.
3. Satellite imagery was collected to compare the suspended sediment concentration obtained from field measurement and numerical model.

Quarterly report ending 12-31-13
1. Surface water samples were collected from 31 different locations in Enid Lake on Nov. 19-20, 2013. The samples were analyzed for TSS and Total-Hg. Results are being tabulated.
2. Risk assessment of mercury in Enid Lake is being analyzed.
3. A mercury model has been developed to simulate the mercury concentration in Enid Lake.
4. Satellite imagery on Nov. 19-20 was collected for comparing the suspended sediment concentration obtained from field measurement.

Quarterly report ending 3-31-14

1. Satellite imagery acquired on Nov. 19-20 has been processed and calibrated with the suspended sediment concentration (TSC) and associated mercury concentration (Hg) measurements obtained from field measurement. Based on new calibration results both TSC and Hg are being estimated using both March 12 and Nov 20, 2013 imagery.
2. Developed a 3D model to simulate suspended sediment and Total Hg in the lake, and compare the results with field measurements, and satellite imagery.
3. A statistical analysis of mercury data for Crappie (CR), Largemouth Bass (LMB), and Channel Catfish (CC) from Enid Lakes has been conducted.
4. A mercury risk assessment for consumption of fish from the lake was also conducted.

Problems Encountered:

None

Publications/Presentations (Please provide a citation and if possible a .PDF of the publication or PowerPoint):

Chao, X., Jia, Y., and Hossain, A. K. M. A. (2013), Three-dimensional Numerical Modeling of Wind-induced Flow and Mass Transport in Natural Lakes, The 35th Congress of International Association for Hydraulic Research (IAHR), Sept.8-13,Chengdu, China (CD-ROM).

Chao, X., Jia, Y., Hossain, A. K. M. A, Cizdziel, J. (2013), Numerical Modeling of Flow and Sediment Transport in Enid Lake, Mississippi, Mid-South Annual Engineering and Science Conference (MAESC 2013), MAESC 2013, Oxford, MS, Oct.28-29.

Hossain, A. K. M. A, Jia, Y., Chao, X., Altinakar, M.S., Ding Y. and Wang S.S.Y. (2013), Application of Remote Sensing Techniques in Modeling Flow, Sediment and Pollutant Transport in Surface Water, Mid-South Annual Engineering and Science Conference (MAESC 2013), MAESC 2013, Oxford, MS, Oct.28-29.

Preparation two presentations (oral and poster) for the 2014 MWRC annual conference April 1-2 in Jackson, MS.

Student Training (list all students working on or funded by this project)

Name	Level	Major
Garry Brown	graduate student	Chemistry
Divya Nallamo	graduate student	Chemistry
Stacy Wolff	undergraduate	Forensic Chemistry

Next Quarter Plans:

Quarterly report ending 6-30-13

1. Organize, assess, and interpret the data collected in Quarter 1.
2. The field sampling data will be used to calibrate the satellite imagery.
3. Analyze the calibrated satellite data to generate the spatial distribution of suspended sediment for the entire lake.
4. Mercury concentration will also be studied for the entire lake based on the suspended sediment distribution obtained from satellite data analysis.
5. A 3D numerical model will be developed to simulate the concentration of suspended

sediment in Enid Lake.
6. More satellite imagery will be collected to validate the numerical model.

Quarterly report ending 9-30-14
1. We are having a student estimate mercury concentration in a standard-size fish to facilitate comparisons between the lakes and compensate for size-effects.
2. Field trip to Enid Lake to collect more samples and measure the flow fields of the lake.
3. More satellite imagery will be collected to validate the numerical model and compare with the field measurements.
4. A 3D numerical model will be developed to simulate the mercury concentration in Enid Lake.
5. A student will conduct default and site specific risk assessments based on fish tissue analyses.

Quarterly report ending 12-31-13
1. Complete the risk assessment of mercury in Enid Lake.
2. Complete the analysis of samples collected in Enid Lake on Nov. 19-20, 2013.
3. Apply the developed model to simulate the flow, SS and Total Hg in the lake, and compare the results with field measurements, and satellite imagery.
4. Complete the final project report.
Quarterly report ending 3-31-14
1. Complete the final project report.
2. Publish more papers.

Section III. Signatures

Project Manager **Date**

Non-linear downward flux of water in response to increasing wetland water depth and its influence on groundwater recharge, soil chemistry, and wetland tree growth

Basic Information

Title:	Non-linear downward flux of water in response to increasing wetland water depth and its influence on groundwater recharge, soil chemistry, and wetland tree growth
Project Number:	2013MS183B
Start Date:	3/1/2013
End Date:	12/31/2014
Funding Source:	104B
Congressional District:	1st
Research Category:	Climate and Hydrologic Processes
Focus Category:	Wetlands, Hydrology, Management and Planning
Descriptors:	
Principal Investigators:	Gregg R. Davidson

Publication

1. Quarterly reports to MWRRI.

Mississippi Water Resources Research Institute (MWRRI)

Quarterly Report – (From) MM/DD/YY – (To) MM/DD/YY

Reports due: 1st (March 31); 2nd (June 30); 3rd (Sept. 30); 4th (Dec. 31)

Note: Please complete form in 11 point font and do not exceed two pages. You may reference and append additional material to the report.

SECTION I: Contact Information

Project Title: Non-linear downward flux of water in response to increasing wetland water depth and its influence on groundwater recharge, soil chemistry, and wetland tree growth

Principal Investigator: Gregg Davidson
Institution: University of Mississippi
Address: Geology & Geological Engineering, Carrier 120, University, MS 38677
Phone/Fax: 662-915-5824 / 662-915-5998
E-Mail: Davidson@olemiss.edu

SECTION II: Programmatic Information

Approximate expenditures during reporting period:

Federal:_$15,516.94_, Non-Federal (MWRRI):_$12,745.18_, Non-Federal (Dept.):_$6,827.46_, In-Kind:________, Total Cost Share:_$19,572.64_

Equipment (and cost) purchased during reporting period:
Quarterly report ending 6-30-13
All the equipment required to set up the study was purchased during the first quarter. This includes a Dynamax XM1000 data logger and control system, plus accompanying sap flow, pH, temperature, relative humidity, conductivity, and dissolved oxygen probes. Approximate cost: $10k.

Quarterly report ending 9-30-13
All the major equipment required to set up the study was purchased in the first quarter. No additional equipment expenditures were made in the current quarter.
Expenditures this quarter were for PI summer support, travel to the field site, and a battery.

Progress Report (Where are you at in your work plan):
Quarterly report ending 6-30-13
The data-logger/controller was installed along the boardwalk at Sky Lake, piezometers were placed, and all sensors and probes were deployed during the first quarter. Pressure transducers were also deployed in piezometers and in an abandoned irrigation well located inside the Sky Lake meander loop. Probes were tested and data collection has begun. Photos are included with this report.

Quarterly report ending 9-30-13
Second quarter work has largely been devoted to data collection and maintenance of equipment at the field site, as well as preliminary data analysis.

Quarterly report ending 12-31-13
Data continues to be collected following the end of the growing season and the initiation of the winter flooding. Data is being analyzed to determine the usefulness of sap flow as a measure of

tree growth by comparing with a record of daily changes in tree circumference. The growing season chemistry and water level data is being analyzed to determine if any changes need to be made in preparation for the next growing season.

Quarterly report ending 3-31-14
Progress is on track for completion of data collection through a second growing season. All equipment is installed and functional, and a first round of analysis has been carried out on the Eh, groundwater, and radial expansion data, with results that suggest that water is moving downward through the wetland sediment in response to increasing wetland water depth. Eh levels consistently rose at two locations in response to water depths in excess of 1 m, which is consistent with the downward transport of oxygenated water at these sites when the threshold water depth is reached.

Problems Encountered:
Quarterly report ending 6-30-13
Animal life poses a continuous threat to instrumentation and wiring. Birds pecked away at insulation on some wiring, but all sensors appear to be functioning correctly.

Quarterly report ending 9-30-13, 12-31-13, and 3-31-14
Animal life poses a continuous threat to instrumentation and wiring, though all equipment is currently working as designed.

Publications/Presentations (Please provide a citation and if possible a .PDF of the publication or PowerPoint):
Chayan Lahiri will present preliminary results at the WRRI conference in April.

Student Training (list all students working on or funded by this project)

Name	Level	Major
Chayan Lahiri	Ph.D. candidate	Hydrology
Michael Jones	undergraduate	Geological Engineering

Next Quarter Plans:
Quarterly report ending 6-30-13, 9-30-13
Continued data collection through the growing season and data analysis.

Quarterly report ending 12-31-13
Continued data collection through the winter. Data analysis. Submission of abstract for the WRRI conference. A no cost extension request is being prepared (independent of the quarterly report) to allow data collection through a second growing season. An undergraduate student is also being brought into the project to assist with data collection and analysis.

Quarterly report ending 3-31-14
Continued data collection through a second growing season. Additional data analysis that will include the sap flow data and environmental variables such as relative humidity, temperature, and precipitation. Discussion is also underway with MDEQ on adding more groundwater wells at the site to increase the ability to specifically link groundwater changes with recharge from the wetland.

Section III. Signatures

Project Manager **Date**

Submit form electronically on or before due date to:
Jessie Schmidt, Coordinator, jschmidt@cfr.msstate.edu
4/16/2014

Information Transfer Program Introduction

The research approach described in this document is designed to inform water resources planners and managers by providing them with the scientific information and understanding that they need. Also, the effective transfer of knowledge to water users and stakeholders is essential for a well-informed public in order to realize the overarching goal of sustainable water resources and ecosystems of good quality and ample quantity while sustaining a good economy and quality of life for current and future generations. Working with MWRRI's member Institutions of Higher Learning, MSU's Extension Service and REACH program are uniquely positioned to advance and sustain the transfer and application of knowledge gained through MWRRI's integrated water resources research approach. As a function of its role as an information hub on water resources issues within the state and region, MWRRI routinely uses Extension and REACH to transfer its research findings to the public in addition to the outreach provided by its cooperators through published articles, formal presentations, technical poster sessions, and other outreach materials.

USGS Summer Intern Program

None.

Student Support					
Category	Section 104 Base Grant	Section 104 NCGP Award	NIWR-USGS Internship	Supplemental Awards	Total
Undergraduate	8	0	0	0	8
Masters	4	0	0	0	4
Ph.D.	2	0	0	0	2
Post-Doc.	0	0	0	0	0
Total	14	0	0	0	14

Notable Awards and Achievements

Through the expertise and dedication of its academic and professional staff, MSU and the MWRRI have earned enviable reputations for their water resources-related work. As a result of this recognition, on April 9, 2013, MSU through the MWRRI was designated by Region 4 of the U.S. Environmental Protection Agency (EPA) and the Mississippi Department of Environmental Quality (MDEQ) as a Center of Excellence for Watershed Management with the formal signing of a Memorandum of Understanding (MOU) by these parties. The MOU acknowledges that the MWRRI had demonstrated to the satisfaction of EPA and MDEQ that it has the capacity and capability to identify and address the needs of local watershed stakeholders and that it has support at the appropriate levels of MSU. It also specifies the Center of Excellence to serve as the point of contact and primary coordinating entity for colleges and universities in Mississippi. The primary purpose of the Center of Excellence is to utilize the diverse talent and expertise of colleges and universities by providing hands on practical products and services to help communities identify watershed-based problems and develop and implement locally-sustainable solutions. The MOU also guides the Center of Excellence to actively seek out watershed-based stakeholders that need assistance with project development and management, research and monitoring, education and outreach, engineering design, computer mapping, legal and policy review, and other water resource planning and implementation needs. Annual commitments of the MWRRI to maintain the designation are also identified in the MOU.