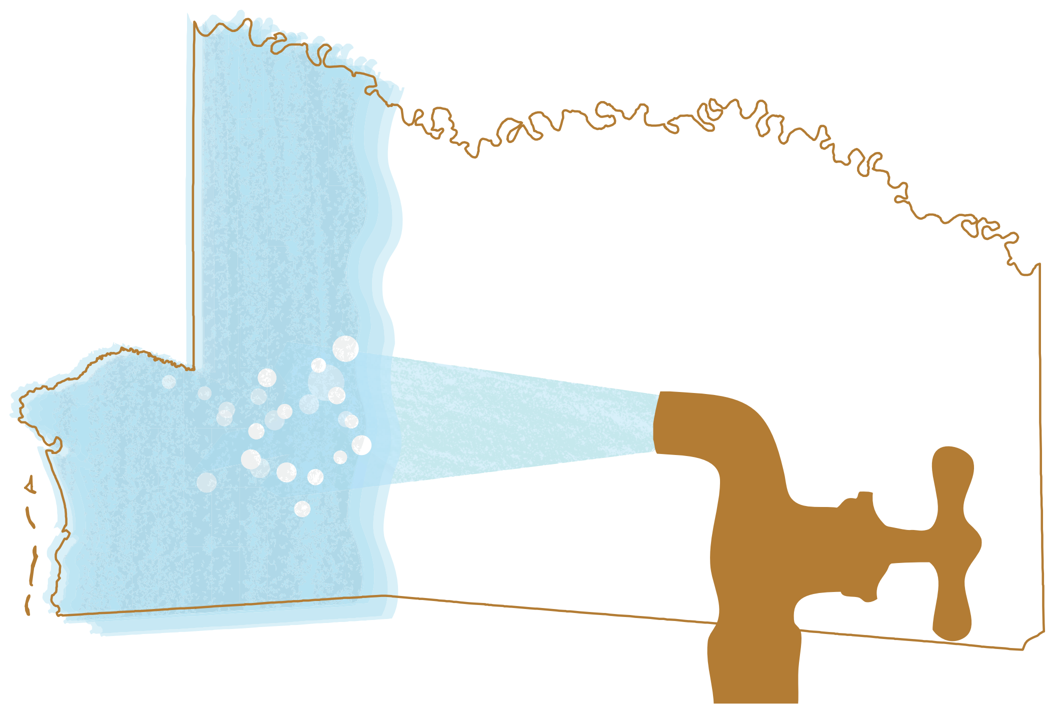
2009

# Mississippi Water Resources Conference

Harrah's Mid-South Convention Center Tunica, MS



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# Improving the Capacity of Mississippi's Rural Water Associations Through Board Management Training

Jason Barrett, Mississippi State University

The Mississippi legislature enacted legislation designed to increase the capacity of Mississippi's rural water associations' boards and small municipal water systems' government officials to provide safe drinking water and be aware of the technical and legal responsibilities assumed by these individuals. This legislation mandated that the Mississippi State Department of Health (MSDH), in cooperation with other organizations such as the Mississippi Rural Water Association (MSRWA), provide training to the governing bodies of these systems. To this end, the MSDH contracted with the Mississippi State University Extension Service (MSUES) to develop training curricula and provide coordination and evaluative services to facilitate the provision of quality training opportunities accessible to clientele across the state. Furthermore, partnerships between MSUES, MSRWA, the Mississippi Water and Pollution Control Operators Association, and the Community Resource Group, have resulted in the development of several cutting edge curricula that have been nationally recognized.

Key words: Board management training, capacity enhancement, curricula development

# Detection of *Salmonella* from Mississippi Coastal Waters and Sediment

Matthew R. Carr, University of Southern Mississippi
Dr. R.D. Ellender, University of Southern Mississippi
Christopher Flood, University of Southern Mississippi

Traditionally, the examination of individual pathogens for assessment of water quality has not been employed. This is mainly due to the cost and time requirements required to perform the appropriate morphological and biochemical analysis for positive identification of these pathogens. However, the employment of molecular analysis techniques supplemented with traditional techniques allows for more rapid and accurate identification. The main goal of this research is to determine if the marker *stn*, which codes for an enterotoxin gene specific for salmonella, is present within Mississippi Gulf Coast waters and creek systems, which flow into the Gulf. This research also is aimed at determining if the salmonella marker is present within coastal sediments. Environmental factors such as salinity, temperature, tidal currents, and significant weather related events will be examined to understand the relationship to the presence of the salmonella marker. Examination of salinity's effect on both laboratory grown and environmentally isolated *Salmonella* indicates a difference in the survivability of this pathogen within given concentrations of NaCl *in situ*. Analysis of *Salmonella* subspecies in coastal waters and sediments using both traditional and genetic analysis has demonstrated that this bacterium is frequently found in samples from fresh water creeks but is found infrequently in coastal waters. Further, sediment samples to date have not revealed the presence of *Salmonella*, implying that this environment is not conducive to the survivability of this animal pathogen.

Key words: Water Quality, Recreational Water, Pathogen, Wastewater, Water use

# Using Human Specific Molecular Markers to Monitor Water Quality Along the Mississippi Gulf Coast

Christopher Flood, University of Southern Mississippi
Matthew Carr , University of Southern Mississippi
Dr. R.D. Ellender, University of Southern Mississippi

Our research examines the efficacy of using library independent methods and human specific marker to monitor the water quality of the Mississippi Gulf Coast. The two markers currently employed are *Methanobrevibacter smithii* and *Bacteroides* sp. *M. smithii* represents a methanogen that is commonly found in human feces and sewage. *Bacteroides sp.* are a major component of the intestinal flora in humans. Our goal is to examine the dynamic relationship of the physical and climatological variables that may influence the presence or absence of these markers in the natural environment. In the future, the inherent survivability of these markers will also be examined with relationship to water temperature, salinity, and turbidity. Temporal spatial relationships of the two markers are considered with respect to the presence or absence at certain collection sites. The collection sites mirror the sites monitored by MDEQ and represent an area of the coast that is commonly used for recreational purposes, but is also frequently closed due to high indicator counts.

An analysis of 12 months of coastal sampling contrasting the average enteroccoccal count at each sampling site, the percentage of times that the *M. smithii* marker appeared in each coastal sample, and the percentage of times that the *Bacteroides* marker appeared indicated that there was no statistical difference between the EN count and the percentages of either marker. In addition, there was a significant correlation between the percentage of *Bacteroides* and the percentage of *M. smithii* when all samples were grouped (0.9503). An analysis of the enteroccocal counts in creeks which drain into the beech environment revealed a significant difference between those coastal sites influenced by creek water versus those not influenced by creek water (P=0.0531). However, both the *M.smithii* and *Bacteroides* markers showed a positive correlation (0.7923) between creek versus non creek sites, demonstrating an apparent influence of the creek water on the presence or absence of the markers in coastal waters.

Key words: Waste water, water quality, water use

# Restoring Canebrakes to Enhance Water Quality Along the Upper Pearl River

Rachel Jolley, Mississippi State University
Diana Neal, Mississippi State University
Brian Baldwin, Mississippi State University
Gary Ervin, Mississippi State University

Large stands of rivercane [*Arundinaria gigantea* (Walt.) Muhl.], called canebrakes, initially covered millions of acres in the southeast US, playing a pivotal role in the hydrology, landscape ecology, and the cultural history of the First Nations of the Southeast. Because canebrakes are composed of very dense stands of rivercane, they act as ideal riparian buffers, dispersing overland flow, increasing soil porosity, and stabilizing streambanks. Unfortunately, large canebrakes have all but disappeared from the landscape due to overgrazing, agriculture, altered fire and flood regimes, and urban encroachment. In an effort to enhance water quality and wildlife habitat along the upper reaches of the Pearl River, a rivercane restoration project was initiated in June 2008. Over 1,200 rivercane seedlings were planted at eleven locations along a half-mile stretch of the Pearl River on land belonging to the Mississippi Band of Choctaw Indians (MBCI). Planting sites were selected as those susceptible to erosion (outer bends) and deposition (inner bends) in order to monitor the effect of canebrake establishment on stream bank stabilization. An additional nine sites were chosen along this same stretch for comparison (three sites with established rivercane and six without). Sediment markers were installed to monitor sediment depths within and outside of planting areas. Additional sediment markers were also inserted horizontally into eroding banks to monitor bank-sloughing along planted areas. Preliminary data indicate low survivorship in plantings at elevations susceptible to extended periods of inundation (less than 3 m above normal flow). Both planted and unplanted banks show moderate rates of erosion. Due to slow initial growth, rivercane seedlings may require several years to form effective riparian buffers.

Key words: conservation, sediments, water quality

**Introduction**

Early explorers and settlers in the southeastern US often noted the huge expanses of "cane", which dominated areas along streams and rivers (Harper, 1998; Platt & Brantley, 1997; Platt et al., 2002; Stewart, 2007). Rivercane, or giant cane [*Arundinaria gigantea* (Walt.) Muhl], was once a dominant feature along rivers and streams in the southeastern US, forming dense stands referred to as canebrakes. These habitats were sought after by hunters, herdsman and farmers for wildlife abundance, nutritious grazing, and rich soils (Rhodes, 2004; Stewart, 2007). Today, remnant canebrakes are valued for the ecological services they provide, including streambank stabilization, water filtration, and increased soil porosity. Although rivercane is still a common component of the forest understory, it is rare to find dense stands of any significant size (Noss *et al.*, 1995). The demise of canebrakes has been attributed to grazing and agriculture activities, changes in fire frequency, alteration of natural flooding regimes, and land development projects (Brantley & Platt, 2001; Platt & Brantley, 1997; Platt *et al.*, 2002; Stewart, 2007) and has likely contributed to increased erosion and non-point pollution in streams and rivers.

The effectiveness of rivercane as a riparian buffer has been demonstrated in a mature canebrake in southern Illinois. On-going studies at Southern Illinois University show that a mature canebrake (30 year-old) was found to reduce groundwater nitrates by 99% (Schoonover & Williard, 2003), reduce nutrients in surface runoff (nitrate-N, dissolved ammonium-N, total ammonium-N, and total orthophosphate masses) by 100% (Schoonover *et al.*, 2005), and reduce sediments by 100% (Schoonover *et al.*, 2006) within a 10 m buffer. In all cases, the canebrake was a more effective buffer than the adjacent forest.

The objective of this study is to restore rivercane along the banks of the upper Pearl River and determine how rivercane establishment affects rates of sedimentation and erosion. We expected to see greater sediment retention and streambank stability in areas planted in rivercane compared with unplanted areas.

**Methods**

This study was conducted along the upper reaches of the Pearl River, Neshoba County, MS (Fig. 1). Eighteen plots were established along the banks of an approximately 800 m reach of the river. Three plots already had native stands of rivercane (natural stands), eleven plots were planted with rivercane seedlings at a density of 1 plant per $m^2$ (planted stands), and four plots were left unplanted for comparison (non-planted areas). Plot size varied according to the bank topography, with larger plots (averaging 100 $m^2$) on sandy beaches on inside bends and smaller plots (averaging 35 $m^2$) on steep, eroding banks of outside bends.

Restoration plots were planted in June 2008 with a total of 1,200 seedlings. Seedlings were grown in greenhouses at Mississippi State University from seed collected at Cullowhee, NC in May 2007. Seedlings were approximately 10 months old at planting. Each seedling was planted with a slow-release fertilizer pellet (Scotts Agriform™, 21-gram pellets, 20-10-5) and watered with approximately 1.5 liters of water following planting. Over 100 erosion pins, consisting of a 1.2 m rebar segment with a metal washer welded to the center (at 60 cm), were installed at each plot at a density of 1 per 8$m^2$. Each erosion pin also served to mark the sampling location for 1 $m^2$ vegetation quadrats. Sediment depth was measured seasonally from July 2008 to July 2009. Vertical cut-banks were monitored using erosion markers, consisting of a welding rod with bright yellow tape on one end, inserted horizontally approximately 30 cm into the bank.

Data were analyzed using analysis of variance (ANOVA), with repeated measures analysis (Proc GLM, SAS software, Version 9.2, Copyright © 2006 SAS Institute Inc., Cary, NC, USA.). Following significant ANOVA, Tukey's mean comparison test was performed. Differences between means were considered statistically significant at $\alpha$=0.05, unless otherwise noted. Non-normal data (proportions) were analyzed using an arcsine transformation.

**Results and Discussion**

Planted seedlings had moderate survival through the first survey in early August 2008 (49.2%). The high initial mortality was likely due to the late planting (middle of June) and lack of rainfall during the first month following planting (0.12 cm). By fall 2008, survivorship had dropped to 23.4% and by spring 2009, survivorship was only 1.2%. Over-winter mortality was likely due to extended periods of inundation (Fig. 2). Seedlings were planted between 2.5 to 3.0 meters above gage height, while the river height was above 3 meters during much of the winter and early spring. The few rivercane survivors in the spring were those seedlings planted at the highest elevations (data not shown). Natural stands averaged 3.7-4.6 meters above gage height.

Not surprisingly, sedimentation rates did not differ between planted, non-planted, and natural sites (Table 1, Fig. 3-4) or between inside bends, outside bends, and straight segments ($p$=0.56 F=0.59, Fig.5-6) over the first eight months of monitoring. We expected natural stands to retain more sediment than non-planted sites, however, natural stands were found at slightly higher elevations than other areas and likely receive less sediment deposition from flood waters. Natural stands likely had little soil movement, as evidenced by the lower percentage of bare soil in these plots compared to non-planted and planted sites (Table 1). Natural stands exhibited slightly different soil composition as well, with significantly lower percentage of sand than planted and reference sites and a higher percentage of silt (Table 1). Natural stands also had no bank scars to monitor vertical bank loss. Therefore, vertical bank loss could only be compared between planted and non-planted sites (Fig. 7). Planted sites had greater bank loss during the third monitoring period ($p$<0.09, F=3.0). This may be attributed to greater soil disturbance associated with planting. Inside bends did exhibit greater sediment loss during the last monitoring period (p<0.001, F=497.4, Fig. 8).

**Conclusion**

After eight months of monitoring, areas planted with rivercane failed to establish, leading to no significant changes in sediment retention or bank stabilization. The lack of establishment was likely due to several factors, including the late planting date, the lack of rainfall following planting, and inundation by flood waters for an extended period of time. The lack of establishment suggests that perhaps future planting should be conducted earlier in the year (spring), when there is generally higher precipitation and lower evapotranspiration, and at higher elevations (similar to those of the natural stands). In an effort to repeat this study, we planted an additional 300 ramets (propagated from rhizome cuttings) in April 2009 along the upper banks of the study areas (approximately 12-15 feet above gage height). These areas will continue to be monitored seasonally through June 2010.

**Acknowledgments**

This research was funded through a EPA Region 4 Wetland Program Development Grant, with additional funding provided by the NRCS Agriculture Wildlife Conservation Center. Land and resources were provided by the Mississippi Band of Choctaw Indians.

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Table 1. Mean comparison among stand type by sedimentation, bare soil, and soil particle size for study plots along the Pearl River, Neshoba Co., MS. Comparisons were made using ANOVA. Means followed by different letters represent significant differences across stand type by Tukey's HSD (a=0.05).

| | *Natural stands* | *Planted stands* | *Non-planted* | *p-value* | *F statistic* |
|---|---|---|---|---|---|
| Sedimentation rate (cm $month^{-1}$) | 0.33 ± 0.2 | 0.99 ± 0.4 | 0.56 ± 0.6 | 0.61 | 0.49 |
| Bare soil (%) | 11.7 ± 0.1 B | 47.1 ± 0.3 A | 50.9 ± 0.1 A | <0.001 | 18.49 |
| Sand (%) | 67.2 ± 3.6 B | 83.4 ± 1.3 A | 80.6 ± 2.4 A | <0.001 | 5.48 |
| Silt (%) | 29.5 ± 3.6 A | 16.2 ± 2.3 B | 13.6 ± 1.3 B | <0.001 | 5.37 |


Figure 1. Map of study area, showing study section of the Pearl River near Edinburg, MS.

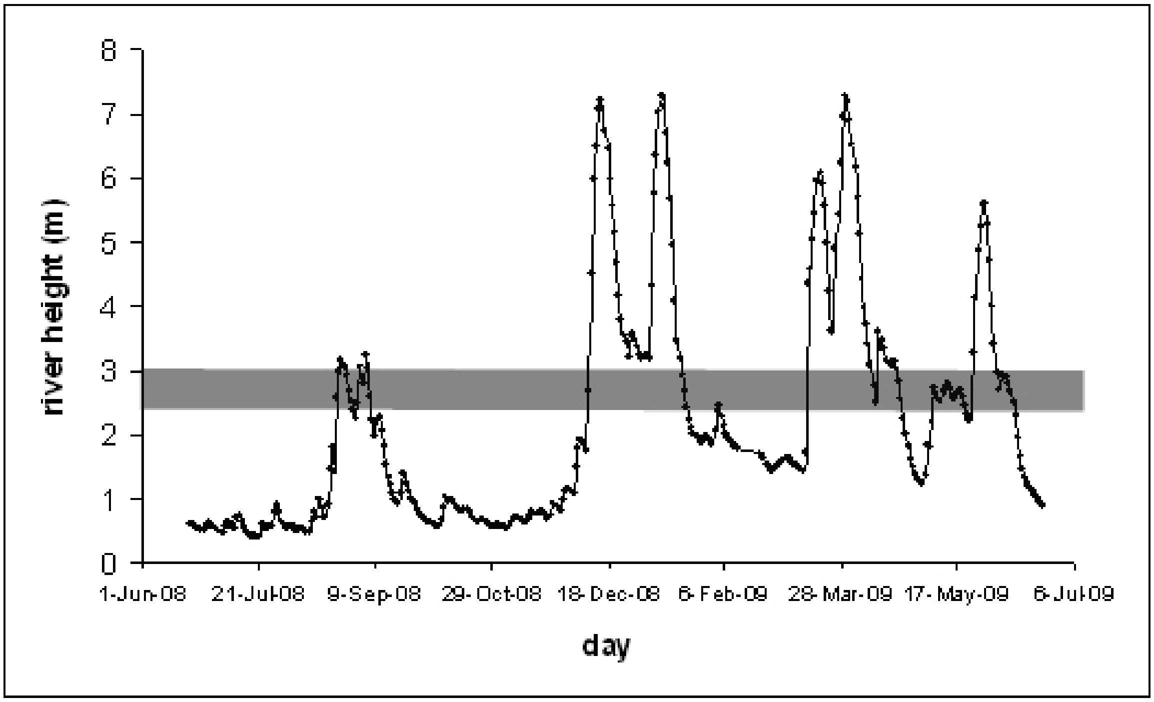


Figure 2. Pearl River water height at the Edinberg Station (approximately 1 mile downstream of study site) from mid-June 2008 to mid-July 2009. Mean planting elevation is represented by the grey band (between 2.5 and 3.0 meters above gage height).

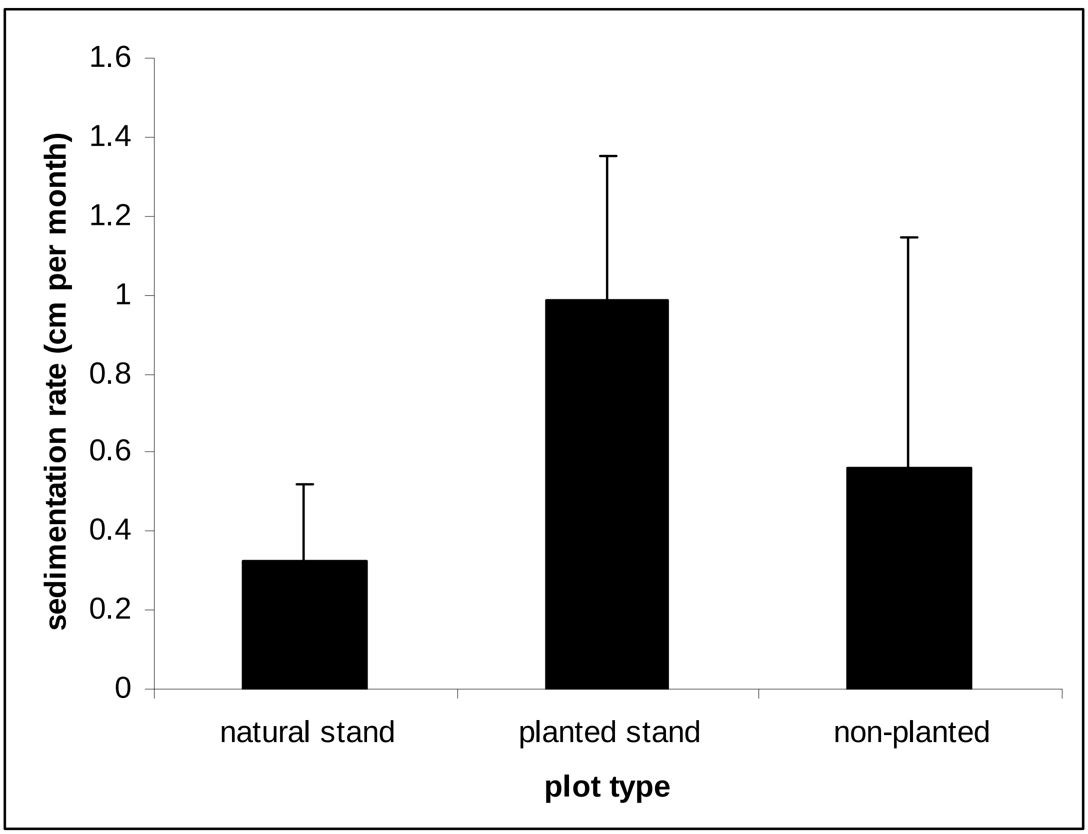


Figure 3. Mean comparison of sedimentation rate among plot types. Means did not differ by type ($\alpha$=0.05).

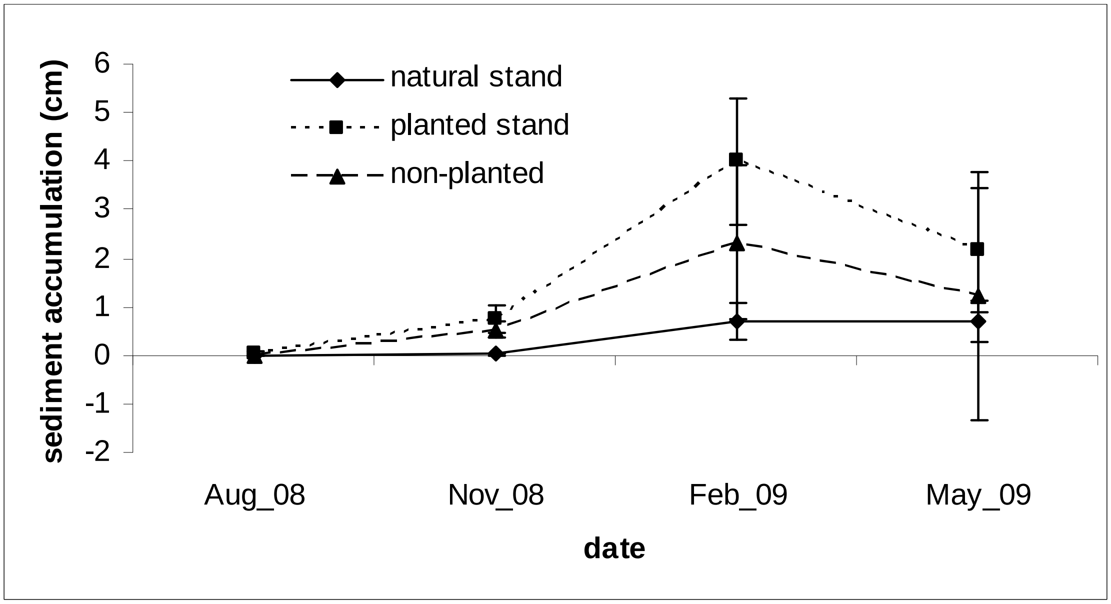


Figure 4. Mean sediment accumulation from August 2008 to May 2009 among plot types. Means did not differ by type ($\alpha$=0.05).

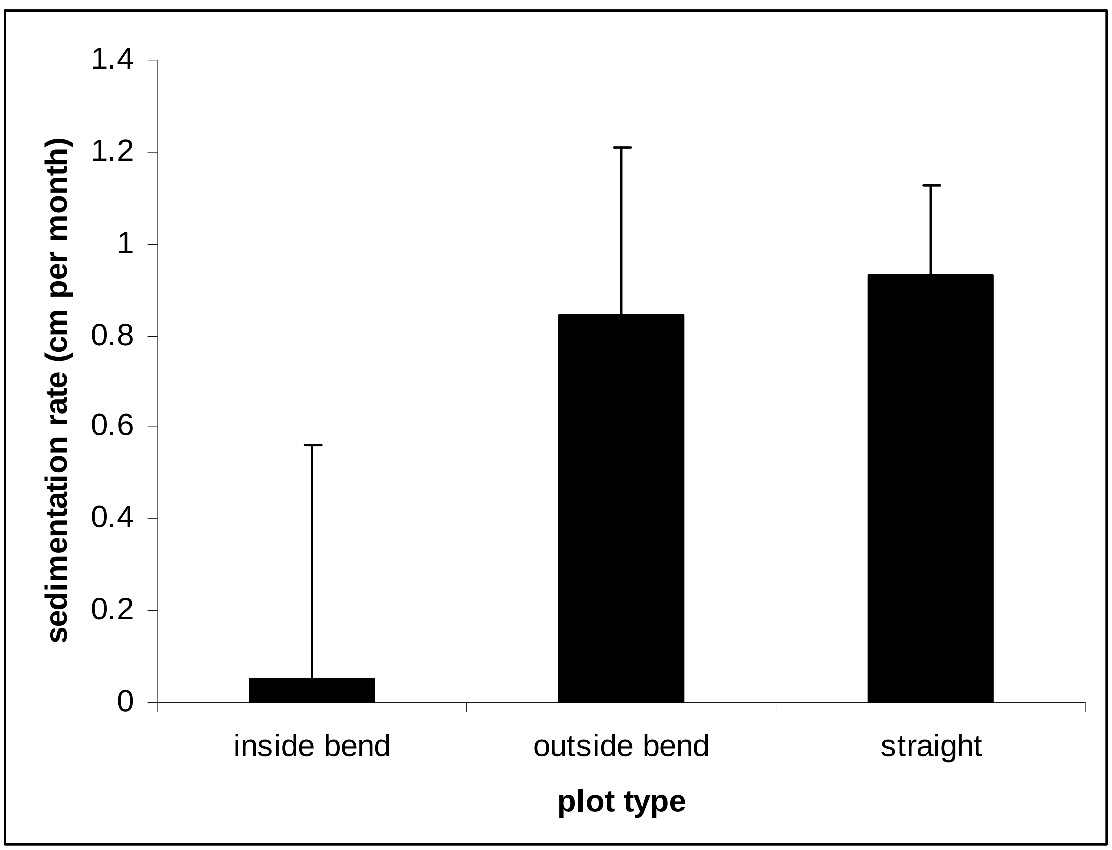


Figure 5. Mean comparison of sedimentation rate among plot types. Means did not differ by type ($\alpha$=0.05).

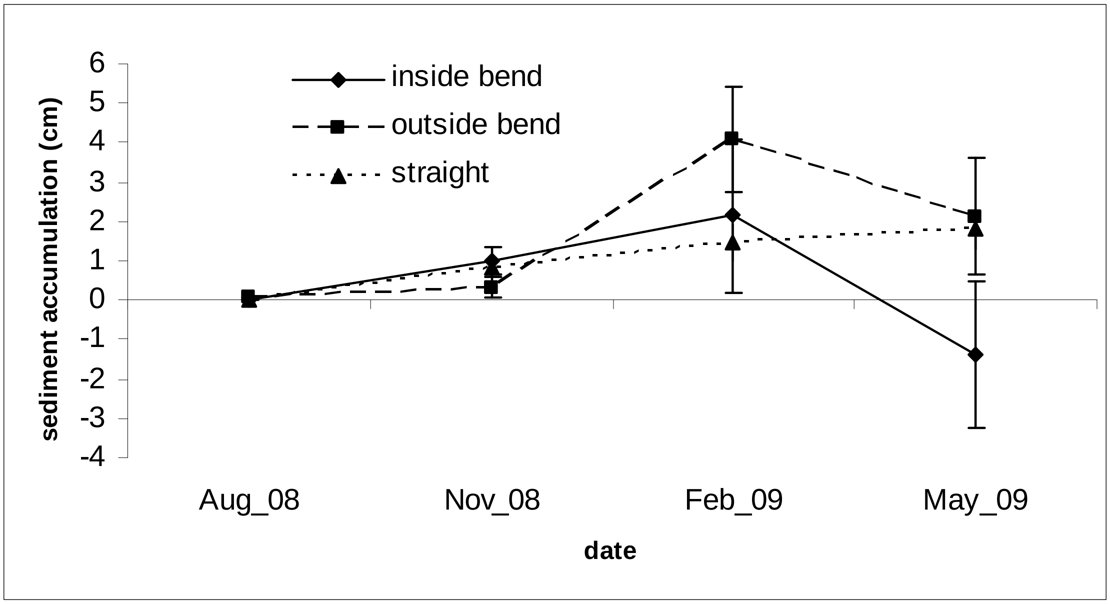


Figure 6. Mean sediment accumulation from August 2008 to May 2009 among plot types. Means did not differ by type ($\alpha$=0.05).

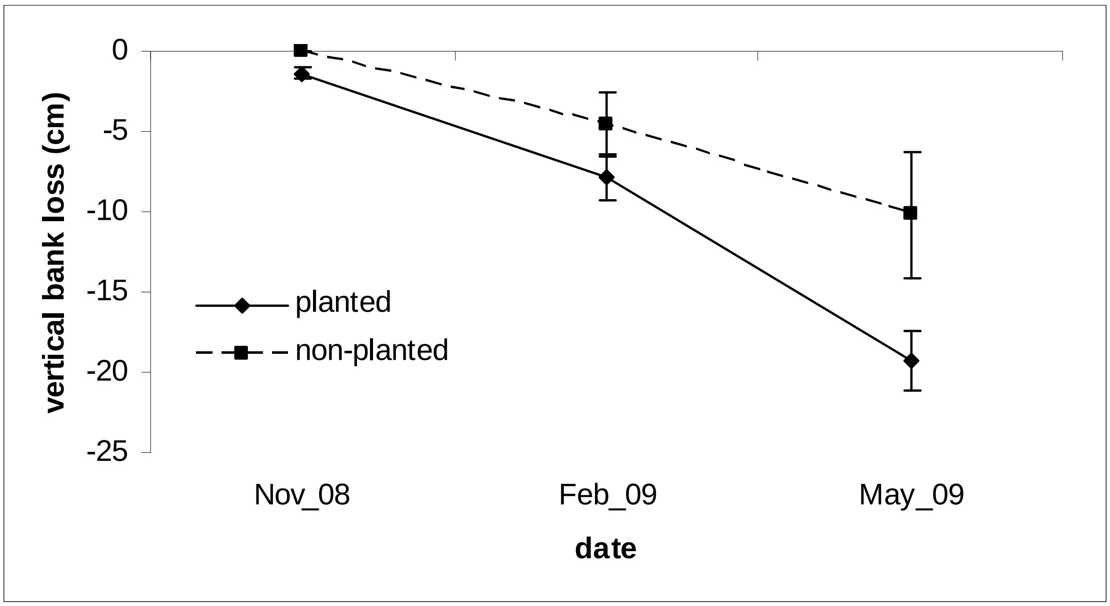


Figure 7. Mean vertical bank loss from November 2008 to May 2009 among plot types. Differences in means in May 09 were significant at $\alpha$=0.09.

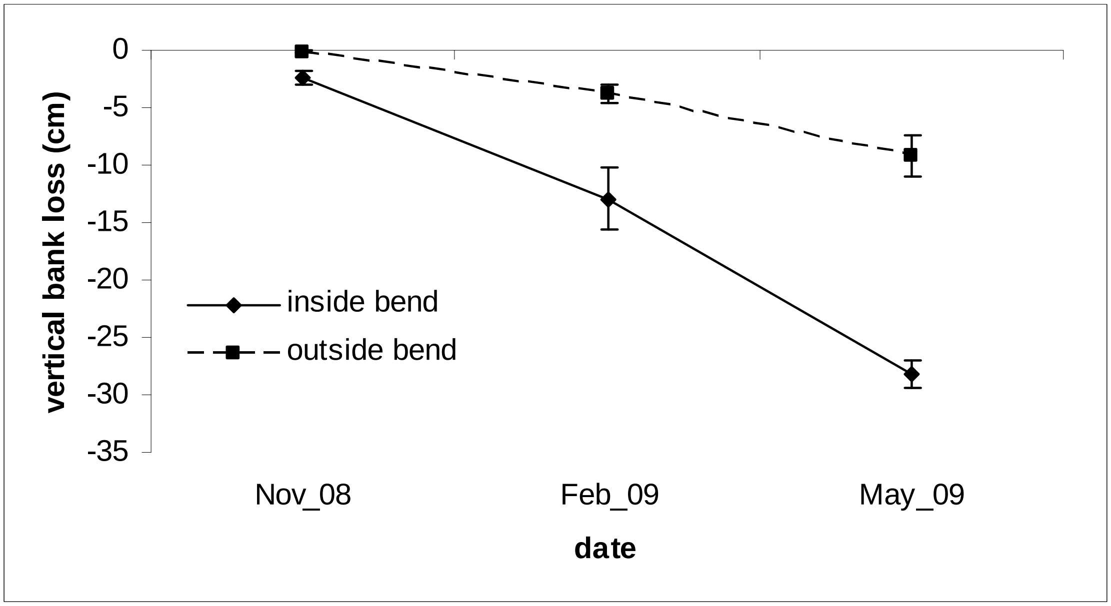


Figure 8. Mean vertical bank loss from November 2008 to May 2009 among plot types. Means differed at each date ($\alpha$=0.05).

# Science Education on the Tennessee-Tombigbee Waterway: An Outreach Effort for K-12 Students and Teachers in Northeast Mississippi

Kenny Langley, Mississippi University for Women
Dorothy Kerzel, Mississippi University for Women

Mississippi University for Women's (MUW) Science Education on the Tennessee-Tombigbee Waterway project endeavors to provide enhanced science education opportunities for K-12 students and teachers in northeast Mississippi. As an institution, MUW has established itself as a leader in Mississippi by offering relevant and innovative educational outreach programs. In particular, the Department of Sciences and Mathematics has a strong track record spanning over a decade of providing high quality science and mathematics enrichment for elementary, middle, and high school groups. By working to increase the knowledge base in science and mathematics, our programs will enable Mississippians to better meet the challenges of the future.

In this program, hands-on science and mathematics activities for students and teachers will be the central focus. These programs will be made useful to participants in one of two contexts: (1) how information presented can be used to improve the quality of life for people, and (2) how it can be used to benefit the environment. Workshop activities will take place primarily at the Plymouth Bluff Environmental Center, a learning facility which is part of MUW. The MUW Explorer, a 36' by 10' pontoon boat which has been designed as a floating teaching laboratory, will be used to engage participants in science activities on the Tennessee-Tombigbee Waterway. Other activities will be outdoors at Plymouth Bluff and in the classroom setting there. These activities will allow the participants to construct their own understanding of science in a real-world setting. Specific topics covered include forest and aquatic ecology, wildlife biology, geology, astronomy, and sustainable living strategies. Much of the program will focus on hydrology workshops conducted on the waterway. These programs will educate teachers and students on chemical and physical properties that dictate water quality, aquatic macroinvertebrates and benthic index concepts, nonpoint source pollution caused by rural and urban landscape alteration, responsible watershed management, and stream morphology, ground water concepts, and the importance of wetlands.

Participants will be evaluated to assess the success of the program in terms of teacher competency and utilization of material in classrooms and student interest and performance in science. Demographic information will also be collected and analyzed to assure that people of all racial, ethnic, socioeconomic, and ability levels are taking advantage of our programs. Work for this entire outreach project has been supported by a generous congressionally funded grant.

Key words: education, water quality, ecology, nonpoint source pollution, and ground water.

# Possible Correlations Among Simple Visual Disturbance Estimates and Hydrologic and Edaphic Parameters in Forested Headwaters of Mississippi

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James O. Palmer, Mississippi State University
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Silvicultural BMPs are designed to provide guidelines for maintaining the overall integrity of surface waters by minimizing non-point source inputs of sediment, nutrients and pesticides. Mississippi Forestry Commission guidelines for management of perennial and intermittent stream channels are specific; however guidance recommendations for ephemeral-flow channels are minimal albeit these flow channels are often incipient streams. Measuring the effects of disturbance due to silvicultural activities within and around ephemeral-flow channels on hydrology and soil quality is often time-consuming and cost-prohibitive. This project expands the scope of ongoing research that is currently characterizing the relationships among surface- and subsurface-hydrology, soil physical properties, vegetative communities, and sediment movement in ephemeral-flow and intermittent portions of incipient headwaters in Webster County, Mississippi. Hydrologic and edaphic monitoring began in January of 2007; timber harvesting was conducted in the 4th quarter of 2007; and the site was replanted with loblolly pine in the fourth quarter of 2008. The objective of this study is to characterize disturbance at multiple levels in hydrologically fluid headwater ephemeral areas using a simple visual classification scheme and determine whether correlations exist among observed disturbance levels, surface- and subsurface-hydrology, and selected soil properties.

Key words: Hydrology, Ground Water, Surface Water, Nonpoint source Pollution, Water Quality

# Identification of Streambank Erosion Processes and Channel Changes in Northeastern Mississippi

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William H. McAnally, Mississippi State University
James L. Martin, Mississippi State University
Sandra L. Ortega-Achury, Mississippi State University
Jairo N. Diaz-Ramirez, Mississippi State University

Identification of streambank erosion processes is important for determining suitable measurement techniques and for choosing appropriate stream remedial measures. Sediment loads from watersheds located in Northeastern Mississippi can have contributions from stream channel degradation as large as 90%. Town Creek watershed is an experimental watershed in the Southeastern Plain Ecoregion of Mississippi (Ecoregion 65). Northern headwaters in Town Creek located within the Black Prairie Subecoregion present incised streams with unstable active bank profiles. The most common gravitational failure mechanisms are slab failure, soil fall, and cantilever failure, accompanied by a basal clean out process when stormflow events occur. An active agricultural land use near streambanks with limited or reduced presence of riparian zones increases the streambank instability and favors gully erosion activity. This condition is predominant along the different headwater reaches. The middle 20 km of the principal channel system is located within the transitional zone between the Tombigbee Hills and the Black Prairie subecoregions. Wide stable channels showing evidence of streambank erosion induced by fluvial erosion, shallow slides, and rotational failures are mixed with natural, vegetated zones and regions with sediment deposition on bed and streambanks. Especially along this section of the principal channel, sediment bed deposition and erosion are significantly modified seasonally by flow conditions. Low flow velocities and sediment deposition occur on the inside of incipient meander bends in the sinuous reach, along the downstream most 10 km before the outlet at the Tombigbee River.

Key words: Surface water, nonpoint source pollution, geomorphological processes, streambank erosion.

**Introduction**

Streambank erosion is a geomorphic process which occurs in all channels as adjustments of channel size and shape are made to convey the discharge and sediment supplied from the stream catchment. However, increases in sediment supply due to accelerated streambank erosion are often linked to land use change and contribute up to 90% of sediment yield in watersheds within northeastern Mississippi. Identification of streambank erosion processes is important for determining suitable measurement techniques and for choosing appropriate stream remedial measures.

**Study Area**

The Town Creek watershed is a 1769 km2 watershed near Tupelo, Mississippi, with the outlet at latitude 88o 32o 38.78" and longitude 33o 59' 33.88". The watershed is located within the Tombigbee River Basin, representing 50% of the Upper Tombigbee River Basin at Aberdeen pool on the Tennessee Tombigbee Waterway and approximately 10% of the entire Basin. The Town Creek watershed and some of its tributaries group with the reference code HUC 03160102 within the Tombigbee River Basin, which comprises East-Central Mississippi. This group of water bodies was listed as evaluated water bodies impaired due to sediments (MDEQ, 2006).

Preliminary reference of sediment transport rates have been developed for various Ecoregions in the USA including Southeastern Plains (Ecoregion 65) which contains Town Creek watershed. However, limited work monitoring the sediment concentrations has been developed. A water quality monitoring and watershed characterization has been conducted to quantify sediment in Town Creek tributaries as a reference to produce remedial measures for reducing water quality impairment within the entire watershed.

Town Creek watershed could be the primary source of sedimentation in Aberdeen pool, where annual sediment dredging is around 310,000 ton/yr. To produce remedial measures for reducing water quality impairment and sediment costs (expressed in terms of a percent reduction of sediment loads) and to address future BMP's in Town Creek watershed, is necessary to know the sedimentation sources and sediment loads currently transported within the watershed. Without actual (last 10 yr) sediment transport data for Town Creek, a combination of methods have been used in this project, including field reconnaissance, detailed data collection and surveying, and modeling of upland areas and channels. The study is performed to evaluate sediment processes in the Town Creek watershed and identify remedial measures to reduce water quality impairment and sediment costs.

Tributaries:
Yonaba Creek
Mud creek
Chiwapa Creek
Cooneewah Creek
Tallabinella Creek

**Assessment**

Northern headwaters in Town Creek are located within the Black Prairie Subecoregion:

Incised streams with unstable active bank profiles.

Slab failure, soil fall, and cantilever failure, accompanied by a basal clean out process when stormflow events occur.

Agricultural land use near streambanks with limited or reduced presence of riparian zones increases streambank instability and favors gully erosion activity.

Middle 20 km of the principal channel system located within the transitional zone between the Tombigbee Hills and the Black Prairie Subecoregions.

Wide stable channels showing evidence of streambank erosion induced by fluvial erosion.

Shallow slides, and rotational failures are mixed with natural, vegetated zones and regions with sediment deposition on bed and streambanks.

Sediment bed deposition and erosion are significantly modified seasonally by flow conditions.

Low flow velocities and sediment deposition occur on the inside of incipient meander bends in the sinuous reach, along the downstream most 10 km before the outlet at the Tombigbee River.

**Recommendation**

The development of a program and implementation plan for streambank and riparian buffer zone restoration and establishment of other BMPs, is necessary to reduce sediment and nutrient concentrations to attain water quality standards within Town Creek watershed.

*Identification of Streambank Erosion Processes and Channel Changes in Northeastern Mississippi*
*Ramirez-Avila, Langendoen, McAnally, Martin, Ortega-Achury, Diaz-Ramirez*

Figure 1. View of a creek at the headwaters of Town Creek, MS

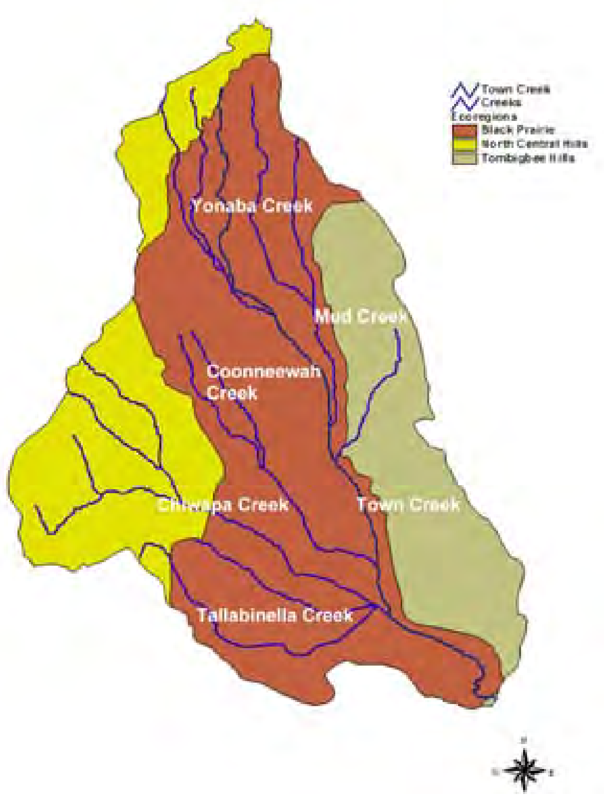


Figure 2. Principal tributaries for Town Creek, MS

Figure 3. Incised unstable channel at the Yonaba Creek, MS

Figure 4. Gully erosion formation in an agricultural field with reduced presence of riparian zones at the Town Creek headwaters.

Figure 5. Fluvial erosion at the Town Creek headwaters in MS.

Figure 6. Sand deposition on streambanks at the middle section of the Town Creek, MS

Figure 7. Mobile ber at the middle section of the Town Creek, MS

Figure 8. Meandering low flow velocities and bed sediment deposition at the least 10 km of Town Creek, MS

Figure 9. Meandering low flow velocities and streambank sediment deposition at the least 10 km of Town Creek, MS

Figure 10. View of agricultural fields with an established riparian zone

# Hydrologic Services Provided by the National Weather Service

David B. Reed, NWS Lower Mississippi River Forecast Center
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The National Weather Service (NWS), part of the National Oceanic and Atmospheric Administration (NOAA), is responsible for providing river and flood forecast sand warnings across the country to save lives and property. The NWS has 122 Weather Forecast Offices (WFOs) across the country that maintain a 24-hour weather watch and provide watches and warnings for severe weather and flooding. The NWS operates 13 River Forecast Centers that model the most important portions of the hydrologic cycle and use those models to provide forecasted river levels for five days into the future.

The backbone of the NWS Hydrologic Services is the issuance of river forecasts at over 4,000 locations. At these sites, the NWS issues forecasted river stage levels for the next five days. To run hydrologic models to support the issuance of these forecasts, the NWS must develop estimates of precipitation on a 4x4 km grid each hour. These quality controlled precipitation estimates are posted to the Internet for customers and the general public to use.

To complement river stage forecasts, the NWS also provides individualized hydrologic support to the emergency management community and other federal, state, and local water resource agencies. This support may take the form of customized hydro-meteorological briefings which can be disseminated through the web, telephone and/or chat services. In high impact events, the NWS may also station a hydrologist or meteorologist at a state or local emergency management office to provide a heightened level of support.

In addition to providing real-time hydrologic support, the NWS and the RFCs must also perform hydrologic and hydraulic model calibration to support their models. To accomplish this mission, the NWS has a dedicated hydrologist stationed at about 80 of the 1220 WFOs. These personnel are strategically located to provide support across the entire country. RFCs are staffed with 12-20 professionals who are responsible for the hydrologic modeling and forecast preparation.

Key words: Floods, Hydrology, Models

# Oceanic-Atmospheric Modes of Variability and their Effects on River Flow in the Northcentral Gulf of Mexico

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The present study examined the individual and combined influences of four oceanic-atmospheric modes of variability on Mississippi River and Pascagoula River flows. Mississippi River and Pascagoula River mean flows, within long-term climatic phases, were compared using a parametric t-test. While the combination of Pacific Decadal Oscillation (PDO), Atlantic Multidecadal Oscillation (AMO), and North Atlantic Oscillation (NAO) phases determined long-term Mississippi River regimes, the coupling of AMO and NAO phases determined long-lasting Pascagoula River flow regimes. Mississippi River mean flow was higher during the PDO warm (PDOw), AMO cold (AMOc), and NAO positive (NAOp) phases than during the PDO cold (PDOc), AMO warm (AMOw), and NAO negative (NAOn) phases. Pascagoula River mean flow was higher during AMOc and NAOp phases than during AMOw and NAOn phases. During a long-term drought regime in the Pascagoula River basin, interannual fluctuations in the Pascagoula River flow were associated with the El Niño Southern Oscillation (ENSO) events. During the AMOw/NAOn phase, Pascagoula River flow showed a significantly steady reduction from ENSO warm to ENSO neutral to ENSO cold events. In the northcentral Gulf of Mexico, more than 90% of the freshwater is discharged by the highly correlated Mississippi, Atchafalaya, Pascagoula, and Pearl Rivers. Climate-related hydrological regimes have been associated with fisheries resources availability and the economic and social wealth of coastal communities.

Key words: Climatological Processes, Hydrology, Surface Water, Water Quantity

# Preliminary Assessment of Ecosystem Services Provided by Moist-soil Wetlands

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Management of moist-soil wetlands is intended to promote seed and tuber producing annual vegetation and production of aquatic invertebrates, both of which provide critical food for waterfowl and other wetland wildlife. Moist-soil management of marginal cropland and other similar lowlands can potentially enhance quality of discharge water and run-off in agricultural landscapes such as the Mississippi Alluvial Valley. Seasonal decay of wetland vegetation sustains nutrient cycling and is the foundation of detrital based food webs in these systems. Crayfish (*Procambarus* sp.) populations are dependent upon the detrital based food web, provide a source of protein and other nutrients for wetland wildlife, and can be harvested for human consumption. During late-winter to early summer 2009, we monitored water quality, detritus accumulation and decay, invertebrate abundance, and crayfish harvest characteristics in public and privately managed moist-soil wetlands throughout Mississippi. The results from our monitoring efforts will be used to estimate potential ecosystem services provided by moist-soil management such as sediment abatement, nutrient retention, invertebrate production, and crayfish harvest. Demonstrating multiple ecological and economical benefits of moist-soil wetlands may encourage landowners to develop and manage natural wetlands within guidelines of conservation programs such as the Farm Bill's Wetland and Conservation Reserve Programs.

Key words: Conservation, Water Quality, Wetlands

# Molecular Identification of Pentachlorophenol (PCP) Tolerant Bacterial Communities in Contaminated Groundwater

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Pentachlorophenol (PCP), a highly toxic and recalcitrant wood preservative, contaminates groundwater aquifers in many areas of United States. Improper handling, storage, and disposal practices in the past have led to the contamination of groundwater at many wood treatment facilities. Biosparging, the injection of clean air and nutrients under pressure into the groundwater system, has emerged as a viable in-situ treatment option for removal of this type of contamination. Previous studies in this area have relied on growth media cultures for isolation and identification of the bacterial community that is responsible for the degradation of the pollutant. However, molecular identification of DNA extracted from the contaminated groundwater will provide a more accurate description of the microbial community. Seven biosparging wells located at a wood treatment facility with a PCP groundwater contamination in central Mississippi have been monitored since 2001. Groundwater samples from these existing wells were taken quarterly and examined for total PCP concentration. DNA was extracted from these water samples using a WaterMaster DNA purification kit. The 16s region from this DNA was also amplified using bacterial specific primers and then cloned into *E. coli* cells. Cloned *E. coli* cells were extracted and sequenced for identification. The goals of this research were to identify the most PCP-tolerant bacterial communities and to determine the PCP tolerance limits of these bacterial communities.

Key words: toxic substances, treatment, ground water, methods

Delta Water Quality

**Stephanie Showalter**
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Water Quality Trading: Is it Realistic for the Mississippi River?

**Billy Justus**
*U.S. Geological Survey*

Water Quality of Least-Impaired Lakes in Eastern and Southern Arkansas

**Karen Myers**
*U.S. Army Corps of Engineers*

Methyl Mercury in Water and Fish Tissue in the Lower Yazoo Basin

**Matthew B. Hicks**
*U.S. Geological Survey*

Water-Quality Data of Selected Streams in the Mississippi River Alluvial Plain, Northwestern Mississippi, September–October 2007-08

**Matthew B. Hicks**
*U.S. Geological Survey*

Water-Quality Monitoring Plan and Implementation, Lake Washington, Mississippi, 2008

# Water Quality Trading: Is it Realistic for the Mississippi River?

Stephanie Showalter, University of Mississippi

Although significant progress has been made since passage of the Clean Water Act in 1972, the stated Congressional goal of assuring that all waters are "fishable/swimmable" remains elusive. Traditional "end-of-pipe" pollution-control measures must be supplemented with new policies to diffuse sources of pollution such as stormwater and agricultural runoff.

One such innovative policy is water quality trading. In December 2006, the State of Pennsylvania joined ten states that currently have some form of a water quality trading program by approving a state administrative policy to allow point sources to offset pollution discharges by purchasing "credits" from other facilities or farmers. Similarly, in August 2008, the Florida Department of Environmental Protection proposed regulations to establish procedures for water quality trading, and. trading programs also are in development in Minnesota, West Virginia and Maryland. In selecting ten finalists for its "Targeted Watershed Grants" on water quality trading this past December, the U.S. Environmental Protection Agency (EPA) is encouraging states along the Mississippi River to consider implementing trading programs to address the hypoxia, or low oxygen levels, in the Gulf of Mexico.

Nonetheless, the courts have not reached consensus on whether the Clean Water Act allows point sources to offset discharges into impaired waterbodies, or waters failing to meet state water quality standards. For example, in *Friends of Pinto Creek v. EPA*, 504 F.3d 1007 (9th Cir. 2007), the Ninth Circuit sided with an environmental group claiming that the EPA's authorization of upstream remediation to offset a company's copper discharges into the impaired Pinto Creek violated the Clean Water Act.

This presentation will analyze the existing state water quality trading programs in light of the legal and scientific issues that may arise as states in the Mississippi River Basin consider implementing such programs.

Key words: Law; Water Quality; Policy, Management and Planning

# Water Quality of Least-Impaired Lakes in Eastern and Southern Arkansas

Billy G. Justus, U.S. Geological Survey

A three-phased study identified one least-impaired (reference) lake for each of four Arkansas lake classifications; three classifications in the Mississippi Alluvial Plain (MAP) ecoregion and a fourth classification in the South Central Plains (SCP) ecoregion. Water quality at three of the least-impaired lakes generally was comparable and also was comparable to water quality from Kansas and Missouri reference lakes and Texas least-impaired lakes. Water quality of one least-impaired lake in the MAP ecoregion was not as good as water quality in other least-impaired lakes in Arkansas or in the three other States; a probable consequence of all lakes in that classification having a designated use as a source of irrigation water. Chemical and physical conditions for all four lake classifications were at times naturally harsh as limnological characteristics changed temporally. As a consequence of allochthonous organic material, oxbow lakes isolated within watersheds comprised of swamps were susceptible to low dissolved-oxygen concentrations to the extent that conditions would be limiting to some aquatic biota. Also, pH in lakes in the SCP ecoregion was < 6.0, a level exceeding current Arkansas water-quality standards but typical of black water systems. Water quality of the deepest lakes exceeded that of shallow lakes. N:P ratios and trophic state indices may be less effective for assessing water quality for shallow lakes (< 2 m) than for deep lakes because there is an increased exposure of sediment (and associated phosphorus) to disturbance and light in the former.

Key words: Least-impaired, reference, lake, reservoir, oxbow, and nutrients

# Methyl Mercury in Water and Fish Tissue in the Lower Yazoo Basin

Karen F. Myers, U.S. Army Corps of Engineers

Mercury is a leading cause of fish consumption advisories in the United States and is the only metal with a fish consumption advisory in Mississippi. While none of the affected water bodies are within the Mississippi Delta, a 2001 ambient water quality criterion established by the EPA would lower Mississippi's fish tissue threshold from 1 mg mercury per kg of fish tissue to 0.3 mg methyl mercury per kg of fish tissue. Since studies have shown that most of the mercury that bioaccumulates in predator fish tissue is methyl mercury, the new fish tissue criterion would become 0.3 mg/kg mercury in fish tissue. Implementation of this criterion within the State of Mississippi will increase the number of water bodies with fish tissue consumption advisories within the State and within the Mississippi Delta in particular.

Recently the USACE Vicksburg District analyzed the potential for increases in methyl mercury concentrations in surface water and fish tissue based upon completion of the Yazoo Backwater Project's reforestation component. The analysis used a simple linear model that compared the potential for changes in methyl mercury production based upon changes in land use, flooded acres, and flood duration. The model predicted that completion of the Yazoo Backwater Project recommended plan and reforestation of up to 55,600 acres of currently farmed agricultural land could increase methyl mercury production by 3 percent over base conditions.

The Vicksburg District's mercury database includes surface water samples for methyl mercury collected between 2003 and 2008 and mercury in fish tissue samples collected between 1993 and 2008. Surface water samples were collected during flooded conditions in Delta National Forest greentree reservoirs, during flood and non-flood conditions in Delta Nation Forest wetlands, and during summer, non-flood conditions in streams and lakes in the lower Yazoo Backwater Area. The data show that methyl mercury production is highest in areas rich in easily accessible organic matter that undergo extended flooding. Fish tissue mercury concentrations appear to be related to flood duration and the number of acres flooded.

Key words: Floods, Nonpoint Source Pollution, Surface Water, Water Quality, Wetlands

*Methyl Mercury in Water and Fish Tissue in the Lower Yazoo Basin*
*Myers*

**Introduction**

Mercury contamination is an environmental concern in the United States. Nearly all fish and shellfish contain traces of mercury; however, some fish contain higher levels of mercury than others. Mercury is cited as a cause of fish consumption advisories in more than 42 states and is responsible for approximately 80 percent of such advisories in the country (Brigham et al., 2003). Mercury has also become an issue in the Gulf of Mexico where EPA and FDA advise susceptible sectors of the population to limit or avoid consumption of certain species of fish (FDA, 2004). Mercury has historically been used in its metallic and inorganic forms in a wide variety of industrial uses. Combustion of mercury containing fuels or waste is the source of most of the anthropogenic mercury entering the environment today (EPA, 2006). Some of the mercury emitted into the atmosphere can be transported over long distances where it can be deposited onto land or directly into waterways or the ocean (NSTC, 2004). In Mississippi, it is likely that atmospheric deposition is the source of mercury impairment in the Yazoo Basin (MDEQ, 2004; NADP, 2008). Inorganic mercury is generally not a health concern because it is poorly absorbed by the digestive tract. In contrast, methyl mercury is an organic form of mercury that is toxic to the nervous system (Brigham, et al., 2003). It is generally accepted that most of the mercury in fish tissue is methyl mercury (Grieb et al., 1990). Methyl mercury is passed through the food chain and eventually passed to man primarily through the consumption of fish.

The USACE Vicksburg District completed the Supplemental Environmental Impact Statement (SEIS) for the Yazoo Backwater Area Reformulation in 2007. The recommended plan included construction of a 14,000 cfs pump station with a year-round pump operation elevation of 87.0 feet, NGVD, at the Steele Bayou Structure; perpetual conservation easements and reforestation/conservation measures on up to 55,600 acres of agricultural land obtained from willing sellers; and modified operation of the Steele Bayou Structure to maintain water levels between 70.0 and 73.0 feet, NGVD, during low water periods.

A possible impact of wetland reforestation within the Yazoo Backwater study area was the potential for increased methyl mercury production. This is because under flooded, anaerobic conditions, the large amounts of detritus on a forest floor are believed to provide the organic precursors for the methyl group in methyl mercury. While existing forests have been shown to produce methyl mercury during backwater flooding, agricultural fields that contain limited detritus under current conditions would provide substantially more detritus when converted into forests with trees, underbrush, and leaf litter. Given the necessary redox conditions, the amount of methyl mercury produced is dependent on the availability of precursors and the period of inundation. If inundated for extended periods of time, these newly created forests could increase the production of methyl mercury above current levels. Although the Yazoo Backwater Project (YBWP) would have some effect on the extent and duration of flooding, the net result would be an increase in the number of forested wetlands by up to 55,600 acres (shown in red in Figure 1). One of the issues the SEIS addressed was the potential increase in methyl mercury and its impact on fish tissue concentrations within the project area. To better understand mercury distribution within the YBWP area, the Vicksburg District began collecting surface water methyl mercury samples during flood and non-flood conditions and resumed its analysis of mercury in fish tissue.

**Site Selection and Methods**

Surface water samples were collected five times between March 2003 and May 2008 (Figure 1). In 2003, 2004, and 2005 samples were collected in the Delta National Forest, Mississippi, in greentree reservoirs, at the leading edge of flood waters and in two permanent water bodies, the Little Sunflower River and Cypress Bayou. In July 2006, nine summer background samples were collected in permanent lakes and rivers in and around the Delta National Forest (DNF) and in Steele Bayou. In May 2008, a more extensive flood, samples were collected in DNF, Cypress Bayou and the Little Sunflower River, and an adjacent flooded USDA Wetland Reserve

Program (WRP) forest. Samples were also collected from a young WRP field and an unharvested winter wheat field in Valley Park, Mississippi. These fields received flood waters from the Steele Bayou Basin. Fish samples were collected in 1993, 1994, 2005, 2007 and 2008. Fish used in this analysis were collected from the Big Sunflower River, the Little Sunflower River, Steele Bayou, and the Connecting Channel between the Big Sunflower River and Steele Bayou.

Mercury water samples used in this analysis were collected by the USGS, Louisiana Water Science Center and analyzed by the USGS Wisconsin Mercury Research Laboratory in Middleton, Wisconsin. Water samples were collected using clean sampling techniques outlined in USGS TWRI Book 9 Chapter 5.6.4.B. Total mercury (filtered and unfiltered) was analyzed using EPA Method 1631. Methyl mercury (filtered and unfiltered) was analyzed using USGS OFR 01-445 (De Wild et al., 2002). Flood water samples were collected by wading; summer background samples were collected mid-channel from a boat.

Fish tissue used in this analysis was collected by the Fish Ecology Team of the Engineer Research and Development Center (ERDC), U.S. Army Corps of Engineers. All of the fish were collected with seines. Fish were identified by species, then weighed and measured before filleting. Skinless filets were kept frozen until processed and analyzed. Fish tissue collected in 1993, 1994 and 2005 were analyzed (EPA Method 7471) by the Environmental Chemistry Branch at the ERDC, U.S. Army Corps of Engineers in Vicksburg, Mississippi. Fish tissue collected in 2007 and 2008 were analyzed (EPA Method 7471) by the Mississippi State Chemical Laboratory at Mississippi State University.

**Factors Controlling Methyl Mercury Production**

Although the factors controlling methyl mercury production are not fully understood, a correlation between methyl mercury and forested wetlands is well established in scientific journals. Studies by Canadian researchers have shown that water and fish tissue methyl mercury concentrations increase following inundation of forests surrounding newly formed reservoirs (St. Louis et al., 1994; and Jackson, 1991). Other researchers have shown that methyl mercury production can begin after 7 to 10 days of inundation or the time it takes for the newly inundated forest floor to become anaerobic (Wright and Hamilton, 1982; Kelly et al., 1997). A recent USGS report ties methyl mercury levels in the Gulf of Mexico to south Louisiana wetlands (Hall et al., 2008). Another study links methyl mercury production to the inundation of forest soils and leaf litter from an alluvial floodplain (Roulet et al., 2001). "The flooding of terrestrial surfaces and the inundation of vegetation appear to be important facilitating processes in the production of methyl-mercury in natural settings," (Balogh et al., 2005). Several studies have shown that natural settings are major sites of methyl mercury production (St. Louis et al., 1994; Hurley et al., 1995; Krabbenhoft et al., 1995; St. Louis et al., 1996; Branfireun et al., 1996; Babiarz et al., 1998; Galloway and Branfireun, 2004).

Most researchers agree that mercury methylation occurs within microbial 'hotspots' of organic carbon metabolism such as sediment pore water. DeLaune and others (2004) demonstrated the relationship between sediment redox conditions and methyl mercury production in surface sediment of Louisiana lakes. Many researchers believe that once the redox potential becomes low enough for sulfate reduction, naturally occurring sulfate-reducing bacteria become primary agents of the environmental production of methyl mercury. Some studies suggest that mercury methylation can occur in the water column (He et al., 2007). Under anoxic, low redox conditions in the water column, dissolved organic carbon can provide an energy source that stimulates microbial activity such as mercury methylation (Ullrich et al., 2001; Eckley and Hintelmann, 2005).

While the concentration of inorganic mercury is important for methyl mercury production, it is not the only factor nor is it necessarily the controlling factor. Other factors identified as important include the chemical form of mercury, temperature, the availability of organic substrate for sulfate-reducing bacteria, mercury demethylation activity, *in situ* redox conditions, and pH. In addition to these factors, researchers in the Everglades have found that sulfide concentrations can control methyl mercury production by affecting the species of mercury available to the sulfate-reducing bacteria (Benoit et al., 2003). Dissolved organic carbon can also bind with inorganic mercury making it less bioavailable (Ullrich et al., 2001). Seasonal temperature variations also affect methylation rates (Hall, et al., 2008). In their experiments, Guimarães and others (2006) reported that initial methylation rates can be up to four times higher at 35 degrees C than at 25 degrees C (the difference between a Yazoo Backwater flood occurring in May or June and a flood occurring in January or February). At both temperatures, rates were found to decrease over time as microbial production decreased.

In aquatic environments, especially flowing water, many of the above parameters vary temporally and spatially. Any of these factors can impact the concentration of methyl mercury in aquatic systems. Researchers in the Everglades found that the highest levels of methylation and methyl mercury in water and fish were associated with sediments showing intermediate levels of sulfate and sulfate reduction (Benoit et al., 2003). In their "National Pilot Study of Mercury Contamination of Aquatic Ecosystems," Brumbaugh and others (2001) found positive correlations between percentages of wetlands in a watershed and concentrations of dissolved organic matter to mercury fish tissue concentration.

**Estimation of Potential Increases in Methyl Mercury Production from Reforestation Proposed in the Yazoo Backwater Project**

For the Yazoo Backwater SEIS, the Vicksburg District estimated the potential increase in methyl mercury production by comparing the number of acres of existing forested wetlands to the total number of forested wetland acres in each alternative plan. Assuming the necessary conditions for methyl mercury production are present, if each acre of flooded wetland forest has the potential to produce a unit of methyl mercury per day of inundation, any increase or decrease in acres should also increase or decrease the amount of methyl mercury produced. The measure of the potential for methyl mercury production, then, becomes one methyl mercury unit for every day an acre of forest is flooded. Assuming methyl mercury production begins after 7 days of inundation as observed by Wright and Hamilton (1982), the worst-case measure of the potential for methyl mercury production becomes one methyl mercury unit for every day an acre of forest is flooded beyond the first 7 days.

Table 1 presents the results of the methyl mercury analysis used to determine YBWP impacts to water quality for the recommended plan and a non-structural alternative (alternatives 5 and 2). This analysis is based upon the Vicksburg District's 2005 land use analysis and uses the change in the acre-days of forest flooding during a typical 2-year frequency, 5 percent duration flood. The number of flooded existing forest acres (base) and the reforested acres are converted into the number of potential methyl mercury units that could be produced from implementation of each alternative. The number of preproject forested acres that would continue to be flooded after the pump station was in operation was multiplied by the estimated number of days of flooding minus 7 days. For example, lands within the 7.5 to 10 percent duration band would have been flooded a minimum of 20 days. Methyl mercury would then be produced for 13 days (20 days minus 7 days) on these acres. These numbers were summed to yield the maximum number of methyl mercury units produced annually from existing forests during backwater flooding (i.e., total from existing forests). Next, the total acres proposed for reforestation by the alternative plans were assumed to be flooded for at least 14 days (5 percent duration flood). Again, multiplying the number of reforested acres by 7 days (14 days minus 7 days) yielded the number of methyl mercury units produced from the proposed reforestation. Although agricultural fields targeted for reforestation may produce methyl mercury when flooded under base conditions (Rogers, 1976), the methyl mercury unit analysis assumed that current production in these fields was zero. This simplified analysis provided a method for estimating and comparing the potential for project induced methyl mercury production under predefined conditions and demonstrated that increasing the number of forested acres in areas subject to flooding has the potential to increase the amount of methyl mercury produced in the YBWP area. Completion of the recommended plan could have increased methyl mercury production by up to 3 percent. Completion of the nonstructural plan evaluated in Table 1 could have increased methyl mercury production by up to 32 percent.

**Existing Methyl Mercury Surface Water Concentrations**

Subsequent to completing the methyl mercury reforestation analysis for the SEIS, the Vicksburg District asked the USGS to assist in the collection of surface water mercury samples. Table 2 shows the results of discrete methyl mercury samples collected during late winter and early spring flooding over a 4 year period. During late winter floods in February and March, the highest methyl mercury concentrations were found in the greentree reservoirs that had been flooded up to 3 months. Lowest concentrations were in the receiving waters, the Little Sunflower River and Cypress Bayou. During a late spring flood in May 2008, the highest concentration was in a WRP forest that had been flooded for 50 days out of a 130 day flood. The Valley Park wheat field sample was collected from an unharvested field of winter wheat that had been flooded for 2 weeks. Surprisingly, with a concentration of 0.65 ng/L, methyl mercury in this field was as high as concentrations found in greentree reservoirs in previous years. Methyl mercury concentrations in the DNF flood water and adjacent water bodies were fairly uniform (from 1.3 ng/L to 1.7 ng/L), but considerably higher than in previous years. Overall, concentrations of methyl mercury collected in the May 2008 flood were higher than samples collected in February or March of the previous years. These observations can be explained by the much longer duration of the 2008 flood; however, the timing of the flood may have also played a role. Hall and others (2008) suggested that seasonal temperature differences may impact methyl mercury production. In-stream water temperature in the Yazoo Backwater Area is typically 10 degrees C in early March and 20 degrees C in early May. In shallow edge of field flooding, water temperatures can be higher than in-stream temperatures. For example at Valley Park the 24 hour mean water temperature was 23 degrees C (less than 1 foot deep), while nearby in-stream water temperature means were around 17 degrees C (4 feet deep). Samples collected during flood events were collected from water 3 feet deep or less. It is possible that the water and sediment around the periphery of the flood could warm enough to increase biological activity and methylation rates during late spring floods.

Water samples were also collected from nine permanent water bodies during July 2006 to show representative summer background concentrations in the Yazoo Backwater area. Methyl mercury concentrations were 0.15 ng/L or less for all water bodies (Table 3).

**Fish Tissue Mercury Concentrations**

The Vicksburg District has analyzed 292 fish from the lower Yazoo Basin for mercury since 1993. Table 4 summarizes the results for three of the most frequently collected groups (buffalo, catfish and gar) and the totals for all fish sampled. Fish were collected during four sampling efforts: fish collected in the fall of 1993 and 1994; fish collected in 2005 before and after Hurricane Rita caused extensive fish kills in the Yazoo Basin; fish collected in 2007 and February 2008 before spring flooding; and fish collected in 2008 after flood waters had receded.

Mean concentrations of mercury were higher in the early 1990s. Although maximum concentrations for buffalo and catfish exceeded the existing fish consumption advisory limit of 1.0 mg/kg mercury, 90 percent of all fish had concentrations less than 0.8 mg/kg. Since 2005 very few fish have had mercury concentrations greater than 1.0 mg/kg; and for most, the mean concentration was around 0.3 mg/kg with 90 percent of the samples at 0.5 mg/kg or less. In 2001, the EPA recommended a methyl mercury water quality criterion for the protection of human heath (EPA, 2001). The criterion, based on advances in the understanding of toxicology, bioaccumulation, and exposure, set the concentration of methyl mercury in fish tissue at 0.3 mg/kg. Under the current advisory limit of 1 mg/kg mercury in fish, Mississippi Delta waters are not under a fish consumption advisory; once the new EPA limit is adopted it is likely that some Delta waters could become listed for mercury fish tissue consumption.

**Potential Changes in Fish Tissue Mercury Concentrations**

Grieb and others (1990) showed that 99 percent of the mercury in the fish tissue in their study was methyl mercury. While one can assume an increase in potential methyl mercury production would lead to an increase in mercury fish tissue concentrations, it is impossible to estimate the resulting increase in fish tissue concentration from the YBWP reforestation analysis. Just as the amount of methyl mercury produced depends on mercury concentration, flood duration, and limiting factors, so does methyl mercury bioaccumulation in the aquatic food chain. In their "National Pilot Study of Mercury Contamination of Aquatic Ecosystems", which analyzed data collected between June and October, 1998, Brumbaugh and others (2001) found a positive correlation between mercury in fish tissue and the percent of wetlands in a watershed. They also found that methyl mercury in water was a better predictor of fish tissue mercury concentrations than was methyl mercury in sediment. In a seasonal wetland system such as the Yazoo Backwater where out-of-bank floodwaters can last from a few weeks to a few months on a given year, fish tissue concentrations are probably more related to year-round ambient concentrations of methyl mercury in permanent water bodies than the total amount of methyl mercury produced in the system during short duration backwater flooding. There is also some evidence that fish exposure during long duration floods may be limited. Unpublished data collected by the Vicksburg District and ERDC show that during extended floods the water column becomes anoxic to less than 1 foot below the surface. Attempts to sample fish populations during these periods have yielded relatively few adult fish. It may be that larval fish make up the majority of the flood plain population exposed to maximum methyl mercury concentrations in long duration floods.

Backwater floods in 2003, 2004 and 2005 occurred during late winter and were relatively short events. The 2008 flood was a late spring flood (March to July). Once the floodwaters recede and forested wetlands lose connectivity to the river, methyl mercury concentrations become diluted and move out of the system with the effect of moderating aquatic biota exposure in the study area. The period of longest fish exposure to methyl mercury in the study area would be during summer and fall months when seasonal flow is reduced, but methyl mercury concentrations are lowest. The eutrophic nature of streams and lakes in the basin may be a factor that further reduces summer exposure to methyl mercury. Warner and others (2005) found a weak negative correlation between concentrations of Chlorophyll A and mercury concentrations in large mouth bass in the Mobile River Basin. Other researchers (Lange, et al., 1993 and Cizdziel, et al., 2002) show that the trophic status of lakes affects methyl mercury bioaccumulation with eutrophic systems tending toward lower concentrations in predatory fish.

Algae and zooplankton have been identified as important intermediates in the trophic uptake of methyl mercury (Plourde, et al., 1997 and Westcott and Kalff, 1996). Pickhardt and others (2002) found that increases in algal biomass decreased the concentration of mercury per algal cell. This results in a lower dietary input to zooplankton grazers feeding on algae and reduced bioaccumulation in algal-rich systems. This result has important implications for the transfer of methyl mercury. Uptake of methyl mercury remaining in project area streams after backwater floods recede would be diluted (bloom dilution) by the increase in algal biomass that begins in June and July and lasts into October. The more algae cells there are, the authors found, the lower the methyl mercury concentration in each cell. The authors show that increasing the number of algae cells reduced the body concentration of methyl mercury in the zooplankton that feed on these algae. This, in turn, has the potential to decrease methyl mercury body concentrations in planktivorous fish that feed on the zooplankton. Fish uptake of methyl mercury is driven by concentration and exposure. These data suggest that during the period of longest exposure (i.e., summer and fall when the Steele Bayou Structure is operated to hold water to benefit aquatic life) the concentration of methyl mercury available to the food chain would be at its most dilute. Thus, uptake of methyl mercury by omnivorous and piscivorous fish could also be reduced during this period.

Figure 2 shows a relationship between flood duration, flood extent, and fish tissue mercury concentration. Bar heights and numbers show the number of days flooded greater than 83.5 ft, NGVD, at the Steele Bayou structure; while the color indicates the flood frequency or acres flooded. Navy blue bars represent floods that were less than or equal to the 1-year flood frequency elevation of 87.0 ft, NGVD, (75,882 acres). Maroon bars represent floods that were less than or equal to the 2-year flood frequency elevation of 91.0 ft, NGVD, (109,491 acres). The figure shows that the 1993/1994 fish (mean concentration of 0.422 mg/kg) were collected in a cluster of extended floods followed by 10 years of shorter duration floods during which no fish were collected. Fish collected in 2005 (mean concentration of 0.175 mg/kg) had the lowest mercury concentrations in the period studied. After Hurricane Rita made landfall in late September 2005 (shown by the dotted vertical line in Figure 2) water in the Mississippi Delta turned dark, black in color from the large amount of organic carbon washed into the system. Dissolved oxygen concentrations immediately plummeted as the microbial system processed this material. This same organic carbon source may also have stimulated methylation processes. Fish sampled in 2007 after Hurricane Rita showed that mean mercury concentrations had increased (0.263 mg/kg) despite 2 years with 15 days of flooding or less. Following a 130 day late spring flood in 2008, mean fish tissue concentrations increased to 0.310 mg/kg. While the study area fish were not collected frequently enough to determine whether the data are anything more than normal variation in a long-term trend, there does seem to be a delayed relationship between fish tissue concentration, the extent and duration of flooding, and organic loading.

**Conclusions**

An examination of stage data at the Steele Bayou structure suggests some periodicity in flood extent and duration. It is possible that methyl mercury concentrations decreased throughout the basin during a period with several years of reduced flooding. This reduction in flooding might account for the decrease in fish tissue mercury concentrations between 1993/1994 and 2005. Fish tissue concentrations increased in 2007 and 2008 following years with high organic loading or increased flood extent and duration. Contrary to the assumption made in the methyl mercury model for the SEIS, spring flooding of unharvested crops (winter wheat) or young plants (early corn or soybeans) cannot be discounted as sources of methyl mercury. The limited data suggest that young forests and flooded crops can be sources of high organic loading that could result in localized increases in methyl mercury during extended, warm weather flooding. Additional data need to be collected to examine the methyl mercury contribution from unplanted fields in both winter and spring. Despite the uncertainty of the current methyl mercury contribution from agricultural land, it is clear that reforestation would provide a reliable, continuous source of organic material on these lands. Therefore, it is likely that reforestation of large tracts of frequently flooded agricultural land, such as proposed in the YBWP, would increase methyl mercury production in the lower Yazoo Basin.

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Table 1. Potential Increase in Methyl Mercury Units from Proposed Reforestation

| Alternative Plans | Total from Existing Forests | Total from Project Reforestation | Total from Both Sources | % Increase from Reforestation |
|---|---|---|---|---|
| Base | 2,722,837 | 0 | 2,722,837 | - |
| Recommended Plan | 2,414,684 | 389,200 | 2,803,884 | + 3 % |
| Non-Structural | | | | |
| Plan | 2,722,837 | 870,800 | 3,593,637 | + 32 % |

Table 2. Total Methyl Mercury (ng/L)

| | Late Winter Flood | | | Late Spring Flood |
|---|---|---|---|---|
| | 3/11/03 | 2/26/04 | 3/03/05 | 5/08/08 |
| Long Bayou GTR | 0.90 | 0.40 | 0.54 | - |
| Green Ash GTR | - | - | 0.64 | - |
| Sunflower GTR | - | - | 0.94 | - |
| DNF Flood Water | 0.44 | - | - | 1.7 |
| Little Sunflower River | - | 0.20 | 0.11 | 1.5 |
| Cypress Bayou | - | 0.21 | 0.25 | 1.4 |
| Little Sunflower WRP Forest | - | - | - | 6.2 |
| Valley Park Wheat Field | - | - | - | 0.65 |
| Valley Park WRP Forest | - | - | - | 1.3 |

Table 3. Total Methyl Mercury (ng/L) in Summer Background Samples

| | 7/19/06 |
|---|---|
| Big Sunflower River – Big Bend | 0.11 |
| Steele Bayou | 0.10 |
| Black Bayou | 0.14 |
| Main Canal | 0.05 |
| Little Sunflower River | 0.14 |
| Cypress Bayou | <0.04 |
| Blue Lake (DNF) | 0.12 |
| Fish Lake (DNF) | 0.14 |
| Lost Lake (DNF) | 0.15 |

Table 4. Mercury (mg/kg) in Fish Tissue in the Lower Yazoo Basin

| | | Buffalo | Catfish | Gar | All Fish |
|---|---|---|---|---|---|
| 1993-1994 | No. | 24 | 10 | 10 | 49 |
| | Mean | 0.430 | 0.494 | 0.495 | 0.422 |
| | 90th % | 0.787 | 1.18 | 0.724 | 0.807 |
| | Max | 1.14 | 1.56 | 0.858 | 1.56 |
| 2005 | No. | 29 | 13 | 8 | 70 |
| | Mean | 0.214 | 0.153 | 0.237 | 0.175 |
| | 90th % | 0.340 | 0.293 | 0.407 | 0.320 |
| | Max | 1.10 | 0.618 | 0.407 | 1.10 |
| 2007* | No. | 36 | 53 | 8 | 106 |
| | Mean | 0.358 | 0.160 | 0.237 | 0.263 |
| | 90th % | 0.550 | 0.270 | 0.407 | 0.500 |
| | Max | 0.700 | 0.550 | 0.560 | 1.60 |
| 2008 post-flood | No. | 24 | 12 | 14 | 67 |
| | Mean | 0.288 | 0.255 | 0.381 | 0.310 |
| | 90th % | 0.540 | 0.420 | 0.550 | 0.500 |
| | Max | 0.620 | 0.500 | 0.650 | 0.650 |
| All Years | No. | 113 | 88 | 40 | 292 |
| | Mean | 0.322 | 0.210 | 0.368 | 0.279 |
| | 90th % | 0.568 | 0.419 | 0.568 | 0.517 |
| | Max | 1.14 | 1.56 | 0.858 | 1.60 |
| * Includes Pre-flood February 2008 | | | | | |
| No Consumption Criteria: MDEQ = 1.0 mg/kg; EPA Proposed = 0.3 mg/kg | | | | | |

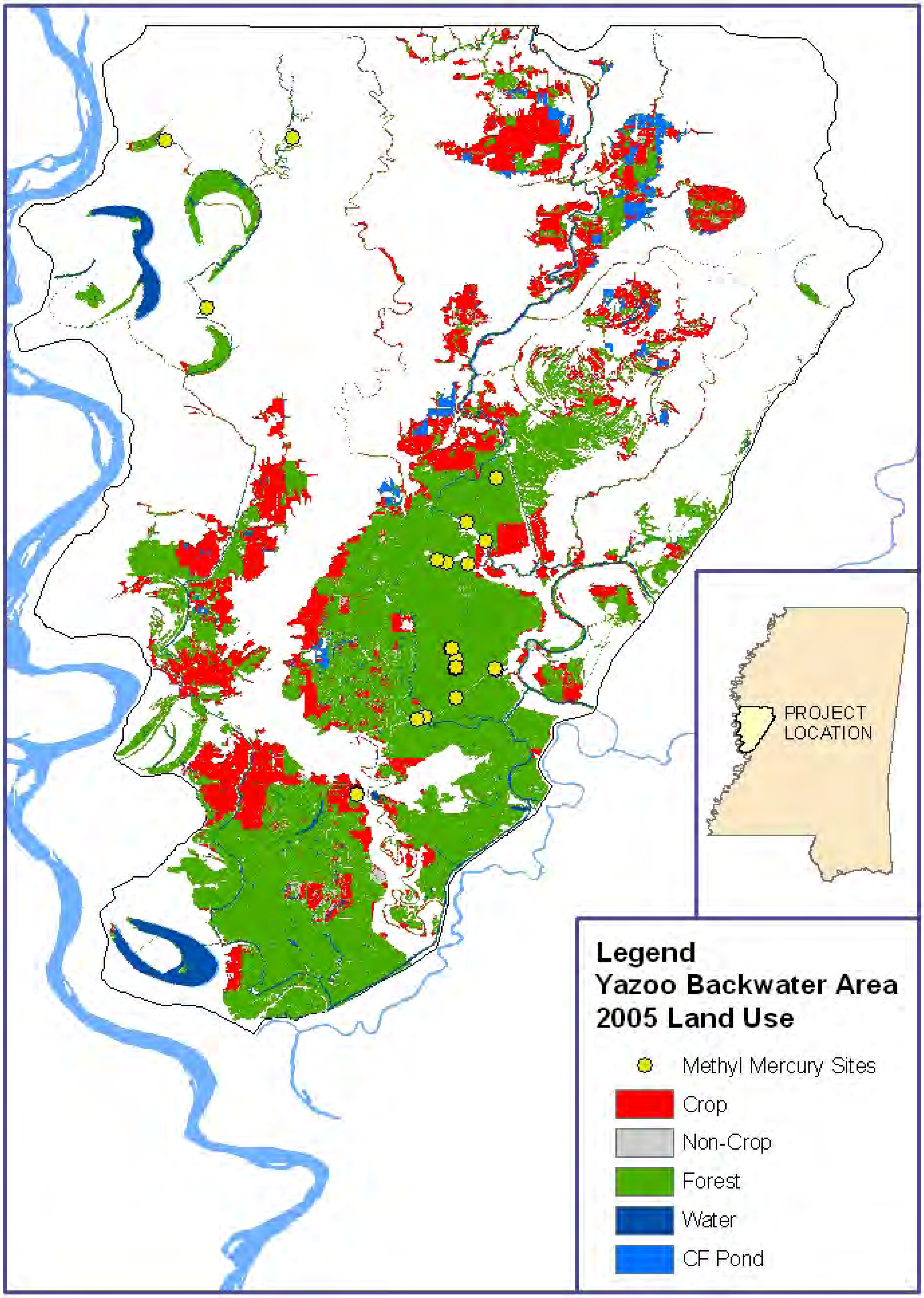


Figure 1. Yazoo Backwater Area 2005 land use with location of methyl mercury surface water sample sites.

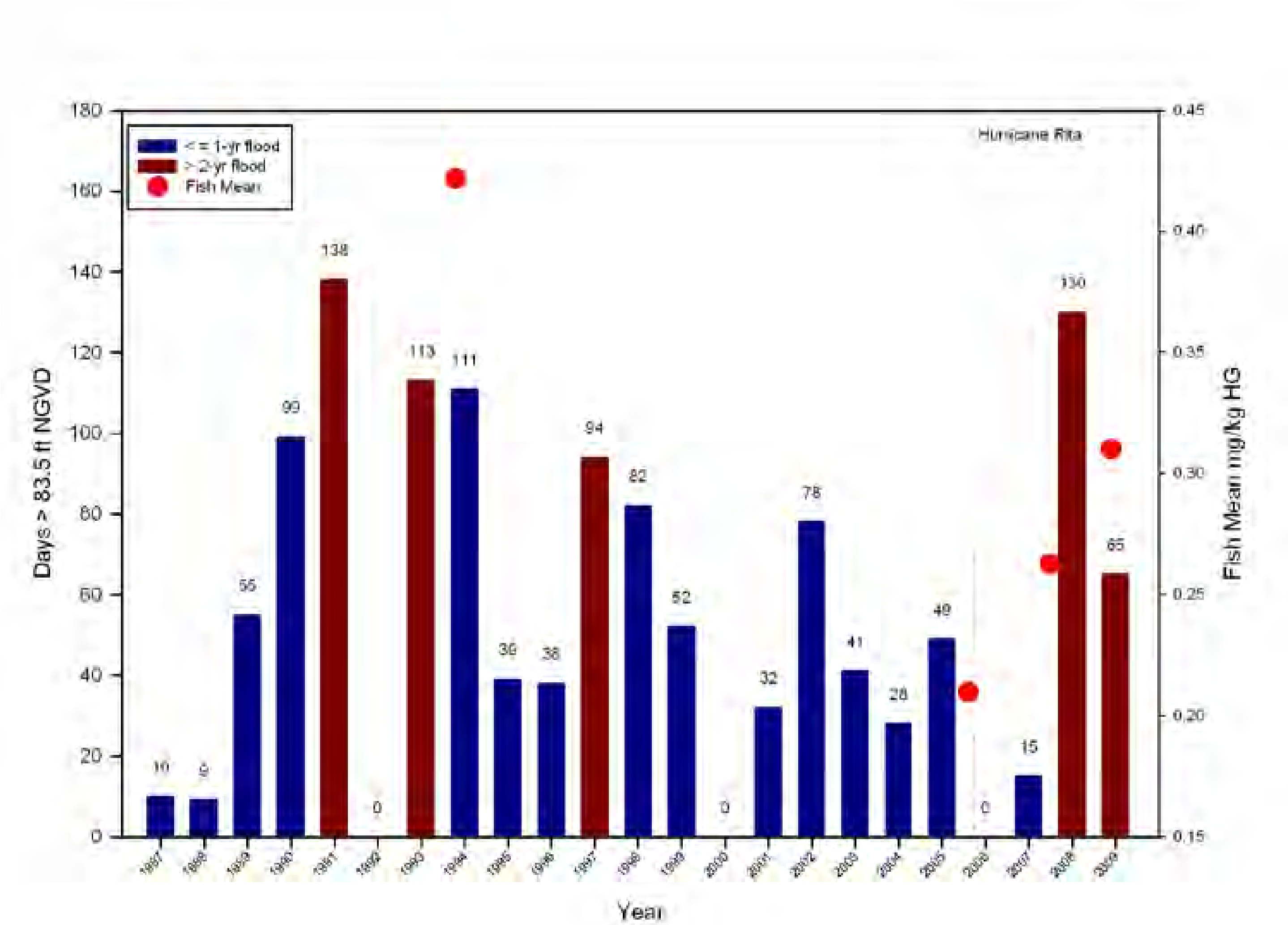


Figure 2. Fish tissue concentrations compared to flood extent and duration based on stage at the Steele Bayou structure.

# Water-Quality Data of Selected Streams in the Mississippi River Alluvial Plain, Northwestern Mississippi, September–October 2007-08

Matthew B. Hicks, U.S. Geological Survey
Shane J. Stocks, U.S. Geological Survey

Between September 2007 and October 2008, the U.S. Geological Survey, in cooperation with the U.S. Environmental Protection Agency and the Mississippi Department of Environmental Quality, collected and analyzed water-quality samples from streams in the Yazoo River basin within the Mississippi River Alluvial Plain in northwestern Mississippi. Water-quality samples were collected and analyzed for various physical and chemical characteristics, including but not limited to suspended sediment, nutrients, and chlorophyll a. In addition, continuous field parameter measurements (water temperature, pH, specific conductance, dissolved oxygen and turbidity) were collected at 30-minute intervals for a minimum of 72 hours using deployed multi-parameter water-quality sondes. In 2007, water-quality samples were analyzed from 56 sites located across the study area with continuous data measured at 28 of these sites. In 2008, water-quality samples were analyzed and continuous data measured at an additional 16 sites across the study area. Data collected throughout this project will be used in the development of water-quality indicators to assess water-quality health. These indicators will assist in the development and evaluation of restoration and remediation plans for water bodies not meeting their designated uses, as stated in the U.S. Environmental Protection Agency's Clean Water Act Section 303(d).

Key words: Surface Water, Water Quality, Ecology

# Water Quality Monitoring Plan and Implementation, Lake Washington Mississippi, 2008

Matthew B. Hicks, U.S. Geological Survey
Shane J. Stocks, U.S. Geological Survey

Lake Washington is located in Washington County in northwestern Mississippi, and drains into Washington Bayou, a tributary of Steele Bayou. The lake is an oxbow formed by an abandoned meander of the Mississippi River. About half of the land use in the watershed is agriculture: major crops are cotton, corn, soybeans, wheat, and rice. Although the watershed is relatively rural, housing development has increased near the lake since 2003. Water quality in Lake Washington has gradually declined during the last 30 years. In 1991, results of a study by the Mississippi Department of Environmental Quality (MDEQ) indicated that nutrient enrichment was affecting Lake Washington as a result of high phosphorus and nitrogen concentrations in the lake. In that same year, a watershed restoration project was initiated by MDEQ to demonstrate and assess best management practices to reduce sediment and nutrient concentrations in Lake Washington. Results of a follow-up study by MDEQ in 1996 indicated that nutrient enrichment in Lake Washington was continuing due to continued high phosphorus and nitrogen concentrations in the lake.

A group of State and Federal agencies and local organizations, known as the Yazoo Basin Team and part of the Basin Management Approach of MDEQ, identified Lake Washington as a priority area for watershed restoration, and as a result, the Lake Washington Watershed Implementation Team was formed in 2005. The team developed a Watershed Implementation Plan in 2007 with the goal of improving water quality of Lake Washington, in which reduction of sediment and nutrient loads were considered high priorities. The plan calls for reduction of sediment loading by 55 percent and associated organic matter loading by about 50 percent through implementation and maintenance of various best management practices. In coordination with water-quality improvement efforts outlined in the Watershed Implementation Plan, water-quality data are being collected to document suspended-sediment and nutrient characteristics of Lake Washington and loads in runoff entering Lake Washington before, during, and after implementation of efforts outlined in the plan. Nutrient concentrations (nitrogen and phosphorus), suspended sediment concentrations, and flow at two major inflows of Lake Washington are being monitored by the U.S. Geological Survey, and MDEQ personnel are collecting nutrients and chlorophyll-a data at two main lake sites. In addition, multi-parameter water-quality sondes will be deployed by USGS at two sites near the two MDEQ main lake sites, at a single depth (approximate of the middle of photic zone) to collect hourly readings of water temperature, specific conductance, dissolved oxygen, pH, and turbidity.

Key words: Surface Water, Water Quality, Nutrients Reduction

Delta (Ag) Water

**Delta (Ag) Water**

| | |
|---|---|
| **Heather Welch**<br>*U.S. Geological Survey* | Occurrence of Nitrate in the Mississippi River Valley Alluvial Aquifer at a Site in Bolivar County, Mississippi |
| **Jeannie R.B. Barlow**<br>*U.S. Geological Survey* | Evaluating the Role of Groundwater and Surface-Water Interaction on the Transport of Agricultural Nutrients to the Shallow Alluvial Aquifer Underlying Northwestern Mississippi |
| **Antonio L. Cerdeira**<br>*Brazilian Department of Agriculture* | Effects of Transgenic Glyphosate-Resistant Crops on Water Quality |
| **Jamie Dyer**<br>*Mississippi State University* | Influences of Land Surface Characteristics on Precipitation Over the Lower Mississippi River Alluvial Plain |
| **Charles Wax** Mississippi State University | Climatological and Cultural Influences on the Potential for Conservation of Groundwater in the Mississippi Delta Shallow Alluvial Aquifer by Substituting Surface Water for Irrigation |

# Occurrence of Nitrate in the Mississippi River Valley Alluvial Aquifer at a Site in Bolivar County, Mississippi

Heather Welch, U.S. Geological Survey
Richard H. Coupe, U.S. Geological Survey
C.T. Green, U.S. Geological Survey

Annually in the United States, about 12 million tons of nitrogen are applied as commercial fertilizer causing contamination of surface and groundwater resources. In the Mississippi Delta, large amounts of agricultural chemicals are applied to crops on an annual basis, but are rarely detected in groundwater. Previous studies have indicated that the shallow alluvial aquifer in the Delta is unaffected by anthropogenic activities at the surface because of an overlying impervious clay layer. However, model simulations have indicated that the alluvial aquifer is recharged by a small percentage (5%) of rainfall. In 2005, the U.S. Geological Survey National Water-Quality Assessment (NAWQA) Program began a study in the Bogue Phalia basin to assess how environmental factors and agricultural practices affect the source and transport of agricultural chemicals. Two wells located in a cotton field (surveyed as very fine sandy loam and silty clay) in Bolivar County, Mississippi were sampled for inorganic compounds, nutrients, and field parameters from June 2006 to November 2008. Nitrate was detected at concentrations ranging from 7.2 to 13 mg/L in a shallow well screened near the water table from 27 to 32 feet, but was not detected in a deeper well screened from 70 to 120 feet located approximately one-quarter mile from the shallow well. In June 2008, depth interval sampling was conducted in test holes drilled adjacent to the shallow well to better define the occurrence of nitrate at five depths ranging from 32.5 to 60 feet - between the depths of the shallow and deep wells. Nitrate concentrations decreased with depth in the water column, and there were no detections below a depth of 36 feet. Data indicate that some nitrate is being transported through the unsaturated zone into the alluvial aquifer, but it is being converted fairly quickly into ammonia and nitrogen gas under strong, reducing conditions in the aquifer. The data imply that the aquifer may not be as invulnerable to anthropogenic activities as previously thought.

Key words: Nitrate, groundwater, water quality

# Evaluating the Role of Groundwater and Surface-Water Interaction on the Transport of Agricultural Nutrients to the Shallow Alluvial Aquifer Underlying Northwestern Mississippi

Jeannie R.B. Barlow, U.S. Geological Survey
Melinda S. Dalton, U.S. Geological Survey
Richard H. Coupe, U.S. Geological Survey

Between April 2007 and November 2008, the U.S. Geological Survey (USGS) has collected various hydrogeologic and water-quality data to evaluate the role of groundwater and surface-water interaction on the transport of agriculturally applied nutrients to the shallow (less than 25 feet deep) sand and gravel aquifer underlying the Mississippi Alluvial Plain in northwestern Mississippi. Despite stringent best management practices, agricultural activities seemingly contribute to nutrient and pesticide loads in the region's groundwater and surface waters. A pervasive, near-surface, semi-impermeable clay layer appears to substantially inhibit movement of nutrients into the shallow alluvial aquifer. However, many streams and ditches are incised below the clay layer into more permeable material, thus suggesting another, more direct route for nutrient transport into the underlying alluvial aquifer. Such transport would be further enhanced by declining water levels in the aquifer. Previous investigations by the USGS showed that during periods of high surface-water flow, groundwater flow reverses direction, and the stream changes from a gaining stream (groundwater flow into the stream) to a losing stream (surface-water flow into the streambed sediments and potentially into the shallow alluvial aquifer). A one-dimensional model developed for the investigations considered only the movement of water in the vertical direction (into and out of the streambed). The present investigation expands on the previous model by evaluating both the vertical and horizontal flow components and couples this information with water-chemistry data.

Key words: Ground Water, Models, Agriculture

# Effects of Transgenic Glyphosate-Resistant Crops on Water Quality

Antonio L. Cerdeira, Brazilian Department of Agriculture, Agricultural Research Service
Stephen O. Duke, U.S. Department of Agriculture, Agricultural Research Service

Glyphosate (*N*-[phosphonomethyl] glycine) is a highly effective, non-selective herbicide. Herbicide-resistant crop (HRC) has been the most successful trait used in transgenic crops throughout the world. Transgenic glyphosate-resistant crops (GRCs) have been commercialized and grown extensively in the Western Hemisphere and, to a lesser extent, elsewhere. GRCs have generally become dominant in those countries where they have been approved for use, greatly increasing the utilization of glyphosate. Potential effects of glyphosate on ground and surface water are lower than the effects of the most herbicides that are replaced when GRCs are adopted. Perhaps the most positive indirect effect is that GRCs crops promote the adoption of reduced- or no-tillage agriculture, resulting in a significant reduction in soil erosion and water contamination. Glyphosate and its degradation product, aminomethylphosphonate (AMPA), residues are not usually detected in high levels in ground or surface water in areas where glyphosate is used extensively. There are some concerns about AMPA in water since it has higher mobility and persistence in the environment than glyphosate. However, neither glyphosate nor AMPA are considered to be significantly toxic. Of greater concern are the formulation ingredients, which can vary from country to country, from product to product, and even over time with the same product. There is some published evidence that formulation ingredients might adversely affect amphibians in some situations.

Key words: Agriculture, Ground Water, Nonpoint Source Pollution, Toxic Substances, Water Quality

**Introduction**

Herbicide resistance and insect resistance are the only two types of transgene-conveyed traits for crops that have so far had a marked effect on agriculture (Gutterson and Zhang, 2004). The term ‘herbicide-resistant crop’ (HRC) describes crops made resistant to herbicides by transgene technology. HRCs have been the subject of numerous previous reviews (Cerdeira and Duke, 2006; Cerdeira and Duke, 2007; Cerdeira *et al.*, 2007b; Dekker and Duke, 1995; Duke, 1998; Duke, 2002; Duke, 2005; Duke and Cerdeira, 2005; Duke *et al.*, 1991; Duke and Powles, 2008; Duke *et al.*, 2002; Gressel, 2002; Hess and Duke, 2000; Warwick and Miki, 2004) and two books (Duke, 1996; McClean and Evans, 1995), and special issues of the journal *Pest Management Science* in 2005 and 2008. A review has covered agronomic and environmental aspects of HRCs (Schuette *et al.*, 2004). Other reviewers have discussed the environmental impacts of all transgenic crops, with coverage of HRCs (Carpenter *et al.*, 2002; Uzogara, 2000). Lutman *et al.*, 2000 and Kuiper *et al.*, 2000 published brief reviews of environmental consequences of growing HRCs. Other reviews have focused entirely on GRCs (Cerdeira and Duke, 2007; Cerdeira *et al.*, 2007b)

The vast majority of HRCs used in agriculture are glyphosate-resistant crops (GRCs). So, in this review, we focus on the potential effects of GRCs on soil and water quality. Different formulations of glyphosate will not be discussed, as the actual composition of additives to these products, other than the active herbicide ingredients, are generally trade secrets and can vary between geographical regions and with time. The potential environmental impact of a technology is often geography and/or time dependent. Thus, extrapolation of the results and conclusions of studies to all situations is impossible. Generalizations from reported studies may not cover every situation. For a realistic assessment of risk, we will contrast certain risks of GRCs with the risks that the GRCs displace.

### Glyphosate-resistant crops

Glyphosate (*N*-[phosphonomethyl] glycine) is a highly effective, non-selective herbicide. Prior to introduction of GRCs, glyphosate was used in non-crop situations, before planting the crop, or with specialized application equipment to avoid contact with the crop (Duke, 1988; Duke *et al.*, 2003. ; Franz *et al.*, 1997). It inhibits the shikimate pathway by inhibiting 5-enolpyruvyl-shikimate-3-phosphate synthase (EPSPS). This results in reduced aromatic amino acids and deregulation of the pathway. The latter effect causes massive flow of carbon into the pathway, with accumulation of high levels of shikimic acid and its derivatives. Glyphosate is particularly effective because most plants metabolically degrade it very slowly or not at all, and it translocates well to metabolically active tissues such as meristems. Its relatively slow mode of action allows movement of the herbicide throughout the plant before symptoms occur. Glyphosate is only used as a post emergence herbicide, as it has little or no activity in soil. Glyphosate is an anion and is sold as a salt with different cations (e.g., isopropyl amine, trimethylsulfonium, diammonium).

Most GRCs are produced using the CP4 gene of *Agrobacterium* sp, found to encode a highly efficient, glyphosate-resistant EPSPS. Plants transformed with this gene are highly resistant (ca. 50X) to glyphosate Nandula *et al.*, 2007. Glyphosate oxidoreductase (GOX), encoded by a gene from the microbe *Ochrobactrum anthropi* (strain LBAA), degrades glyphosate to glyoxylate, a ubiquitous and safe natural product, and aminomethylphosphonate (AMPA). This gene has been used along with the CP4 gene in GR canola. GR canola also as a resistance factor of about 50X Nandula *et al.*, 2007. A multiple missense mutation in endogenous maize EPSPS produced by site-directed mutagenesis (GA21 gene) has been utilized to generate commercial glyphosate resistance in some varieties of maize (Lebrun *et al.*, 1997).

To date, GR soybean, cotton, canola, sugarbeet, and maize are available to farmers of North America (Table 1). All varieties use the *CP4* EPSPS gene, except for the GA21 maize varieties. The GOX gene is also found in GR canola. The adoption rate of GR cotton and soybeans in North America has been high (ISB, 2008). This has been in large part because of the significantly reduced cost of excellent weed control obtained with the GRC/glyphosate package (Gianessi, 2005; Gianessi, 2008). Simplified and more flexible weed control also contributed to the rapid adoption. Approximately 62% of the canola acreage in the USA was planted in GR varieties in 2005 (Sankula, 2006,). Adoption of GR soybeans was more rapid in Argentina than in the U.S. (Monjardino *et al.*, 2005; Penna and Lema, 2003). Initially, the economic advantage was not been as clear with GR maize, but after a lag phase adoption has increased rapidly to to approach the level of adoption of cotton.

### Surface and groundwater quality

In a recent review, (Borggaard and Gimsing, 2008), concluded that the risk of ground and surface water pollution by glyphosate seems limited because of sorption onto variable-charge soil minerals (e.g. aluminum and iron oxides) and because of microbial degradation. Although sorption and degradation are affected by many factors that might be expected to affect glyphosate mobility in soils, glyphosate leaching seems mainly determined by soil structure and rainfall. Glyphosate in drainage water runs into surface waters but not necessarily to groundwater because it may be sorbed and degraded in deeper soil layers before reaching the groundwater. According to the World Health

Organization WHO, 2004 quidelines, under usual conditions, the presence of glyphosate and AMPA in drinking-water does not represent a hazard to human health. For this reason, the establishment of a guideline value in drinking water for glyphosate and AMPA is not deemed necessary.

An extensive review conducted by Vereecken, 2005, about the mobility and leaching of glyphosate concluded that in the USA and Europe there was a low occurrence of glyphosate in groundwater. An interesting finding from a study by Laitinen *et al.*, 2007, suggested that plant translocation of glyphosate to roots should be included both in leaching assessments and pesticide fate models. After glyphosate fate was simulated with the PEARL 3.0 model, the observed and simulated glyphosate residues in soil after canopy applications did not correlate, highlighting the importance of the translocation process in glyphosate fate in soil. Their studies indicated that some soil glyphosate residues must originate from exudation from plant roots, and that the translocation process should be included both in leaching assessments and pesticide fate models.

Klier *et al.*, 2008, studying glyphosate behavior based on the pesticide transport model LEACHP and the model PLANTX to simulate the pesticide uptake by plants implemented in the modular modeling system EXPERT-N, concluded that glyphosate transport measurements and the mathematical modeling results indicate that, due to the high sorption of glyphosate to the soil matrix and the high microbial capacities for glyphosate degradation, soil leaching risks can be considered to be low. On the other hand, Mamy *et al.*, 2008, found that the main metabolite of glyphosate, AMPA, was more persistent than glyphosate and because of the detection of AMPA in the deep soil layer, the replacement of both trifluralin and metazachlor due to glyphosate resistant oilseed rape might not contribute to decreasing environmental contamination by herbicides. They also concluded that predictions of the pesticide root zone model (PRZM), underestimated the dissipation rate of glyphosate and the formation of AMPA in the field.

Scorza and Da Silva, 2007, using the PEARL model to establish a ranking considering the main pesticides and their potential to contaminate groundwater in Brazil, evaluated 4,374 agronomic prescriptions used in the Dourados river watershed and concluded that the most used pesticides on the watershed area were glyphosate followed by 2,4-D, fipronil, methamidophos, imazaquin, parathion-Me, trifluralin, and atrazine. Although glyphosate scored high in the amount used, their simulations revealed that the pesticides with the highest potential of groundwater contamination were bentazon, imazethapyr, fomesafen, 2,4-D, methamidophos, imazaquin, followed by the less used thiodicarb, and monocrotophos.

Long term studies conducted in Canada with the herbicides glyphosate, dicamba, 2,4-D, bromoxynil, methylchlorophenoxyacetic acid (MCPA), diclofop, and triallate showed no residues of glyphosate in groundwater Miller *et al.*, 1995. Various studies have shown that glyphosate contaminates surface water less than several alternative herbicides (summarized by Carpenter *et al.*, 2002). Once in surface water, it dissipates more rapidly than most other herbicides. In the intensely farmed maize-growing regions of the mid-western USA, surface waters have often been contaminated by herbicides, principally as a result of rainfall runoff occurring shortly after application of these to maize and other crops (Wauchope *et al.*, 2002). A model was used to predict maize herbicide concentrations in the reservoirs as a function of herbicide properties comparing broadcast surface pre-plant atrazine and alachlor applications with glyphosate or glufosinate post-emergent herbicides with both GR and glufosinate-resistant maize (Wauchope *et al.*, 2002). Because of greater soil sorptivity, glyphosate loads in runoff were generally one-fifth to one-tenth those of atrazine and alachlor, indicating that the replacement of pre-emergent maize herbicides with glyphosate would dramatically reduce herbicide concentrations in vulnerable watersheds. A more recent study by Shipitalo *et al.*, 2008 found in a multi-year study of GR soybeans grown in no-tillage or tilled conditions, that glyphosate runoff in surface water was below drinking water standards, whereas levels of certain other herbicides used as a comparision were not always below maximum allowable levels. AMPA levels in runoff water were also low.

In a comprehensive survey of the U.S. Geological Service, USGS, 1998, more than 95% of all samples collected from streams and rivers contained at least one pesticide, compared to about 50% for ground water. Glyphosate was not among them. Although this study was done before the widespread adoption of GRCs, glyphosate was widely used as both a preplant and postharvest herbicide, as well as a harvest aid. Other studies also found no glyphosate in ground water in the United States where glyphosate is applied on no-tillage cropping systems (Kolpin *et al.*, 1998) and in Brazil in various cropping systems (Cerdeira *et al.*, 2003; Cerdeira *et al.*, 2007a; Cerdeira *et al.*, 2005; Lanchote *et al.*, 2000; Paraiba *et al.*, 2003). Similar results were found for surface waters (Clark *et al.*, 1999).

Leaching of glyphosate and/or its metabolite AMPA was studied in a low-tillage field and a normal tillage field. A significant difference between the soil residual concencentrations of AMPA was seen, with the higher concentration found where low-tillage had been practiced and where glyphosate had been used several times in the years before sampling soil. Spatial and temporal variations in concentrations of glyphosate and AMPA have been observed in pre-and post-application 45-cm deep soil cores divided into 15-cm intervals (Meyer *et al.*, 2005). Simonsen *et al.*, 2008, studying the fate of glyphosate and its byproduct AMPA in soil, found that both compounds were better extracted from soil when phosphate was used as an extraction agent, compared with pure water indicating that the risk of leaching of aged glyphosate and AMPA residues from soil is greater in fertilized soil.

Degradation of pesticides in aquifers has been evaluated, and glyphosate was found to be degraded under both anaerobic and aerobic conditions, as opposed to some other herbicides such as MCPA and mecoprop (Albrechtsen *et al.*, 2001). Certain pesticides were not degraded in water under aerobic or anaerobic conditions (dichlobenil, bentazon, isoproturon, and metsulfuron-methyl). This could be important when using glyphosate on transgenic crops, if the herbicide leached sufficiently to reach ground water, which is a more anaerobic environment. Half-lives of glyphosate vary from 60 h for ground water samples exposed to sunlight to 770 h for those stored under dark conditions (Mallat and Barceló, 1998).

Ground water contamination risks for a particular herbicide use should be evaluated in the context of the herbicides are replaced. As shown on Table 2. special attention should be given to atrazine, the most used herbicide under conventional crops considered. Atrazine was used in most acreage before GRC introduction. Atrazine is banned in Europe due to the water contamination potential. Wauchope, 1987 has shown that it has a high potential for groundwater contamination despite its moderate solubility, which explains the detection of the pesticide in concentrations that exceed the health advisory level in some wells in the United States located on irrigated lands (Belluck *et al.*, 1991). According to Shipitalo *et al.*, 2008, replacing atrazine and alachlor with glyphosate can reduce the occurrence of dissolved herbicide concentrations in runoff exceeding drinking water standards.

Glyphosate is considered to have a low risk for leaching Wauchope *et al.*, 1992 and has a low GUS (Ground-water Ubiquity Score) index (Cerdeira *et al.*, 2007b). The GUS index Gustafson, 1989 assesses the leachability of molecules and the possibility of finding these herbicides in groundwater. The index is based on two widely available herbicide properties: half-life in soil ($t_{½}^{soil}$) and partition coefficient between soil organic carbon and water (Koc). It can be calculated by the equation:

$$GUS=\log_{10}(t_{1/2})\times[4-\log_{10}(Koc)]$$ (Table 2)

**Aquatic biota**

Peterson and Hulting, 2004 compared the ecological risks of glyphosate used in GR wheat with those associated with 16 other herbicides used in spring wheat in the northern Great Plains of the USA.

A Tier 1 quantitative risk assessment method was used. They evaluated, among other things, acute risk to aquatic vertebrates, aquatic invertebrates, and aquatic plants, and also estimated groundwater exposure. They found less risk with glyphosate than with most other herbicides to aquatic plants and groundwater (Table 3).

As we mentioned earlier, glyphosate is less likely to pollute ground and surface waters than many of the herbicides that they replace. A life-cycle assessment technique used to compare conventional sugarbeet agricultural practices with risks that might be expected if GR sugarbeet were grown suggested that growing this GRC would be less harmful to the ecology of water for the herbicide-resistant crop than for the conventional crop (Bennett *et al.*, 2004). These results suggest less impact of GRCs on aquatic vegetation than conventionally-grown crops.

Glyphosate was also evaluated for ecological risk assessment, and it was found not to bioaccumulate, biomagnify, or persist in an available form in the environment (Solomon and Thompson, 2003). This study also showed that the risk to aquatic organisms is negligible or small at application rates <4 kg/ha and only slightly greater at application rates of 8 kg/ha. Solomon *et al.*, 2007; also found no significant effect on aquatic organisms of use of glyphosate as aerial spray in Colombia to erradicate coca plantations. Analyses of surface waters in five watersheds showed that, on most occasions, glyphosate was not present at measurable concentrations. Similarly, studies with surface water and sediment with glyphosate have also shown that adsorption to the bottom sediments, microbial degradation, the persistence of glyphosate in freshwater pond and effect on fishes used in the in situ bioassays posed no serious hazard (Tsui and Chu, 2008).

**Conclusions**

Glyphosate/GRC weed management offers significant environmental and other benefits over the technologies that it replaces Duke and Powles, 2008. We have provided an abbreviated survey of the potential impacts (risks and benefits) of GRCs on soil and water quality. Clearly, we and many of the authors that have written on this topic emphasize that risks and benefits of any GRC are very geography and time dependent. For example, increasing GR weeds in GRCs are changing how farmers use these crops, and in most cases reducing the environmental benefits of GRC systems. Glyphosate is more environmentally and toxicologically benign than many of the herbicides that it replaces. Its effects on soil and and water are relatively small. Soil erosion causes long term environmental damage. Being a broad spectrum, foliarly applied herbicide, with little or no activity in soil, glyphosate is highly compatible with reduced- or no-tillage agriculture and has contributed to the adoption of these practices in the Western Hemisphere. This contribution to environmental quality by GRCs is perhaps the most significant one. Numerous regulatory tests of glyphosate and glyphosate products, using rigorous protocols meeting international standards, as well as product post-marketing surveillance, have failed to reveal any effects that could help substantiate any claims of adverse health and environmental outcomes (Farmer *et al.*, 2008). On the other hand, the degradation product of glyphosate, AMPA, has higher mobility and persistence in the environment. The environmental implications of this have not been well studied.

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Table 1. Transgenic GRCs that have been or are now available to farmers (de-regulated) in North America. (adapted from Duke and Cerdeira, 2005; and updated from the Information Systems for Biotechnology ISB, 2008

| **Crop** | **Year made available** |
|---|---|
| Soybean | 1996 |
| Canola | 1996 |
| Cotton | 1997 |
| Maize | 1998 |
| Sugarbeet[1] | 1990 |
| Alfalfa[2] | 2005 |
| [1]Never grown by farmers, withdrawn in 2004, but re-introduced in 2008. | |
| [2]Re-regulated by court order in 2007. | |

Table 2. Leaching potential of the main herbicides used on conventional main crops compared to glyphosate, according to indexes Ground-water Ubiquity Score (GUS) (Adapted from Inoue *et al.*, 2003).

| Herbicides | $K_{oc}$ (ml/g) | $T_{1/2}$ (days) | GUS | Acreage (x1000) | $LD_{50}$ (mg/kg)[1] |
|---|---|---|---|---|---|
| Atrazine | 165 | 60 | L | 42813 | 3090 |
| Metolachlor | 200 | 195 | L | 27295 | 1200-2780 |
| Imazetapyr | 22 | 75 | L | 25490 | >5000 |
| Pendimethalin | 17200 | 44 | NL | 21558 | 1050 |
| Trifluralin | 7000 | 45 | NL | 21242 | >5000 |
| Dicamba | 2 | 14 | L | 18237 | 757-1707 |
| Acetochlor | 55 | 20 | L | 14839 | 1426-2148 |
| Cyanazine | 190 | 14 | IN | 10772 | 182-332 |
| Chorminuron | 110 | 40 | L | 8882 | 4100 |
| Glyphosate | 24000 | 47 | NL | - | >5600 |
| NL= Does not leach, IN=Intermediate, L=Leaches easily, $K_{oc}$= Adsorption coefficient ($mg/g^{-1}$) $T_{1/2}$= Half-life $LD_{50}$= Lethal dose, [1]Lethal dose data from Extoxnet | | | | | |

Table 3. Predicted relative ecological risks of herbicide active ingredients based on modeling. (adapted from Peterson and Hulting, 2004)

| Active Ingredient | Application rate (g ai/ha) | Groundwater value (ppb) | RR[b] | Aerobic soil half-life (days) |
|---|---|---|---|---|
| Glyphosate | 840 | 0.0005 | 1 | 2 |
| 2,4-D | 560 | 0.005 | 10 | 5.5 |
| Bromoxynil | 1,100 | 0.0004 | 0.8 | 2 |
| Clodinafop | 67 | 0.00003 | 0.06 | 1 |
| Clopyralid | 146 | 0.06 | 120 | 26 |
| Dicamba | 280 | 0.1 | 220 | 18 |
| Fenoxaprop | 90 | 0.000006 | 0.01 | 1 |
| Flucarbazone | 34 | 0.2 | 400 | NA |
| MCPA | 1,457 | 0.26 | 520 | 25 |
| Metsulfuron | 9 | 0.004 | 8 | 28 |
| Thifensulfuron | 22 | 0.0001 | 0.2 | 6 |
| Tralkoxydim | 280 | 0.001 | 2 | 5 |
| Triallate | 1,100 | 0.04 | 80 | 54 |
| Triasulfuron | 34 | 0.05 | 100 | 114 |
| Tribenuron | 16 | 0.00003 | 0.06 | 2 |
| Trifluralin | 1,100 | 0.009 | 18 | 169 |
| [a]Abbreviations: RR, relative risk; NA, not available | | | | |
| [b]RR: Relative Risk compared with glyphosate, value in bold indicates greater risk relative to glyphosate | | | | |

# Influences of Land Surface Characteristics on Precipitation over the Lower Mississippi Alluvial Plain

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The lower Mississippi River alluvial valley, covering sections of Mississippi, Arkansas, and Louisiana, is well recognized as a major agricultural center of the US. Since roughly 1940, land use, vegetation, and soil characteristics have remained relatively consistent over the area, with irrigation levels increasing in association with crop density. Research has shown that agriculture can have an influence on regional weather variability through land use, soil type, and vegetation patterns by influencing energy and moisture transport into the atmospheric boundary layer. Due to the relatively sharp contrasts in these surface characteristics between the alluvial valley and surrounding regions, it is suspected that anthropogenic weather modification may be occurring in the form of enhanced mesoscale convective circulations. These circulations are most evident during the warm season when radiational surface heating is greatest and synoptic-scale forcings are minimal, and can have a direct influence on agriculture by varying the intensity and distribution of convective precipitation. The purpose of this project is to define the existence and location of convective boundaries and associated precipitation over the lower Mississippi River alluvial valley. This will aid water resource managers and meteorological forecasters in recognizing the relative climatological patterns of rainfall during the growing season, and will provide information on the influence of anthropogenic land use and soil moisture boundaries on precipitation distribution. Initial results from the study indicate an eastward shift in warm-season precipitation relative to predominantly agricultural areas, such that rainfall is minimized over the lower Mississippi River alluvial valley and maximized directly eastward along the Hwy. 45 corridor. Although there are a number of factors that combine to generate this pattern, it is expected that enhanced soil moisture and latent heat flux due to heavy irrigation over the alluvial plain may play an important role in generating more intense convective boundaries over the region, leading to increased downstream transport of atmospheric moisture and subsequent precipitation.

Key words: Climatological Processes, Water Quantity, Hydrology

## Introduction

The lower Mississippi River alluvial valley (LM-RAV), covering sections of Mississippi, Arkansas, and Louisiana, is well recognized as a major agricultural center of the US. In Mississippi alone, the alluvial valley boasts 80% of the states total agricultural production (Delta Council, 2008), which is substantial given that Mississippi is the fourth largest producer of cotton and rice in the United States (USDA, 2008). Often given the misnomer the "Mississippi Delta" due to its distinctive shape, the alluvial region is characterized by extremely fertile soils deposited through repeated flooding of the Mississippi River. Before 1940, roughly 96% of the existing hardwood forest in the floodplain was converted to cultivated land (MacDonald et al., 1979), and subsequent land use, vegetation, and soil characteristics have remained relatively consistent since that time.

Agriculture is known to be highly dependent on climatological variables related to the surface energy and water budgets; however, research has shown that agriculture can have an influence on regional weather variability through land use and vegetation patterns (Brown and Arnold, 1998). Specifically, soil type and vegetation play a key role in determining the dynamics of energy and moisture transport into the atmospheric boundary layer through spatial variations in evapotranspiration, albedo, and surface heat 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). These effects are well documented, and can occur in various climate zones given weak synoptic forcing. Additionally, agricultural land use can influence the dynamics of the boundary layer through variations in surface roughness over the growing season, effectively modifying existing sub-synoptic and mesoscale flow regimes by varying the intensity of turbulent mixing through the radix layer.

The energy, moisture, and turbulent fluxes all have strong influences on the generation and strength of mesoscale circulations, and therefore precipitation. As a result, variations in land use and/or soil type can lead to changes in regional precipitation patterns (Anthes, 1984). Several studies have demonstrated the role of the sand-clay soil boundary in eastern North Carolina (a.k.a., the "Sandhill Effect") on mesoscale surface convergence and convective precipitation (Boyles et al., 2007; Koch and Ray, 1997). Similar soil contrasts exist within the LMRAV, although no studies have been done to indicate that regional precipitation patterns are affected; however, research has shown that abnormal temperature variations in the floodplain do exist as a result of spatial variations in soil and vegetation (Raymond et al., 1994; Brown and Wax, 2007). These temperature effects could be an indicator of possible boundary layer modification through surface influences, resulting in the generation of mesoscale circulations and localized convective precipitation.

It is the purpose of this research to determine if mesoscale convective boundaries occur along the LMRAV as a result of surface heterogeneities, and to establish how local precipitation patterns are influenced by such features. This will be done using high-resolution radar precipitation estimates and satellite imagery, the former of which is available since 1996. Although modeling studies have been carried out in other locations to examine the sensitivity of mesoscale circulations to surface characteristics (Mahfouf et al., 1987; Boyles et al., 2007; Hong et al., 1995), it is necessary to first study observed data to determine if a relationship is visible. Results of this research can be used to establish the existence of interbasin water transport through atmospheric processes, and will provide information regarding localized weather modification through anthropogenic land cover changes.

**Data and Methods**

***Study Area***

The study area for this research is roughly defined as northern Mississippi, southeastern Arkansas and northeastern Louisiana, which contains within it the LMRAV (a.k.a., Mississippi Delta). This region is heavily agricultural, and is most recognizable in northwestern Mississippi by a sharp change in vegetation, soil type, and elevation. No specific outlines are used to define an area of interest in or around the LMRAV to minimize subjective interpretation of atmospheric patterns; however, the study region is expanded east through Tennessee and Alabama to take into account advection of convective features originating over the Mississippi Delta (Figure 1).

Although convective boundaries could potentially form year-round over the study area, several factors limit the time period of analysis to only the warm season (May – September). First, surface heterogeneities have the greatest atmospheric influence through the sensible and latent heat fluxes, which are driven by surface heating. As a result, only those months where surface heating is maximized will be used for analysis. Second, cool-season precipitation patterns are dominated by large-scale mid-latitude weather systems, minimizing the ability to differentiate localized convective precipitation from the heavier and more persistent stratiform and frontal convective systems.

***Defining Synoptically-Benign Days***

Atmospheric convection is heavily influenced by synoptic-scale circulation patterns and processes, such as surface fronts and upper-level convergence/divergence. These features effectively mask the influence of surface characteristics on localized weather patterns, making it difficult to separate the unique influence of different environmental properties. Ideally, only days with minimal synoptic forcings over the region will be included for analysis since this will give a better indication of the effect of surface features on localized convection. As a result, the first step in this project is defining a synoptically benign day over the LMRAV. These criteria will then be used to differentiate appropriate days to include in the analysis.

To quantify the synoptic conditions over the study region, 00Z and 12Z atmospheric sounding data from Jackson, MS, Shreveport, LA, and Little Rock, AR were used to quantify wind speeds at 850 hPa (~1500 m) and 500 hPa (~6000 m) for all warm-season days (May – September) from 1996 – 2008 (Figure 1). This time period was limited by the availability of high-resolution precipitation data, which first became available in 1996. By using sounding data at these locations, a day influenced by an approaching frontal system from the west can be accounted for. The 850 hPa level was used because it normally describes synoptic conditions just above the planetary boundary layer (i.e., near -surface), while the 500 hPa level describes mid-level winds that act to advect mature convective systems. No upper-level data were utilized because of common missing values, and because the convection resulting from the surface boundaries is often relatively shallow before it produces precipitation.

The median wind speed value at each level was used as the criteria to differentiate synoptically-benign days. These values were 7.7 $ms^{-1}$ (15 knots) at 850 hPa and 14.4 $ms^{-1}$ (28 knots) at 500 hPa. Any day where the 850 hPa and 500 hPa levels at all sounding locations showed a wind speed less than the given criteria value for the 00Z and 12Z value for the given day, as well as the 00Z value for the following day, was considered synoptically weak. This method yielded 245 synoptically weak days out of a possible 4749 days (5.2%).

***Satellite Data***

Available synoptic and precipitation data are not able to recognize mesoscale convective boundaries independently due to spatial and temporal resolution issues; therefore, it was necessary to incorporate satellite imagery to visualize cloud patterns associated with localized surface convection. For this project, visible (~5 μm) and near-infrared (~10 μm) images from the Geostationary Operational Environmental Satellite (GOES) 10 (i.e., GOES East) were used, which have a nominal resolution of 1 km and 4 km, respectively. Imagery was obtained from the Comprehensive Large Array-data Stewardship System (CLASS) (NOAA, 2009).

Whenever possible the higher resolution 1 km visible imagery is used to define the generation and extent of the mesoscale convective boundaries, with the 4 km near-infrared data used to estimate the depth of convection using brightness temperatures. However, when the visible data are not available or are not valid, such as during the night or at extreme low sun angles, the 4 km near-infrared data are used to define the surface boundaries.

***Precipitation Data***

The precipitation data used in this project are 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]). Radar-based precipitation estimates have become a useful and valuable tool in hydrometeorological research due to their high spatial and temporal resolution. This is especially true in research related to small-scale or intense precipitation variability; however, since radar is a remotely sensed platform with inherent, though understood, limitations (i.e., beam blockage, false return signals, truncation error, etc.), the NWS has developed algorithms designed to minimize the error in associated precipitation estimates.

Multi-sensor data are produced by combining hourly radar precipitation estimates (a.k.a., Stage I data), in the form of a digital precipitation array (DPA), with hourly surface-based observations. The surface observations are used to calculate a corrective mean field gauge-radar bias using a Kalman filtering approach, providing a local adjustment to the radar-derived precipitation field (Smith and Krajewski, 1991). Stage II data are then corrected radar-based precipitation estimates for an individual radar coverage. An additional process involves combining the individual corrected radar fields into a mosaic of coverages, resulting in a continuous field of multi-sensor precipitation estimates. These data, termed the Stage III product, are manually quality controlled at NWS river forecast centers to remove areas of known contamination (Briedenbach et al., 1998; NOAA/NWS, 2007).

Since approximately 2003, the Office of Hydrologic Development (OHD) of the NWS has made a transition from the Stage III processing algorithms to the updated Multisensor Precipitation Estimator (MPE) algorithm. The MPE algorithm includes an additional weighted adjustment based on surface gauge distance from a precipitation measurement; therefore, more weight is given to the radar estimate as the precipitation event occurs further from a rain gauge, allowing for adjustment based on within-storm variability (Westcott et al., 2005; Fulton et al., 1998; Seo, 1998). Despite the fact that the algorithm used to calculate the precipitation estimates has changed during the study period for this project, no correction has been made to adjust the data since no quantification of the bias difference between MPE and Stage III is currently available.

Stage III and MPE precipitation estimates are provided by the NWS in XMRG format, and are projected in the Hydrologic Rainfall Analysis Project (HRAP) grid coordinate system. The HRAP coordinate system is a polar stereographic projection centered at 60°N / 105°W, with a nominal 4x4 km grid resolution. For the purposes of this study, the multi-sensor precipitation estimates were decoded such that the latitude and longitude of the respective HRAP grid cell center was associated with the corresponding precipitation value.

Hourly Stage III and MPE data, coded in universal time coordinated (UTC), were used to generate daily precipitation values by averaging values from 0500 – 0500 UTC. This corresponds to 2400 – 2400 local standard time (LST) over the study region, or midnight to midnight. This was done so that all precipitation occurring during the daylight hours for a given day could be accumulated together. Only days with non-missing data for all 24 hours were used for analysis.

Koch and Ray (1997) state that radar data alone cannot detect convergence zones due to inherent physical limitations in the observation process (i.e., varying beam elevation with distance); however, it should be noted that within this project, the precipitation estimates are not being used to detect mesoscale convective boundaries. To be precise, satellite imagery is the primary tool by which the boundaries are detected, at which point the multi-sensor precipitation estimates are used to verify the maturation of the associated convection and to define the rainfall associated with the events.

## Results

### *General Patterns*

Before investigating the defined synoptically-benign days for the existence and extent of mesoscale convective boundaries and the associated precipitation, it is necessary to quantify the associated synoptic conditions and precipitation distribution. The average wind and temperature conditions associated with the 245 synoptically-benign days were calculated using the 32 km NARR data for the 850 hPa and 500 hPa levels, while the precipitation data were summarized using expected value (i.e., mean) and variance assuming the rainfall at individual grid cells followed a gamma distribution (Thom, 1958).

The average conditions at the 500 hPa level for all synoptically weak days are roughly equivalent barotropic through the Ohio Valley, becoming weakly baroclinic over the study region (Figure

2a). Wind speeds are relatively low over the LMRAV (< 5 $ms^{-1}$), and show an anticyclonic flow pattern around an axis in northeastern Louisiana. Based on this synoptic set-up, winds generally flow from the northwest across the LMRAV. Additionally, there is a weak latitudinal temperature gradient across the area. It should be noted that the estimated temperature and height gradients are relatively weak overall, and do not show the variability associated with individual days; therefore, they are meant to show only the general conditions associated with all synoptically-weak days.

Similar patterns exist at the 850 hPa level as at the 500 hPa level with respect to both wind speed and direction (Figure 2b). There is a general anticyclonic circulation, again centered over northeast Louisiana, indicating a minimal vertical offset in synoptic conditions from the top of the planetary boundary layer to the mid-levels. Accordingly, there is weak westerly and northwesterly flow (~<2 $ms^{-1}$) over the study area. The temperature patterns show a weak meridional temperature gradient across the Mississippi Valley with a closed geopotential height contour over the study region. This indicates that the anticyclonic rotation centered over northeast Louisiana is a result of low-level divergence, typical of normal warm-season conditions over this area. Since the atmospheric conditions over the study region at 850 hPa on synoptically weak days are roughly barotropic, it is hypothesized that any vertical development will be a result of thermal instability originating at the surface.

The average daily precipitation for all synoptically-benign days shows localized maxima along the Gulf Coast from central Louisiana through the panhandle of Florida (Figure 3b). This coincides with the sea breeze front that dominates this area on days with minimal synoptic forcings, further verifying the criteria used in this study to define synoptically-benign days. The high precipitation depths follow a line roughly northeast through Alabama into the southern Appalachians, while there is a relatively steep gradient towards lower rainfall amounts over the LMRAV. Within the LMRAV there is a distinct area of low average rainfall in northwest Mississippi, stretching northwest into Arkansas; however, along a north-south line through northern Mississippi there is a slight increase in rainfall depth that separates rainfall minima to the east and west.

The rainfall minimum over the study area may be associated with subsidence from the synoptic high pressure that is shown to exist in the lower levels (Figure 2), which dynamically hampers thermodynamic uplift by limiting the vertical extent of the planetary boundary layer. Additionally, the mean westerly and northwesterly winds over the study area imply decreased mid-level moisture convergence by advecting cooler continental air from the Great Plains, which would further weaken any convective uplift.

The convective nature of precipitation events during synoptically weak conditions inherently suggests higher variability (high intensity, low spatial extent), such that areas with high rainfall amounts should also have high variability; therefore, combining mean and variance estimates will allow for a more detailed analysis of convective precipitation distribution across the study area. Daily precipitation variance (for only synoptically-benign days) mirrors the general rainfall distribution across the study region, including the maximum along the coast and minimum in northern Mississippi and Arkansas (Figure 3b). Additionally, the north-south line of increased rainfall is shown as limited areas of higher variance in northern Mississippi.

This line of increased precipitation is roughly centered between the Mississippi Delta bluffs to the west and the Pontotoc Ridge to the east, which might imply an orographic influence; however, the substantial variations in soil type and vegetation between the areas preclude such a general conclusion. Along this line, however, it is possible that the planetary boundary layer in this region is neutrally stable with a shallow stable layer near the surface, such that the slight increase in elevation along the Mississippi Delta bluffs upwind may provide a weak convective triggering mechanism. Likewise, an enhanced mesoscale circulation may be the cause of the precipitation, which would form as a result of the change in land cover features and an enhancement of the surface heat flux gradient. This is similar to the generation of the sea breeze circulation that is related to the precipitation maxima along the coast.

***Event-specific Analysis***

Using the 245 defined synoptically weak days, visual analysis of the GOES satellite data was performed to define those days when a mesoscale convective boundary occurred. A boundary was recognized as a curvilinear cloud feature that originated and decayed over a single diurnal cycle, normally through the course of one afternoon. The multi-sensor precipitation and associated synoptic data were then utilized to extract only those days where rainfall amounts and/or distribution were associated with convection over the LMRAV. Several techniques were used to minimize the inherent subjectivity in the analysis, which is often a substantial source of error in any manual visual interpretation. The following criteria were used to define a day where a regional surface influence was apparent:

I. Satellite imagery must show a distinct curvilinear mesoscale cloud feature with a diurnal temporal extent over the study area.
II. Multi-sensor precipitation estimates must show a distinct area or areas of scattered rainfall within or in close proximity (~<20 km) to the defined mesoscale convective boundary.
III. The areas of rainfall must not be part of an existing larger-scale mesoscale boundary, defined by a clear enhancement of precipitation beyond the study area.
IV. Flow at 500 hPa must show that the rainfall is downwind of the lower Mississippi River alluvial plain.

Although a strictly visual analysis is not the ideal method of defining and studying mesoscale convective boundaries, it is the objective of this paper to only define their existence over the LMRAV. Quantification of the boundaries over time and space, as well as examination of the surface features associated with the boundaries, is beyond the scope of this paper and is therefore held as a topic for future research.

Evaluation of all synoptically-benign days revealed that mesoscale convective boundaries do develop over the LMRAV, namely along the eastern edge of the Mississippi Delta during days with weak westerly flow at 850 hPa. In general, less than 10% of the synoptically-benign days were characterized as having mesoscale convective development over the study region. Additionally, the strength and spatiotemporal extent of these boundaries varied widely, making it difficult to accurately determine the associated surface influences. The boundaries that did occur produced initial development in the late morning (10:00 – 11:00 LST) and lasted through the late afternoon / early evening (17:00 – 18:00 LST). When precipitation did occur, substantial increases in intensity and/or extent occurred in the early afternoon (13:00 – 14:00 LST) with a temporal extent of several hours.

For most synoptically-benign days with recorded precipitation, a stronger boundary or circulation not associated with the study area overwhelmed localized convection, degrading or preventing any noticeable convective boundaries. For days with no precipitation or convective boundary over the study area, the dominant wind direction was from the east or north. This indicates that the dominate area for the development of a mesoscale convective boundary is along the eastern edge of the Mississippi Delta when westerly near-surface winds are dominate.

To provide a more detailed understanding of the cloud and precipitation patterns associated with a mesoscale convective boundary over the LMRAV, two days in which a distinct boundary developed are looked at in detail. The first occurred on July 12, 1997, and was characterized by a relatively disorganized boundary with localized convection along a north-south line that originally developed in northeast Mississippi (Figure 4). Initial surface conditions showed cellular convection over the region, indicating low-level instability and turbulence within the planetary boundary layer. Additionally, low-level winds were weak and westerly while mid-level winds were somewhat stronger and from the northeast, leading to substantial directional shear over the study area. The convective storms that developed along the boundary showed good vertical development, as can be seen by the bright appearance on the visible satellite imagery; however, precipitation amounts were relatively low and spatially limited since the individual storms were short-lived, most likely due to a lack of low-level moisture.

The conditions on September 9, 2006 were more favorable for the development of a mesoscale convective boundary across the study area in that the 850 hPa flow had a southerly component, increasing the surface moisture convergence over the Mississippi Delta. This can be readily seen by the generation of a sea breeze front along the Gulf Coast during the morning and early afternoon (Figure 5), which are normally associated with weak synoptic forcings. The study area was initially clear with scattered cirrus clouds until roughly 11:00 LST, at which point a distinct convective boundary began to develop along the Mississippi Delta bluff line from Vicksburg, MS northwards (Figure 5). This line continued to develop before producing a linear precipitation pattern at 14:00 LST, which maintained its spatial structure and position for the next few hours. This suggests that some surface feature related to the Mississippi Delta (i.e., elevation, soil and/or vegetation heterogeneity) was the primary cause of the convection.

**Discussion**

The objectives of this research were to identify the generation of mesoscale convective boundaries within or along the borders of the LMRAV, which would likely form due to rapid changes in soil type, vegetation, and elevation. When convective boundaries do form, it was also the intent of this project to ascertain the spatial and temporal extent of the related precipitation. This is an important aspect of the research because downstream advection of precipitation could lead to interbasin transport of water, which is a key aspect in sustainable agriculture within the Mississippi Delta.

Mesoscale convective boundaries normally occur when regional synoptic forcings are weak and surface heating is strong; therefore, only days defined as synoptically benign (wind speeds less than 7.7 $ms^{-1}$ and 14.4 $ms^{-1}$ at 850 hPa and 500 hPa, respectively) during the warm season (May – September) were included in the analysis. This narrowed the days available for study to 245 (5.2% of the total number of days).

Analysis of 1 km visible GOES satellite data revealed that less than 10% of all synoptically-benign days during the study period were associated with distinct mesoscale convective boundaries. Additionally, of those that did form, most were relatively disorganized and short-lived, rapidly deteriorating and merging with the dominate regional circulation. When strong boundaries were generated within the study area, they were nearly always aligned with the eastern boundary of the Mississippi Delta where the strongest gradients of soil type, vegetation, and elevation exist, and usually formed under dominate westerly flow in the lower atmospheric levels. This immediately raises the question as to what specific surface characteristic leads to the convective development.

Conditions over the LMRAV during the warm season are generally warm and relatively humid; however, surface moisture convergence is usually limited on days with dominate westerly flow at the surface. Taking into account the available soil moisture and high rates of evapotranspiration over the cultivated cropland within the Mississippi Delta, it is possible that the surface latent heat flux could intensify at a local scale, destabilizing the boundary layer. At this point a weak triggering mechanism is all that is needed to generate convection, such as low-level winds flowing perpendicular to the Mississippi Delta bluff line. In such a case it is reasonable to assume that the low-level atmospheric conditions are not strong enough to produce deep convection due to the overall thermodynamic conditions of the region in the warm season, but can enhance the formation of a boundary if it were to form due to dynamic mechanisms.

Regarding the precipitation associated with mesoscale convective boundary development over the Mississippi Delta, the large number of surface and atmospheric variables related to the intensity and distribution of precipitation makes it extremely difficult to quantify the conditions necessary for precipitation formation. However, in general it was found that upon boundary formation in the late morning (10:00 – 11:00 LST), the related precipitation began to form in the early afternoon (13:00 – 14:00 LST) and continued for several hours before the boundary weakened and dissipated. The precipitation rates were relatively low and the spatial extent of the convective storms was limited, although localized heavy rains were possible,.

**Future Work**

This project successfully showed that under specific atmospheric conditions during the warm season over the LMRAV, it is possible for mesoscale convective boundaries to form and modify the precipitation distribution across the region. The causes and driving mechanisms related to their development are not well known; therefore, the next logical step in this research is to quantify the influence of surface characteristics on the development of the convective boundaries and the related precipitation. This is a difficult undertaking due to the limited number of observations over the region and the large number of independent variables related to convective development and rainfall generation (i.e., topography, 4D atmospheric flow, surface moisture and heat fluxes, stability in the planetary boundary layer, etc.).

Mesoscale convective boundaries form due to a combination of mesoscale and synoptic atmospheric conditions, which are directly influenced by thermodynamic and kinematic processes associated with surface-atmosphere interactions. As a result, it is possible to augment observational studies of these phenomena using physics-based mesoscale numerical weather models. Accordingly, future research will employ the Weather Research and Forecasting (WRF) model for detailed analysis of the sensitivity of surface convergence zones to soil and vegetation patterns over the LMRAV. WRF is suited for this role since it is a non-hydrostatic mesoscale model with various convective, planetary boundary layer, and cloud physics parameterizations. Initial work with the model over the study area has led to the development of a domain at a nominal 1x1 km spatial resolution with 40 vertical levels. Plans include assimilation of soil moisture data from Soil Climate Analysis Network (SCAN) surface observing stations, which have a relatively high resolution over the study area, which would help resolve the moisture flux in the surface layers of the model.

Additionally, the results from this study can be augmented by employing an objective pattern recognition algorithm on the satellite data to more effectively recognize the development of mesoscale convective boundaries over the LMRAV. This will provide a more robust mechanism for quantifying the frequency, evolution, and intensity of these events. Also, my more accurately defining the occurrence of the convective events, a quantification of the associated rainfall depth and distribution can be obtained, which would provide valuable information to water resource managers and operational weather forecasters regarding local-scale precipitation modification.

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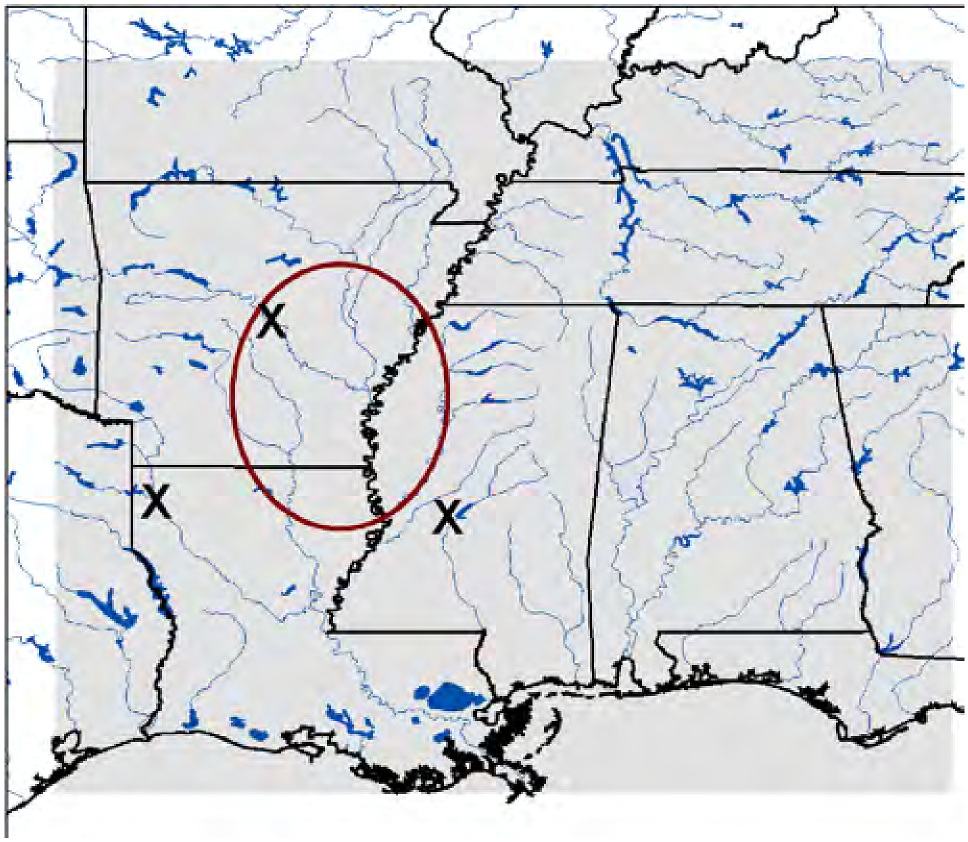


Figure 1. Study area outlined by the shaded area with the general location of the lower Mississippi River alluvial valley shown by the red oval. "X"s mark the location of the atmospheric sounding sites at Little Rock, AR, Jackson, MS, and Shreveport, LA.

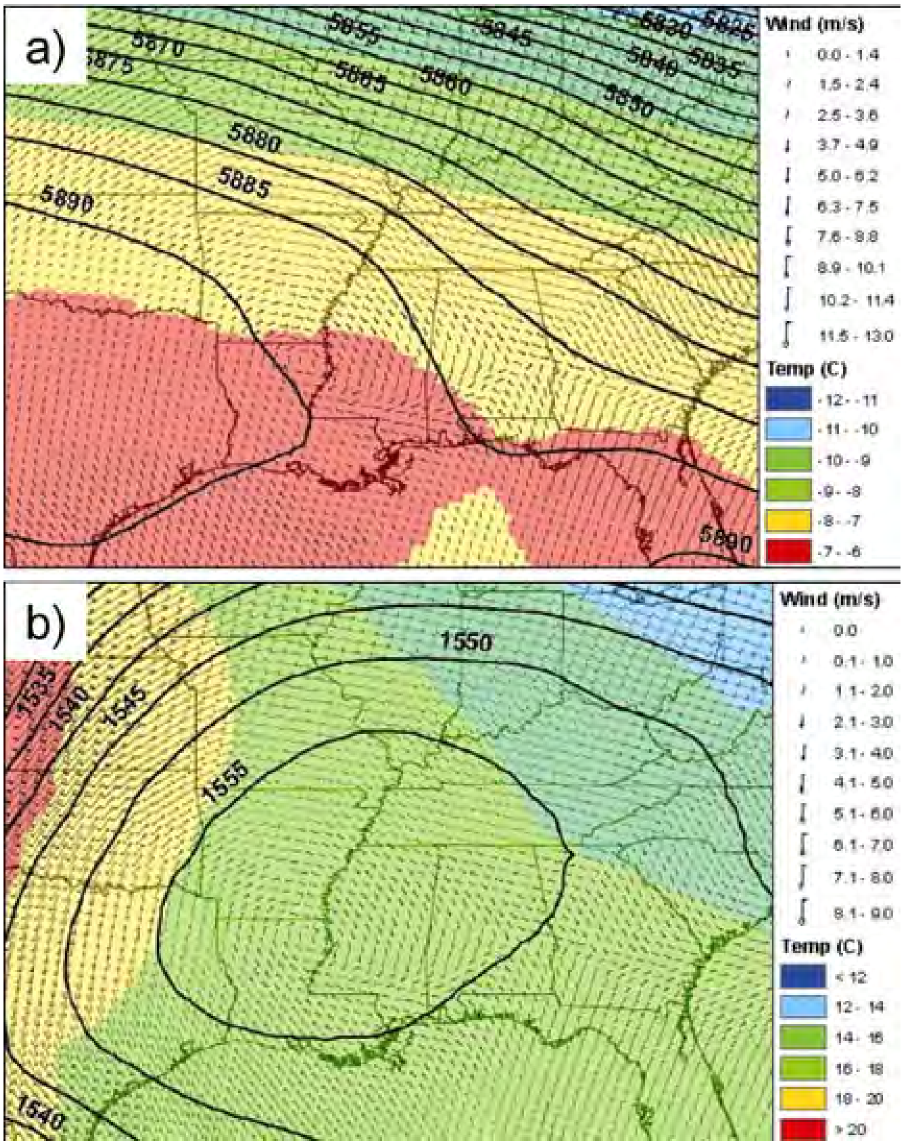


Figure 2. Mean synoptic features (wind speed, direction, temperature, and geopotential height) at (a) 500 hPa and (b) 850 hPa for all synoptically-benign days.

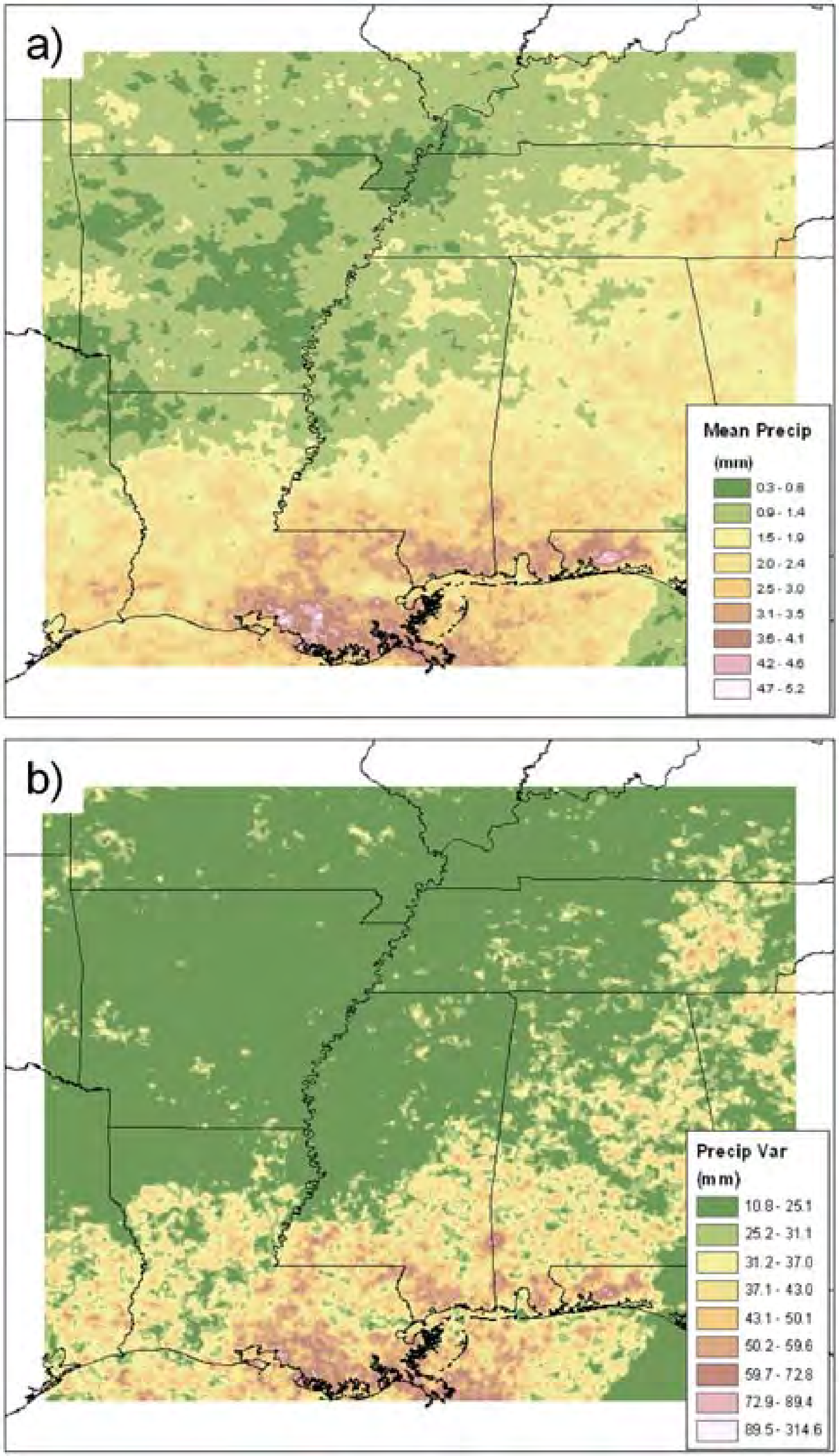


Figure 3. Daily precipitation (a) average and (b) variance for all synoptically-benign days.

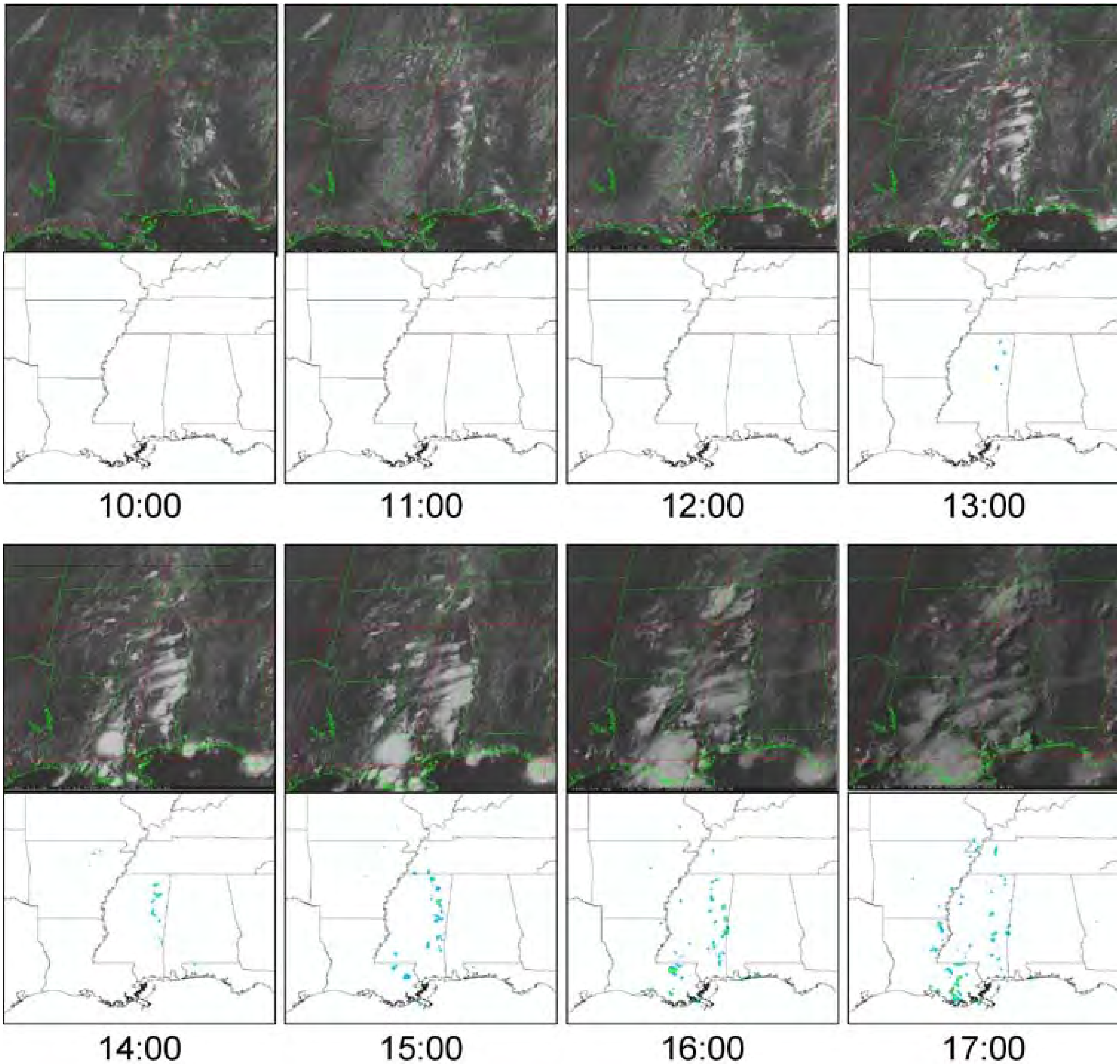


Figure 4. Hourly visible GOES satellite images and multi-sensor precipitation estimates over the study area for the July 12, 1997 event from 10:00 – 17:00 LST.

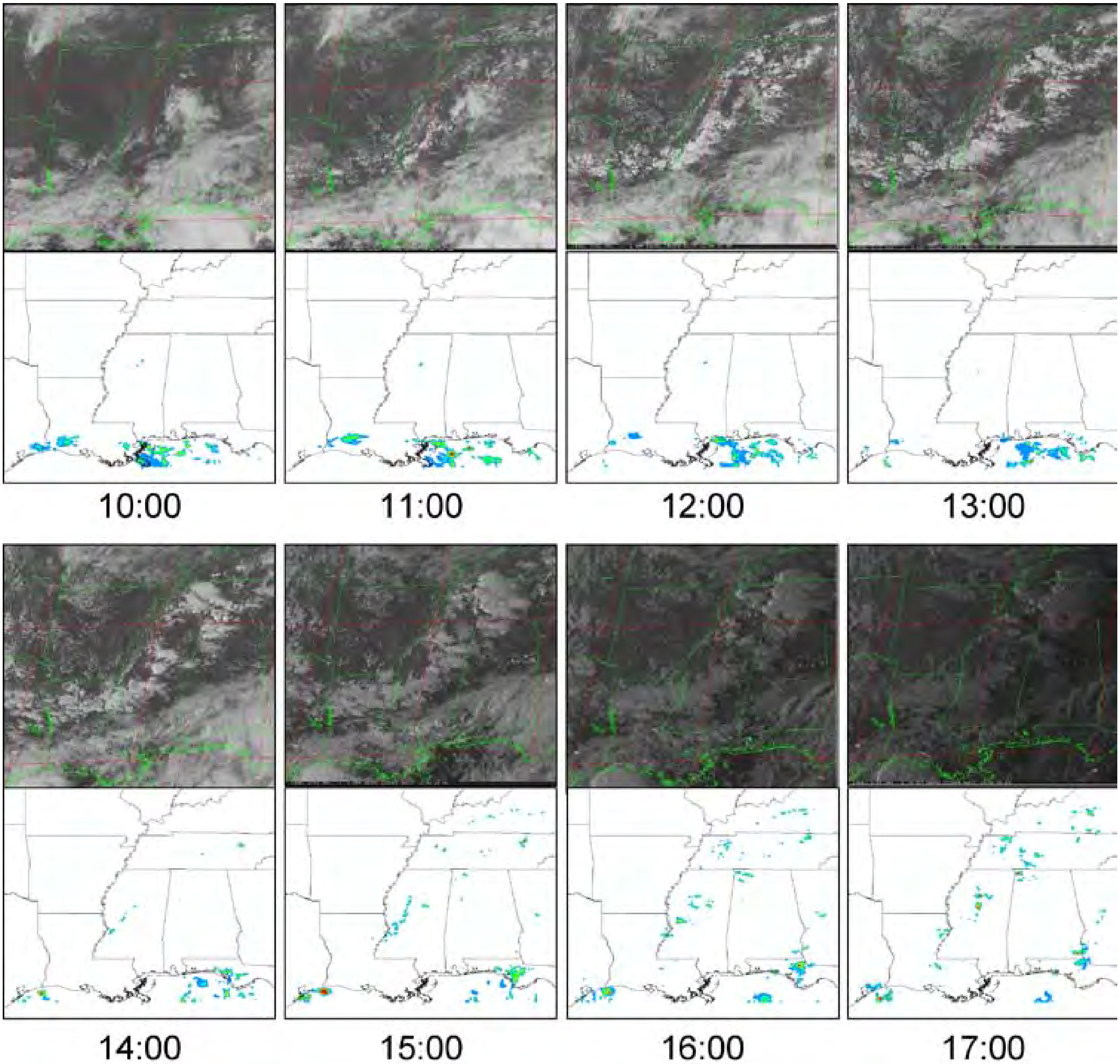


Figure 5. Hourly visible GOES satellite images and multi-sensor precipitation estimates over the study area for the September 9, 2006 event from 10:00 – 17:00 LST.

# Climatological and Cultural Influences on the Potential for Conservation of Groundwater in the Mississippi Delta Shallow Alluvial Aquifer by Substituting Surface Water for Irrigation

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The shallow alluvial aquifer in the Mississippi Delta region is heavily used for irrigation of corn, soybeans, and cotton, as well as for rice flooding and filling aquaculture ponds in the prominent catfish industry. Water volume in the aquifer is subject to seasonal declines and annual fluctuations caused by both climatological and crop water use variations from year-to-year. The most recently documented water volume decline in the aquifer is estimated at 500,000 acre-feet.

Available climate, crop acreage, irrigation water use, and groundwater decline data from Sunflower County were used to construct a model that simulates the effects of climatic variability, crop acreage changes, and specific irrigation methods on consequent variations in the water volume in the aquifer. Climatic variability was accounted for by predictive equations that related annual measured plant water use (irrigation) to growing season precipitation amounts. This derived relationship allowed the application of a long-term climatological record (48 years) to simulate the cumulative impact of climate on groundwater use for irrigation.

Use of the model to simulate changes in irrigation methods and crop acreages from 2008 through 2055 shows potential to stabilize the water volume in the aquifer through implementation of various management strategies. Four scenarios of water management were simulated—static land use/water use in 2006, total efficient irrigation methods, total inefficient irrigation methods, and enhanced surface water use when available in place of groundwater for irrigation. These simulations illustrate the power of the model to assess the long-term impact of climatic variability and changes in the cultural practices on groundwater use in the region. The model is therefore a tool that will be useful in making management decisions that will allow sustainable use of the groundwater resource.

Key words: Climatological processes, Groundwater, Irrigation, Management and Planning, Water Use

**Introduction**

Agricultural producers in Mississippi are increasingly relying on irrigation to insure that crops receive the right amount of water at the right time to enhance yields. The shallow alluvial aquifer is the most heavily developed source of groundwater in the Mississippi Delta region and the entire state (Figure 1). The aquifer is heavily used for irrigation of corn, soybeans, and cotton, as well as for rice flooding and filling aquaculture ponds in the prominent catfish industry. Demand for the groundwater resource continues to grow at a rapid rate (Figure 2).

Water volume in the aquifer is subject to seasonal declines and annual fluctuations caused by both climatological and crop water use variations from year-to-year. These declines can be dramatic and are most notable during the period April-October of each year, particularly in years when normal crop water demands are accentuated by concurrent abnormally dry climatic conditions. Recharge during the remainder of the year has recently been insufficient to restore water volume, and the aquifer is now being mined at the approximate rate of 300,000 acre-feet per year (Figure 3). To underscore the critical nature of this water problem, the most recently documented water volume decline in the aquifer (October 2005-October 2006) is estimated at 500,000 acre-feet (Pennington, 2006). This may represent a worst-case situation in which severe drought combined with consequent increased demand for irrigation. It is estimated that water use for row crops doubled during this period (Pennington, 2006).

It is of critical importance to understand how climatological variability and cultural uses of the water cause the groundwater volume in the aquifer to vary. It is also critical to discover and implement management strategies to change irrigation methods and to use precipitation and other surface water sources as substitutes for aquifer withdrawals and thereby reduce the use of groundwater in the region. Stopping the consistent drop in water volume in the aquifer will require a curtailment averaging about 300,000 acre-feet of groundwater use each year, and the highest priority of this research project is to find and recommend solutions to this problem. This information is essential to agricultural producers in the region and to planners in the Yazoo Mississippi Delta Joint Water Management District who must design sustainable water use scenarios which will allow continuation of the productivity of the region.

**Background Information**

Agriculture is the major water consumer in the southeast region, and aquaculture specifically has the potential to become disproportionately consumptive. For example, most row crops in the region require 30-40 cm/yr, whereas catfish farming requires up to 100 cm/yr under current practices. In the Delta region of Mississippi where nearly 60% of U.S. farm raised catfish are produced, catfish production accounts for about 28% of all water used (Pennington, 2005).

Research to reduce reliance on groundwater in aquaculture has shown remarkable potential reductions in groundwater through use of management strategies to create storage capacity which can capture rainfall to keep ponds filled. For example, studies show the potential to reduce consumption of groundwater in delta catfish ponds by nearly 70% annually through precipitation capture (Pote and Wax, 1993; Pote, et al, 1988; Cathcart et al., 2006). Extension Services in Alabama and Louisiana include variations of those strategies as industry best management practices for reducing groundwater use in those states (Auburn University, 2002; LCES, 2003). In rice production, straight levee systems and use of multiple inlets have been shown to be specific irrigation methods that significantly reduce water use (Smith et al., 2006). Intermittent (wet-dry) irrigation has been shown to reduce water use and non-point source runoff by up to 50% with no yield losses in Mississippi field trials (Massey et al., 2006).

**Methods**

In order to assess the change in volume of water in the aquifer, it was necessary to collect climatological data, crop data, and water use data. In this study, these data were collected and analyzed for Sunflower County only. It was assumed that climate and cultural land uses (crops, acreages, irrigation methods) in Sunflower County were representative of the entire Delta region. These data were used in a model that was developed to identify and account for relationships between climatological variability and cultural water use. The model is interactive, allowing the user to change input values and alter the final output, thus allowing for specific scenarios to be simulated. Successive alternative combinations of variables were simulated with the model to determine possible methods and strategies to aid in groundwater conservation and management.

***Climatological data-***

The climate record from Moorhead, MS (located centrally in Sunflower County) was used in the analysis. Specifically, daily precipitation data from the U.S. Historical Climatology Network were acquired and inspected for completeness. The data were arrayed in an Excel spreadsheet, and missing data were identified. Gaps in the data were filled with data from the next-nearest climate station location. The result was a serially complete and homogeneous daily record of precipitation from 1949-2008. The precipitation data were then organized into growing season totals for each year. Growing season was defined as May through August.

***Crop data-***

Crop data for cotton, rice, soybeans, corn, and catfish were collected from the U.S. Department of Agriculture's National Agricultural Statistics Service (NASS). For the five crops, total acres and total irrigated acres were retrieved for the years 2002-2008 (the only years for which water use data were available. The percentages of each type of irrigation or management method used for each of the five crop types in 2006 are shown in Table 1.

***Water use data-***

Water use data were supplied by Yazoo-Mississippi Delta Joint Water Management District (YMD) in acre-feet/acre (A-F/A). For 2005 through 2008, these data were divided into the amount of water used by each specific irrigation method for cotton, corn, soybeans, and rice (as determined by a survey of about 140 sites monitored by YMD shown in Figure 4), as well as the total average water use for each of the crops. For 2002-2004, only the total average water use amount for each of the four crops was provided. Therefore, a ratio based on the 2005-2008 specific irrigation methods-to-total average water use was formulated to identify relationships between the given average water use and constituent water use amounts associated with each specific irrigation method for the years 2002-2004 (Merrell, 2008). As an example, Table 2 shows that furrow irrigation water use in 2007 was 0.53 A-F/A. The total average water use for furrow irrigation in 2007 was 0.50 A-F/A. Furrow water use was then divided by the total average water use (0.53 A-F/A / 0.50 A-F/A) to get the furrow-to-average water use of 1.06. The same procedure was used for the pivot irrigation method. The ratio was calculated for the years 2005—2008, and the average of those four years is used as the specific irrigation coefficient in the model.

Catfish water use is dependent upon whether the producer uses the maintain-full (MF) or the drop-add (6/3) management scheme. Only total average water use by catfish ponds was provided by YMD, also in A-F/A, and only for 2004 and 2006. So, the catfish water use model developed by Pote and Wax (1993) was used with the Moorhead climate data to estimate the amounts of water used by each of the management schemes in Sunflower County for the period 1960-2008. A ratio between the total average water use and the water use associated with the two possible management schemes in catfish ponds was developed, similar to the water use amounts determined for the specific irrigation methods of the row crops and rice. As shown in Table 3, an average of the four years for which measurements were available was calculated to obtain the percentage of water use by each of the management schemes.

These water use data for row crops, rice, and aquaculture were combined with acreage data to calculate the total amount of water used for irrigation for each crop in the county in 2006. This analysis provided an evaluation of water use by crop type which was the basis for developing a static model. The static model was used as a standard against which all other scenarios of climatic variability, land use and management changes were compared.

***Rainfall-water use relationship***

Recognizing that the amount of rainfall during a growing season significantly influences the amount of irrigation needed, a method was developed to account for this climatological variability. Table 4 shows how growing season rainfall was regressed against the total average water use for cotton, corn, soybeans, and rice for 2002-2008 to develop a function for estimating the amount of water use by crops based on the amount of rain received. Figure 5 gives a comparison of measured water compared to the water use calculated by this method (Merrell, 2008). Catfish water use was obtained from model-estimates based on daily rainfall rather than total growing season rainfall. In this manner, water use by all five crops was linked to climatic variability each year.

***Model development***

The purpose of this research is to determine causes of short-term aquifer declines resulting primarily from cultural water uses and climatological processes. The climate data, crop data, water use data, and rainfall-water use relationships were used to develop a model that could assess water volume declines in the aquifer over a growing season. Based on crop average water use relationships in effect in Sunflower County in 2006, the model calculated amounts of water taken from the aquifer by each specific irrigation method and management method for each of the five crops. The model then summed the specific water uses for each year, resulting in a total annual reduction in the volume of water in the aquifer.

Using the 2006 Sunflower County land use and crop water use relationships with rainfall-water use relationships developed for each crop, growing season precipitation from the past 48 years (1961-2008) was used as a variable in the model to estimate the total water use for each year 48 years into the future (2008-2055). The average of the annual recharge volumes measured in the aquifer between1989-2008 was then used with the modeled water volume declines each year to characterize the cumulative water volume changes over the 48-year period. Then the model was used to simulate different scenarios of water use by changing crop acreages or irrigation methods from the static 2006 data, permitting assessment of changes in water volumes over time under different land use and management conditions. Consequently, the model was used to formulate recommendations for monitoring and managing water volume changes in the aquifer.

**Results**

The model is an interactive Excel spreadsheet consisting of 48 blocks with each block representing one year (Figure 6). Each block is comprised of 13 rows and 15 columns. It is interactive through column 'G' with columns 'H' through 'O' containing formulas based on the information entered in columns 'A' through 'G.' Single or multiple variables can be changed to alter the overall water use amount given in cell 'O13.'

Results of the first 48-year model simulation (2008-2055) using Sunflower County 2006 static cultural water uses (Table 1) for each year with rainfall recorded from 1961-2008 are shown in Figure 7. In this scenario, it can be seen that water volume in the aquifer begins at a little more than negative 200,000 A-F and consistently drops to about negative 600,000 A-F in the first eight years. The drawdown stabilizes and water volume even rises between about 2015-2040, then water volume again drops consistently to about negative 1,600,000 A-F during the period 2041-2055. Subsequent simulations were conducted with alternative scenarios of land uses, irrigation methods, and management strategies employed.

Figure 8 shows the results when water use practices were changed to reflect the most conservative water use method for each crop: 100% pivot irrigation for cotton; 100% zero grade for rice; 100% pivot for corn; 100% zero grade for soybeans; and 100% 6/3 management strategy for catfish. It can be seen that these changes resulted in consistent recovery of water volume beginning after the first year of these practices, ending in 2055 with a positive volume of around 2,900,000 A-F.

Figure 9 shows the results when water use practices were changed to reflect the least conservative water use methods for each crop: cotton 100% furrow irrigation; corn 100% straight; rice 100% contour; soybeans 100% pivot; and catfish 100% maintain full. These changes resulted in consistent water volume declines from the beginning of the 48-year period, ending at about negative 4,200,000 A-F in 2055.

Figure 10 shows results of using surface water in lieu of groundwater. Using surface water when growing season rainfall was 30% or more above average resulted in consistent declines in water volume from the beginning of the period until about 2017. During this 10-year period there were no years in which growing season precipitation met the 30% above normal threshold. From about 2017 to 2044 water volumes in the aquifer increased or stayed level, well above what the volume would have been each year if no surface water had been used. Beginning in 2044 another group of years occurred when the precipitation did not meet the 30% threshold and water volumes declined accordingly until the end of the period, but still ended about positive 800,000 A-F above the static scenario.

**Conclusions**

The model is a sensitive tool that is useful for various forms of analysis. Growing season precipitation can be used to simulate interannual climatological variability through time. Crop acreages and irrigation methods, including use of surface water when available, can be used to account for cultural influences on water use through time. This combination of climatological and cultural drivers of groundwater demand can be used in the model to determine best and worst case scenarios in overall groundwater use in the aquifer. Results indicate that the aquifer responds to small changes in water use associated with crop type, irrigation methods, and use of surface water when available. Results also show that the aquifer water volume is apparently very strongly related to changes in water use methods associated with climatological variability.

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Table 1. Irrigated acres and type of irrigation or management method used for each crop type in Sunflower County, 2006

| Crop | Acres irrigated | % furrow | % straight | % pivot | % con-tour | % zero grade | % multiple inlet | % MF | % 6/3 |
|---|---|---|---|---|---|---|---|---|---|
| cotton | 60,300 | 81 | | 19 | | | | | |
| rice | 27,600 | | 56 | | 20 | 12 | 12 | | |
| corn | 8,910 | 100 | | | | | | | |
| soybeans | 86,350 | 49 | 50 | 3 | 6 | 2 | | | |
| catfish | 24,300 | | | | | | | 34 | 66 |

Table 2. Development of specific irrigation coefficients: cotton example

| | Total Avg (A-F/A) | Furrow (A-F/A) | Pivot (A-F/A) | Furrow to Avg | Pivot to Avg |
|---|---|---|---|---|---|
| 2008 | 0.60 | 0.60 | | 1.00 | |
| 2007 | 0.50 | 0.53 | 0.40 | 1.06 | 0.80 |
| 2006 | 0.84 | 0.89 | 0.62 | 1.06 | 0.74 |
| 2005 | 0.51 | 0.55 | 0.42 | 1.08 | 0.82 |
| | | | | 1.05 | 0.79 |

Table 3. Explanation of catfish management scheme water use

| Equation: MFx + 6/3 (1-x) = Total Water Use (A-F/A) | | | | | |
|---|---|---|---|---|---|
| | MF | 6/3 | Total | X | 1-X |
| 2004 | 3.16 | 0.53 | 1.45 | 0.35 | 0.65 |
| 2006 | 3.52 | 1.56 | 2.4 | 0.43 | 0.57 |
| 2007 | 3.65 | 1.03 | 1.9 | 0.33 | 0.67 |
| 2008 | 3.35 | 0.79 | 1.4 | 0.24 | 0.76 |
| | | | Average | 0.34 | 0.66 |

Table 4. Explanation of rain-irrigation relationship

| Regression Input: Precipitation (x) vs. Total Average Water Use (y) | | | | | |
|---|---|---|---|---|---|
| Year | Precip (growing) | Cotton | Rice | Corn | Soybeans |
| 2002 | 11.19 | 0.54 | 3.15 | 0.93 | 0.68 |
| 2003 | 14.34 | 0.47 | 2.76 | 0.58 | 0.64 |
| 2004 | 23.63 | 0.34 | 2.45 | 0.42 | 0.37 |
| 2005 | 15.22 | 0.51 | 2.97 | 0.96 | 0.60 |
| 2006 | 7.28 | 0.84 | 3.34 | 1.16 | 1.00 |
| 2007 | 15.53 | 0.50 | 3.00 | 0.80 | 0.80 |
| 2008 | 18.69 | 0.60 | 3.10 | 1.20 | 1.00 |

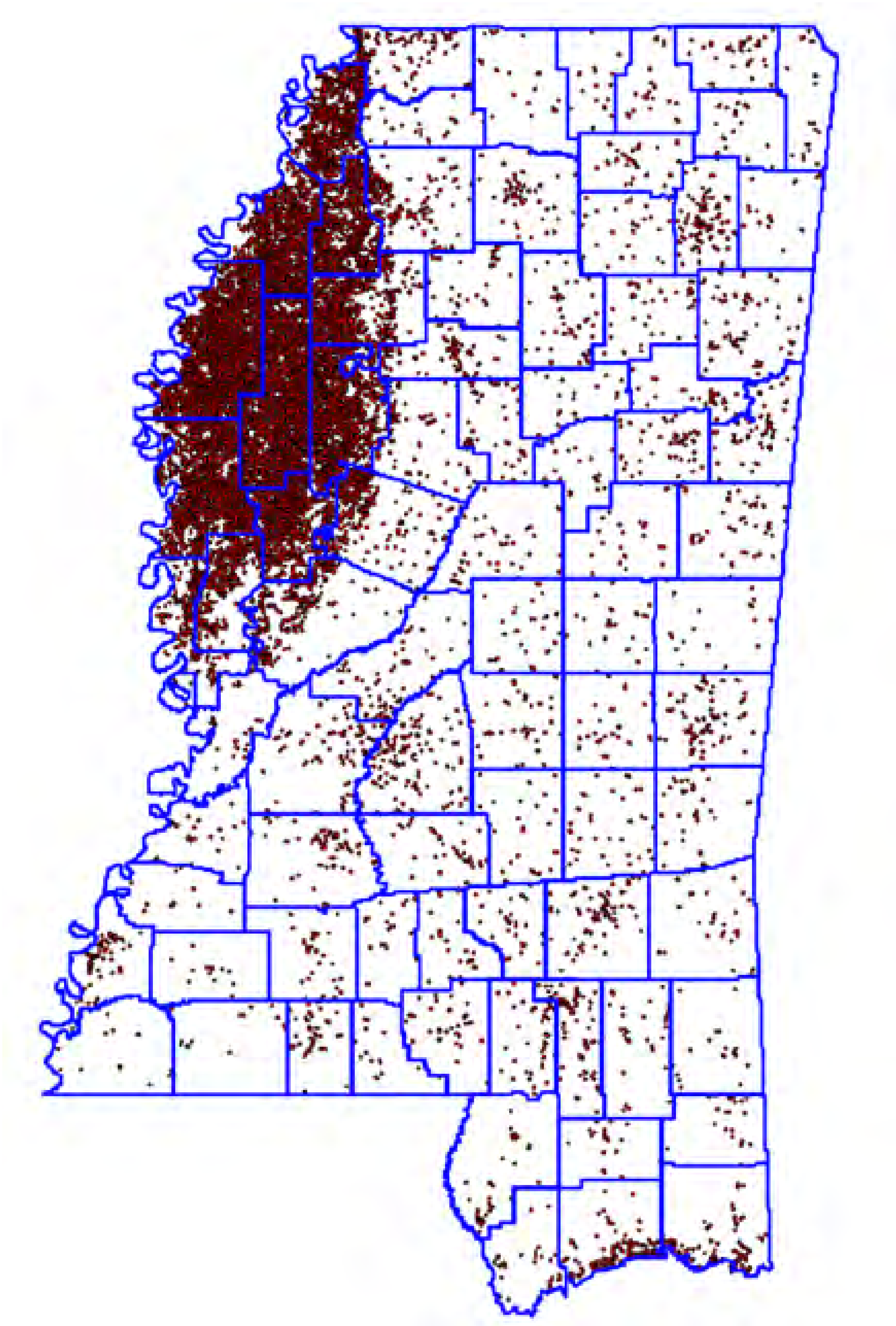

Figure 1. Distribution of permitted wells in Mississippi, 2005.

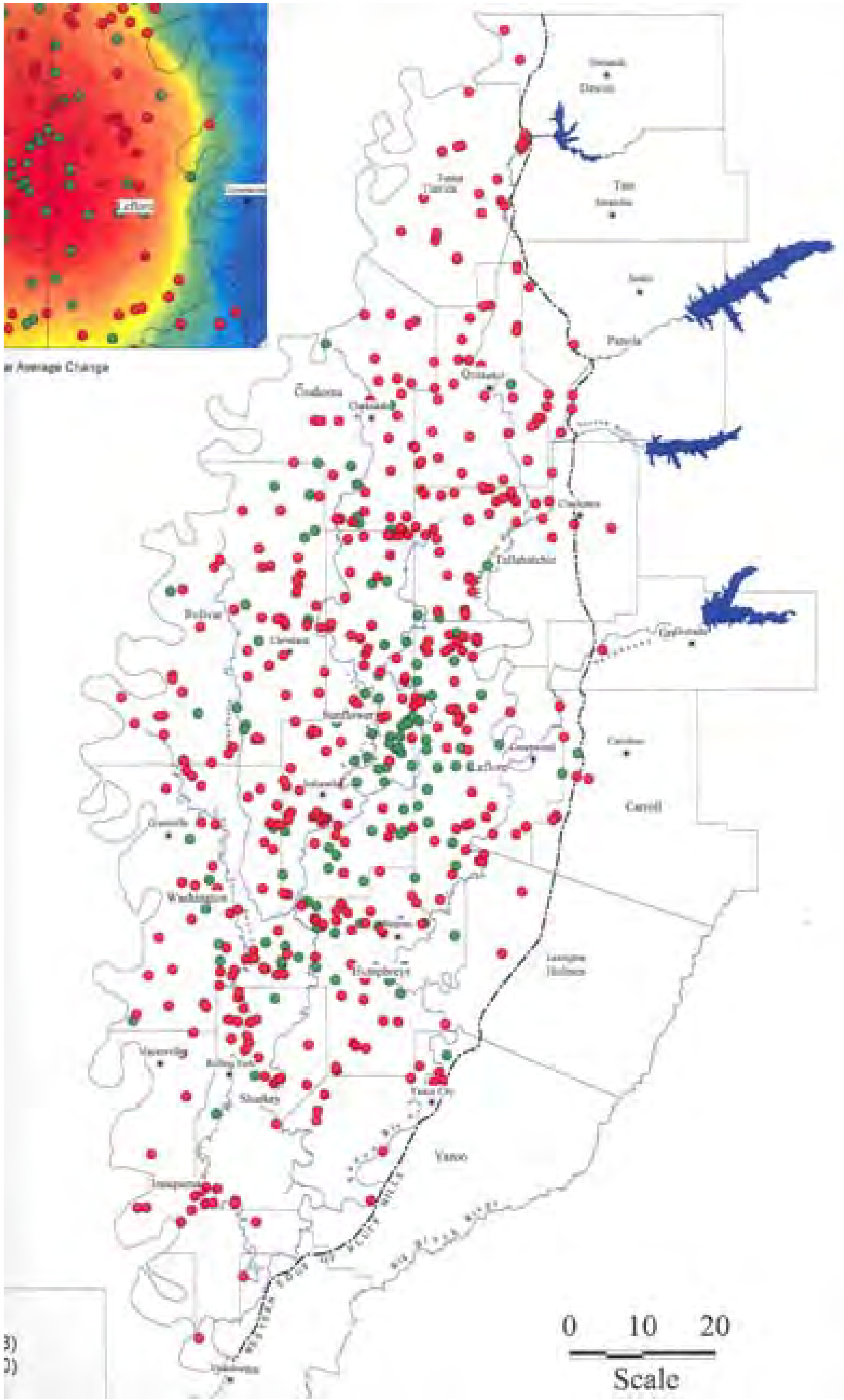


Figure 2. New Permit Requests, 2006.

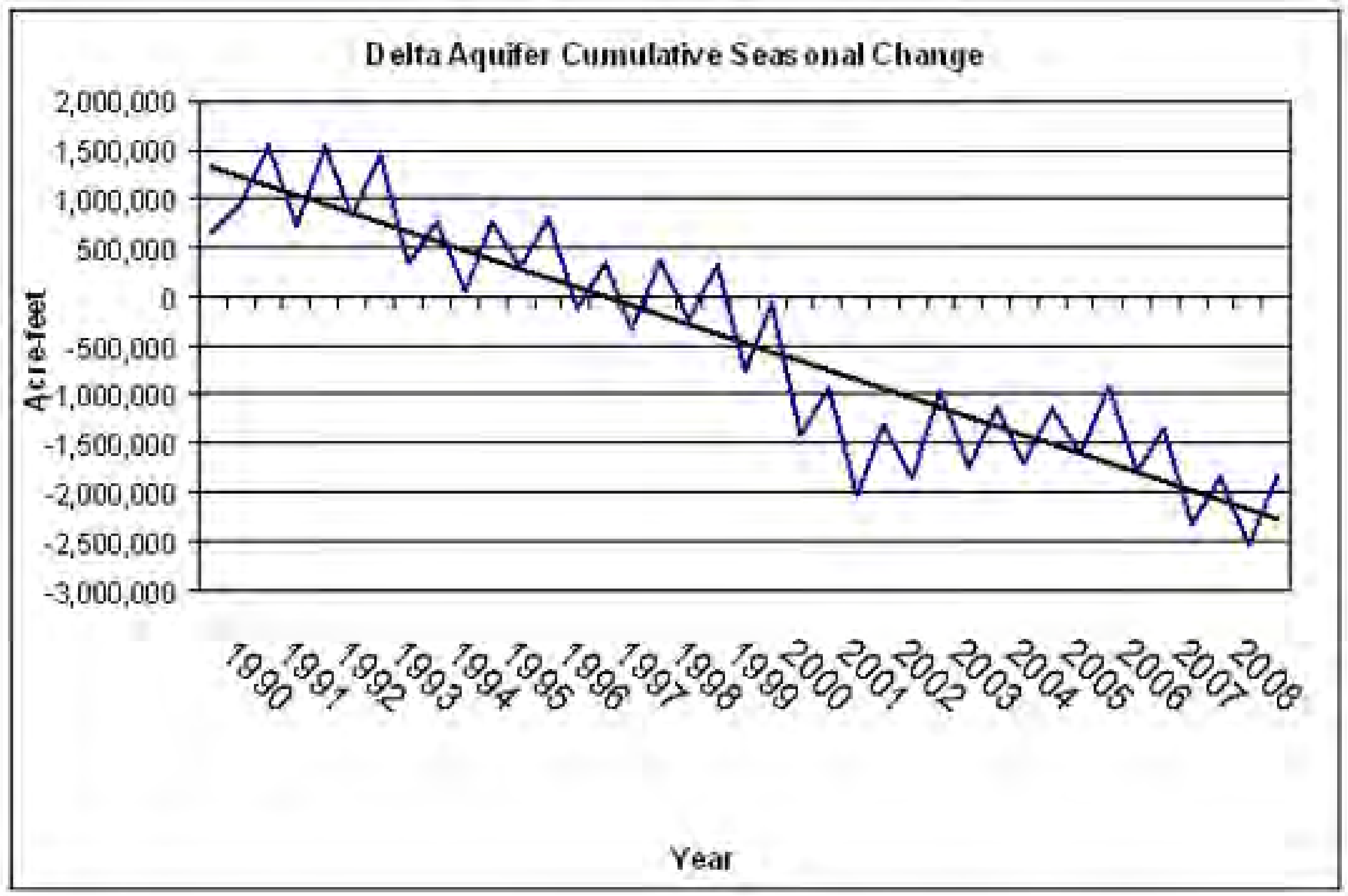


Figure 3. Seasonal Cumulative Aquifer Volume Decline, 1990-2006

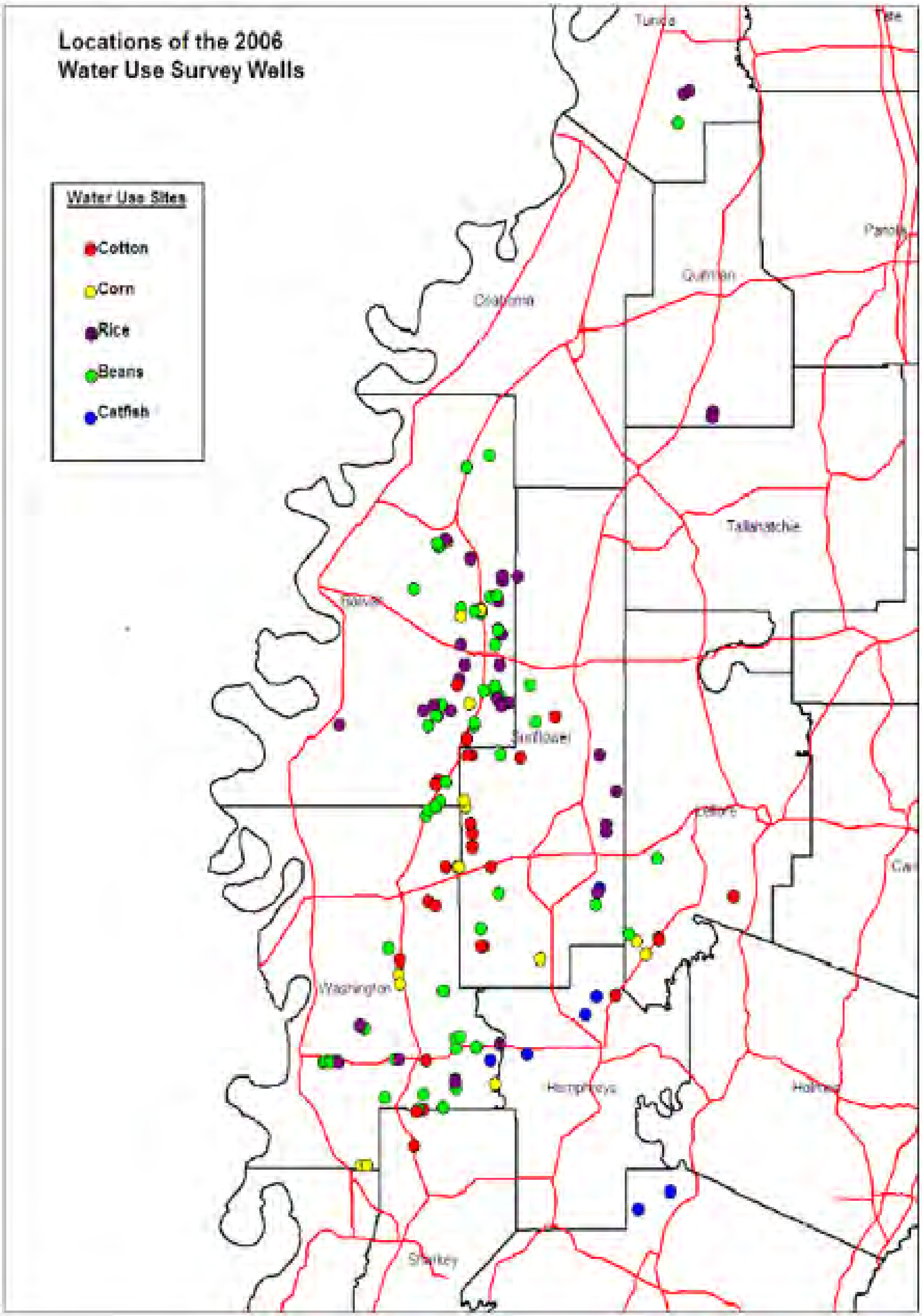


Figure 4. Locations of Water Use Survey Wells, 2006.

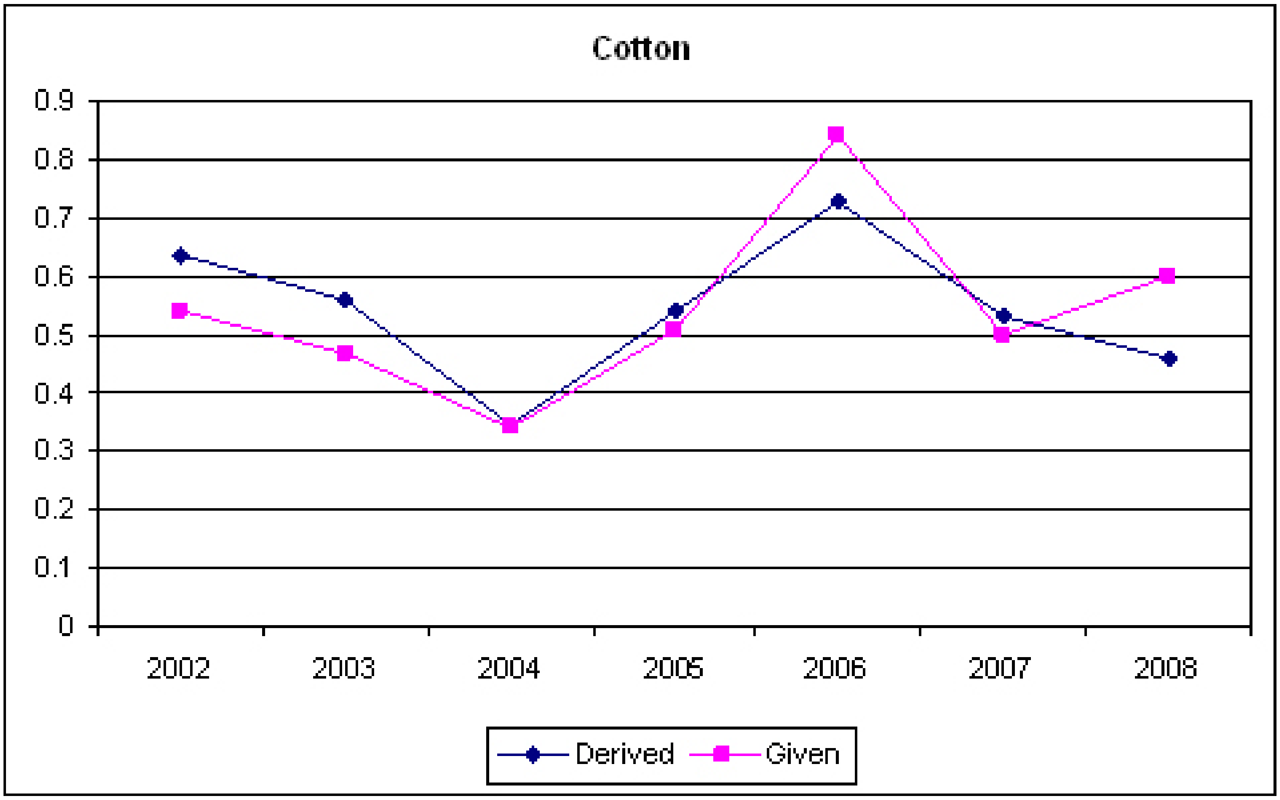


Figure 5. Comparison of calculated and measured water use for cotton. Source: Merrell, 2008.

| | A | B | C | D | E | F | G | H |
|---|---|---|---|---|---|---|---|---|
| 1 | DELTA MODEL--Sunflower County 1961-2006 | | | | | | **GS Precip** | **AVG Use** |
| 2 | **1961/2008** | | | | | | | |
| 3 | Total Acres | | | | | | | |
| 4 | COTTON | % furrow | % pivot | | | | | |
| 5 | 60300 | 0.81 | 0.19 | | | | 19.46 | 0.4316 |
| 6 | RICE | % contour | % straight | % MI | % ZG | | | |
| 7 | 27600 | 0.2 | 0.56 | 0.12 | 0.12 | | 19.46 | 2.8124 |
| 8 | CORN | % furrow | | | | | | |
| 9 | 8910 | 1 | | | | | 19.46 | 0.707 |
| 10 | SOYBEANS | %furrow | % straight | % pivot | % contour | % ZG | | |
| 11 | 86350 | 0.49 | 0.4 | 0.03 | 0.06 | 0.02 | 19.46 | 0.7116 |
| 12 | CATFISH | % MF | % 6/3 | | | | | |
| 13 | 24300 | 0.42 | 0.58 | | | | | |
| 14 | | | | | | | | |

| I | J | K | L | M | N | O |
|---|---|---|---|---|---|---|
| | | | | | **Total Use** | **Yearly Use** |
| | | | | | | |
| | | | | | | |
| Furrow Use | Pivot Use | | | | | |
| 0.461812 | 0.336648 | | | | 26413.26 | |
| Con Use | St Use | MI Use | ZG Use | | | |
| 3.627996 | 2.924896 | 2.334292 | 1.603068 | | 78274.27 | |
| Furrow Use | | | | | | |
| 0.707 | | | | | 6299.37 | |
| Furrow Use | St Use | Pivot Use | Con Use | ZG Use | | |
| 0.804108 | 0.668904 | 0.846804 | 0.547932 | 0.46254 | 62958.25 | |
| MF Use | 6/3 Use | | | | | |
| 3.11 | 0.78 | | | | 42737.09 | 216682.2388 |

Figure 6. Model Illustration (highlighted cells are interactive).

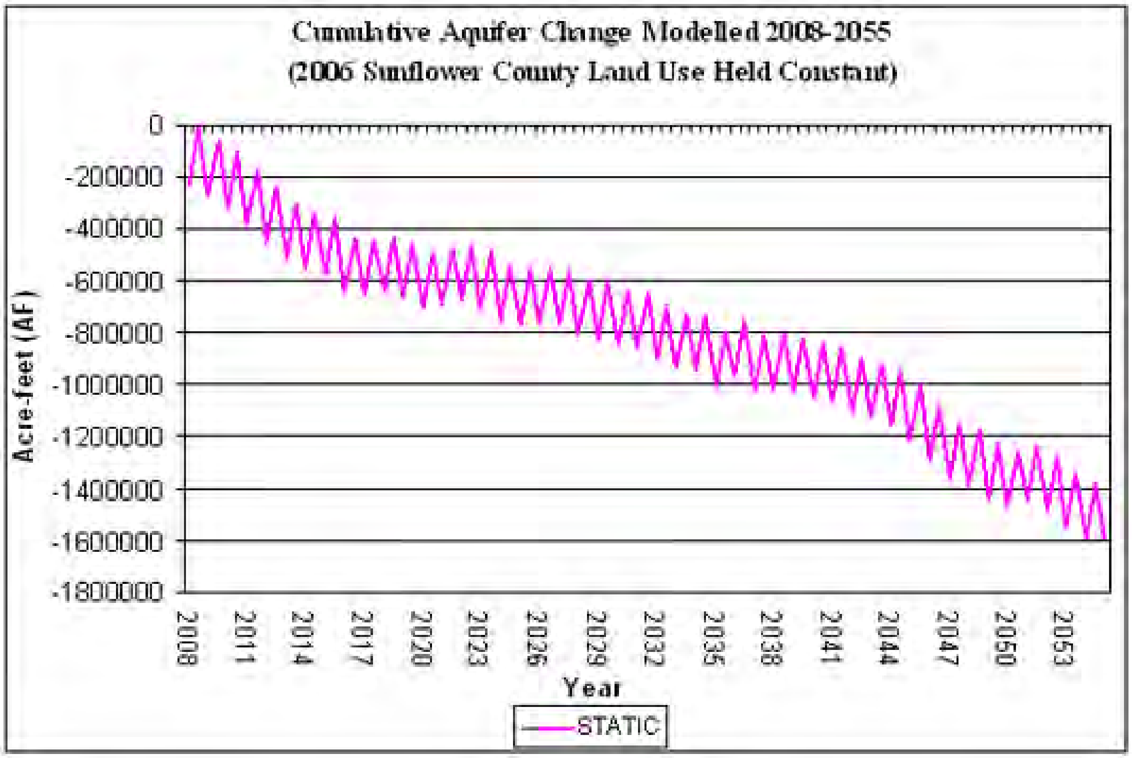


Figure 7. Model Result when land use and irrigation methods are held constant as observed in 2006 in Sunflower County for the 48-year period.

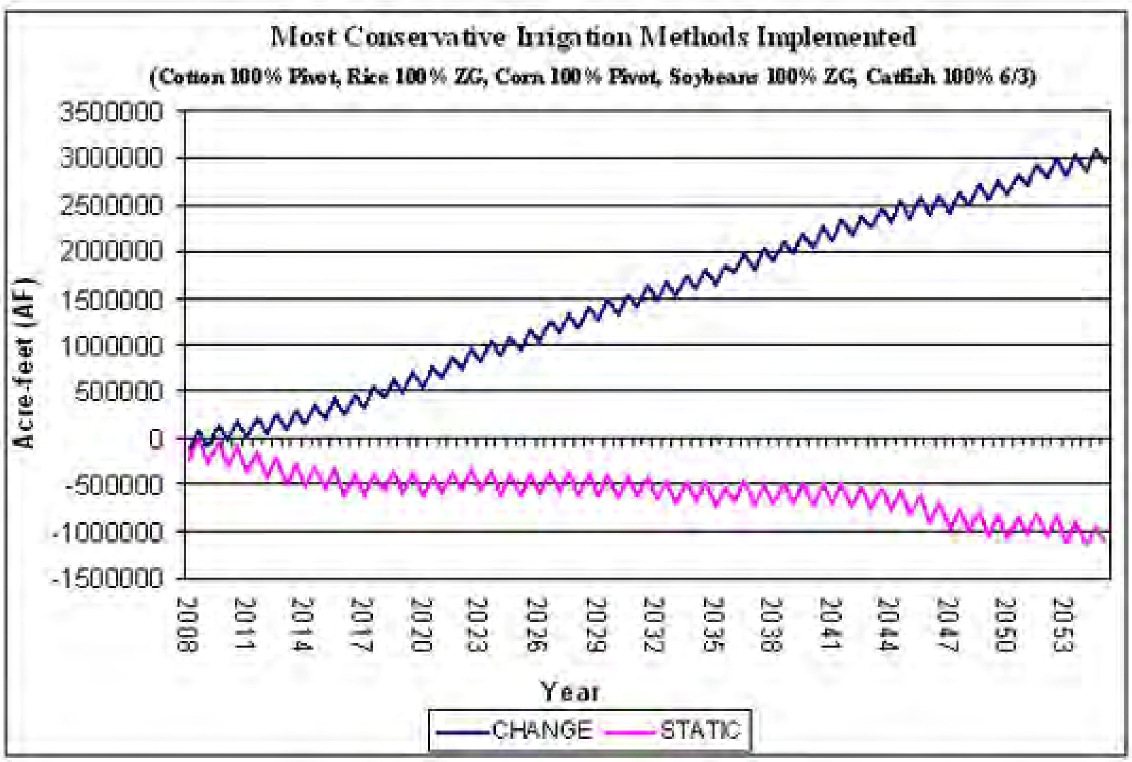


Figure 8. Model results when land use and irrigation methods are changed to reflect adoption of the most conservative irrigation method.

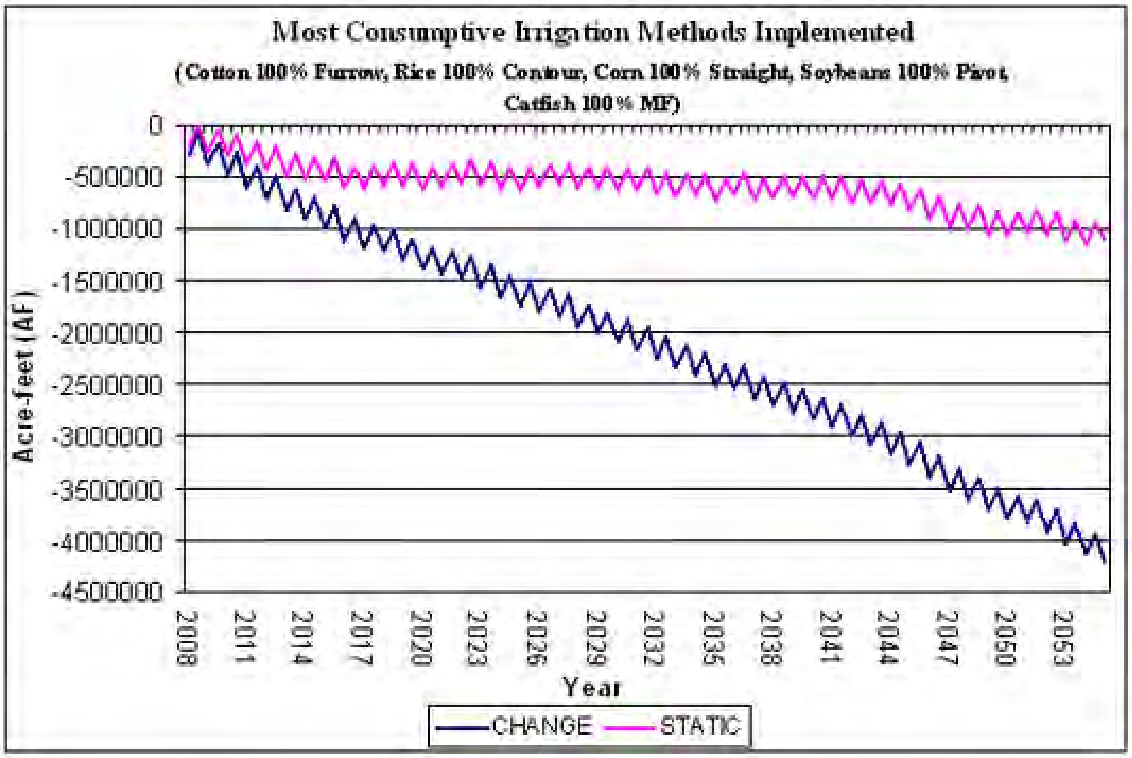


Figure 9. Model results when the most consumptive irrigation methods and management strategies are used.

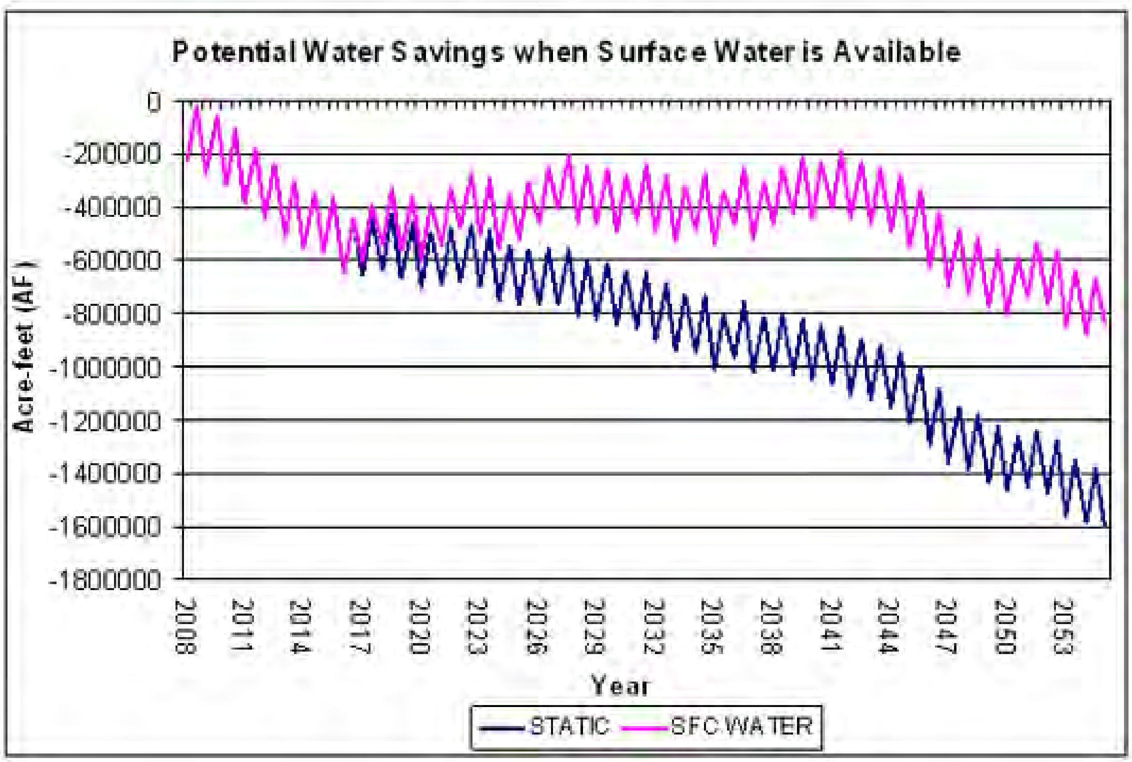


Figure 10. Model results when surface water irrigation is implemented.

Wetlands

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Exploring Biologically Relevant Buffer Zones for Aquatic and Wetland Ecosystems in Northern Mississippi

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*University of Mississippi*

Management of an Abandoned River Channel Wetland for Mitigation of Nonpoint Source Pollution

**Cristina Nica**
*Jackson State University*

A Study of Seagrass at Grand Bay National Estuarine Research Reserve, Mississippi

**David R. Johnson**
*U.S. Army Corps of Engineers*

Flooding or Precipitation: What is the Dominant Source of Moisture Sustaining a Backwater Bottomland Hardwood Forest?

**Daniel Wren**
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Transport of Non-Point Source Contaminants Through Riparian Wetlands in the Mississippi Delta Region

# Exploring Biologically Relevant Buffer Zones for Aquatic and Wetland Ecosystems in Northern Mississippi

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Most of the potential factors that may negatively impact aquatic and wetland biota presently are associated with changes in human land use across watersheds, and many of those land use changes may impact aquatic ecosystems at multiple scales . This project was intended as a comparative examination of biological responses to human land use surrounding wetlands and streams of northern Mississippi. We analyzed correlations between land use and various measures of conservation status of plant and animal species, at several buffer distances surrounding biological data collection sites. Wetland plant, fish, and mussel communities were examined using a series of buffers ranging from 50m to 1km from the boundaries of surveyed wetlands or streams. Fish and mussel communities also were analyzed at the watershed-scale. Results from wetland vegetation analyses indicated that wetlands with a higher percentage of forested land within 70 to 100m were associated with an increase in quality of wetland vegetation. At distances of 50m and greater, the presence of agricultural activities was positively associated with the presence of non-native wetland plant species. All analyses of stream biota failed to reveal any statistically significant effect of land use on the conservation status of fish or of mussels (based on state conservation rank). These incongruent results are interpreted in light of the biological and ecological attributes of the different suites of organisms evaluated, along with a discussion of future approaches to investigate interactions between land use and stream biota.

Key words: Conservation, Ecology, Invasive Species, Surface Water, Wetlands

## Introduction

Within the Northern Gulf Institute (NGI), the *Watershed Modeling Improvements to Enhance Coastal Ecosystems* program aims, in part, to develop new modeling approaches for predicting biological responses to alterations in watershed features. Most of the potential alterations that may impact aquatic and wetland biota presently are associated with changes in land use across watersheds, and many of the impacts may have multiple scales at which they impact aquatic ecosystems. In light of this scaling issue, the present work analyzes interactions between human land use and aquatic biota at multiple spatial scales in an effort to investigate as fully as possible factors that may be associated with ecological risks to these organisms. We use two different sets of biological data in this effort: freshwater vascular plants and stream-dwelling fish and mussels.

Wetland vegetation was collected in 53 wetlands across northern Mississippi (Ervin et al. 2006a), and were used to calculate indices of vegetation wetland ecosystem "quality." Data for fish and mussel collections were provided by the Mississippi Museum of Natural Science. Those data included state conservation status of each species, which was used to summarize the "quality" of fish and/or mussel assemblages at each collection site. The biological data were used as ecological responses to land use patterns on the surrounding landscape in order to assess whether and to what degree biota respond to gradients in specific types of land use (i.e., urban, agricultural, forested, and wetland cover). It was intended that results of these analyses eventually would be used to develop watershed management recommendations that could lead to reduced negative biological impacts on aquatic systems.

We hypothesized that higher levels of more disturbed land cover (i.e., urban and agricultural use) would correlate with decreased quality of aquatic and wetland biota.

**Methods**

***Vegetation data***

Fifty-three wetlands were surveyed during 2004 to determine relative abundance of vascular plant species present (Figure 1; Ervin et al. 2006a). Plant species occupying fifty sampling plots in each wetland were recorded. For species that were unidentifiable in the field, we collected specimens that later were identified with the assistance of Mississippi State University Herbarium (MISSA) personnel, and vouchers were deposited in MISSA.

Two composite indices of vegetation condition were used for these analyses: the Floristic Quality Assessment Index (FQAI; Andreas and Lichvar 1995) and the Floristic Assessment Quotient for Wetlands (FAQWet; Ervin et al. 2006a). The FQAI has been evaluated favorably in Illinois (US EPA 2002), Wisconsin (Nichols 1999; US EPA BAWWG 2002), Ohio (Andreas and Lichvar 1995; Lopez and Fennessy 2002), Michigan (Herman et al. 1997), Pennsylvania (Miller and Wardrop 2006), Florida (Cohen et al. 2004), Hawaii (Carstenn 2008), and Mississippi (Ervin et al. 2006a). The FQAI has been popularized because of the rapidity of response of vegetation to altered habitat conditions, whether degradation or improvement of wetland health (Cronk and Fennessy 2001, Lopez et al. 2002). The FAQWet, on the other hand, has been evaluated only in Mississippi, where it performed similarly to the FQAI (Ervin et al. 2006a).

The FQAI incorporates plant species coefficients of conservatism, which are assigned regionally to plant species, based on their native origin and local or regional distribution (Herman et al. 1997). For example, non-native species and widespread native species receive very low scores (exotics= 0; widespread natives= 1), whereas rare native species receive high scores (10). Coefficients for our list of more than 400 plant species were assigned based on information in regional botanical guides and the USDA PLANTS database, in consultation with regional experts for particular plant groups (Herman et al. 2006). The FAQWet uses species' wetland indicator status (Reed et al. 1988) to derive scores for each sampling site, wherein each wetland indicator status category is assigned a value from -5 (obligate wetland species) to +5 (obligate upland species).

The Floristic Quality Assessment Index is calculated as the average coefficient of conservatism (*C*) of native species at a site, weighted by the square root of native species richness, *N*:

$$FQAI = \bar{C} \times \sqrt{N} = \frac{\sum C}{N} \times \sqrt{N} = \frac{\sum C}{\sqrt{N}}$$

(Andreas and Lichvar 1995).

The Floristic Assessment Quotient for Wetlands is similarly calculated as the average wetness coefficient across all species at a site, weighted by the proportional frequency of native species among all observed species occurrences:

$$FAQWet = \frac{\sum WC}{\sqrt{S}} \times \frac{\sum f}{\sum F}$$

where *WC* is the wetness coefficient for each species; *S* is the total species richness within a site; *f* is the frequency of native species among all sampling units (quadrats, plots, or sample points); and *F* is the total number of all species occurrences among all sampling units. Thus, this formula weights an equivalent representation of FQAI, based on *all species present*, versus the proportional frequency of native species among all survey plots. With both the FQAI and FAQWet, higher index values typically correspond with lower levels of disturbance within and around a given site, suggestive of higher ecological "quality" within the habitat.

Exotic species richness also was included in these analyses as an index of the ecological integrity of wetland vegetation. This index of wetland ecological integrity was included because considerable research has demonstrated strong correlations between the abundance of non-native species and anthropogenic disturbance in and around wetlands (Cohen et al. 2004, Ervin et al. 2006a,b, Miller and Wardrop 2006). Information on the native status of each species in our surveys was obtained from the USDA PLANTS database, in consultation with published taxonomic guides, where USDA PLANTS information was questionable.

***Fish and mussel data***

Data on fish and mussel collections were provided by the Mississippi Natural Heritage Program (Mississippi Museum of Natural Sciences), through a restricted data sharing agreement. The data were screened to determine watersheds within the upper Tombigbee River basin that contained at least four sampled species per watershed. From these data, we calculated species richness, number of species with a conservation rank of 1 (species with 5 or fewer known occurrences in the state) or 2 (species with 6 to 20 known occurrences in the state), and percent of species ranked as 1 or 2 at each sample location (for buffer analyses) or within the watershed (for whole-watershed analyses).

Screening for sites to be included in these analyses also considered the time when samples were collected. Only samples collected during 2002-2004 and 1977-1982 were used for these analyses. The 2002-2004 time period coincides with data collection for the National Land Cover Data set (NLCD 2001), as well as the NASA Moderate Resolution Imaging Spectroradiometer (MODIS) data. The 1977-1982 time period coincides with the period of data collection for the Geographic Information Retrieval and Analysis System (GIRAS; USGS 1986) land cover data, used by the EPA BASINS modeling framework (http://www.epa.gov/waterscience/basins/). In addition to being contemporaneous with two periods of available land cover data, these time periods of biotic data collection provided snapshots of conditions during the intensive collection period before the opening of the Tennessee-Tombigbee Waterway (TTW) in December of 1984, as well as at 18 to 20 years following completion of TTW construction. Because of the much greater emphasis on collection during the earlier of the two periods, there were 2.5-fold more watersheds with appropriate data during 1977-1982 (n=17) than during 2002-2004 (n=7), and 5-fold more samples collected (802 during the earlier period, vs. 157 in the latter)

***Boundaries, buffers, and land cover data***

Boundaries of all the surveyed wetlands were digitized in ArcMap (ArcGIS 9.0, Environmental Systems Research Institute, Inc.), using aerial photographs obtained through the Mississippi Automated Resource Information System (MARIS; http://www.maris.state.ms.us/). The aerial photographs (Figure 2) were digital ortho quarter quad (DOQQ) files, in North American Datum of 1983 (NAD 1983), based on summer 2004 color photography conducted by the USDA National Agriculture Imagery Program (NAIP). The timing of aerial photography (summer 2004) was matched to the timing of the vegetation surveys (March-September 2004). The land cover data layer used for these analyses was the National Land Cover Dataset 2001 (NLCD 2001), downloaded from the Multi-Resolution Land Characteristics Consortium (www.mrlc.gov). The NLCD 2001 dataset is based primarily on 2000 Landsat data (Landsat 7ETM+ and Landsat 5TM) and uses the 29 land cover classes described in Homer et al. (2004). This data set also was created in the NAD 1983 geodetic datum. Data handling for the wetland analyses was performed in the Albers map projection (USA Contiguous Albers Equal Area Conic, USGS version) and the 1983 North American Datum geographic coordinate system (NAD 1983), both of which are the standard configurations for data from the Multi-Resolution Land Characteristics Consortium.

Once wetland boundaries were digitized, wetland buffers were generated at 50m, 70m, 100m, 200m, 300m, 400m, 500m, and 1km from each wetland boundary. These buffers then were used to extract land cover data surrounding each wetland. The developed categories (high, medium, low, open) were consolidated into one "developed" land cover category. Additionally, analyses were conducted with the consolidated land cover categories of "Forest" (combining deciduous, evergreen, and mixed forest), "Natural forest" (deciduous and mixed forest, with the assumption that most evergreen forest in Mississippi is silvicultural in nature), "Agricultural" (pasture and cultivated), and "Wetland" (herbaceous and woody wetlands combined). Data were relativized within each wetland, at each distance, by dividing the area of each land cover type (or consolidated type category) by the total area within the buffer zone to generate a proportion or percent of buffer covered by each land cover type present.

For stream biota, a smaller set of buffer widths spanning the same total distance was used, based on results from the above analyses. These buffers extended from 50m out to 1000m from the collection sites (specifically 50, 100, 200, 500, and 1000m buffers). Land cover from within the buffers was obtained similarly as with wetlands vegetation, with the assistance of Hawth's Tools (www.spatialecology.com). Buffer-based land cover data were available only for the latter time period (2002-2004), providing a useful comparison with results from the wetland analyses above. These data manipulations were carried out in a UTM coordinate system and with the North American Datum (NAD) 1983.

For analyses of responses of stream biota at the watershed scale, land cover data were obtained by compiling the appropriate data set (MODIS, GIRAS) within sub-watersheds situated within the upper Tombigbee River basin. The BASINS v3.3 tool (EPA, 2009) was used to sub-divide the Town Creek watershed into sub-watersheds for these analyses. Through an ArcView interface, Digital Elevation Models (DEM) describing the topography of the area were downloaded, and the BASINS "automatic delineation" tool was applied to the DEM to obtain an initial sub-division based only in topography (i.e., water divides, or *divortia aquarium*, within the watershed defined initial sub-watersheds). Since this preliminary sub-division did not capture the density and distribution of biological organisms in the area, the preliminary delineation was further sub-divided forcing outlet points at mid-stream locations where the presence of biological indicators was more representative.

***Data analyses – wetland plants***

The three vegetation indicators, FQAI, FAQWet, and exotic species richness, all were examined for their distributional characteristics prior to conducting regression analyses against land cover data. Data for FQAI and FAQWet were found to approximate a normal distribution, based on examination of Q-Q plots, whereas exotic species richness, a count variable, was assumed to fit a Poisson distribution. Thus, analyses using FQAI and FAQWet were carried out with linear regression and those with exotic species richness used a Poisson loglinear regression. These regression analyses always consisted of one land cover type being regressed against one vegetation index across all wetlands. These analyses were carried out in SPSS 16.0 for Windows (SPSS, Inc.), using the generalized linear model function.

Regression models depicting the correlation between land cover composition (percent of buffer in a particular land cover type) and wetland vegetation "quality" were evaluated with a combination of three statistics. The first was the relative fit of each the regression model, compared to that regression including only the Y-intercept (intercept-only model). This fit was assessed by the statistical significance of a likelihood ratio Chi-squared test comparing the model of interest against the intercept-only model; significance was assessed at the 0.05 level.

The second statistic used to assess the statistically significant models was the finite-sample corrected form of the Akaike Information Criterion ($AIC_c$); this corrected version of AIC was used because of the relatively low number of samples, relative to the number of parameters estimated in the regression models (Burnham and Anderson 2002). The $AIC_c$ was used to compare across models within a given buffer distance and for each individual vegetation index to determine which land cover type within a buffer distance was the strongest correlate with wetland vegetation condition, as represented by each of the three indices. The comparison was made by evaluating the difference in $AIC_c$ between the best model in a group (lowest $AIC_c$) and each other model. That difference is represented by $\Delta AIC_c$. Only models with a $\Delta AIC_c \leq 4.0$ were considered in evaluating results, as models with $\Delta AIC_c$ greater than 4 are considered to have "considerably less" empirical support than models with a lower $\Delta AIC_c$ (Burnham and Anderson 2002).

### *Data analyses – fish and mussels*

Stream biota were analyzed in two ways: mussel collections as response variable, and combined fish and mussel data as the response. Insufficient fish collection data were available across the study area for those data to be analyzed alone. Data for these analyses all were found to approximate a normal distribution, based on examination of Q-Q plots; thus, no transformations were applied to variables prior to analyses. Because of the number of variables, relationships among biotic responses and land cover were screened with Pearson bivariate correlation analyses in SPSS 16.0 for Windows (SPSS, Inc.). Significant correlations were evaluated at $\alpha$ = 0.05.

## Results

### *Wetland plants*

Detailed results of the vegetation analyses are reported in Ervin (2009). In general, results demonstrated similar patterns in the relationships between land cover and each of the floristic quality indices. Both FQAI and FAQWet were positively correlated with area of forest within 100m of the wetland periphery (Figure 3). Furthermore, the actual value of the regression coefficients were very similar, indicating a comparable level of "quality" enhancement by forested wetland buffer for each vegetation index.

Beyond 200m from the wetland edge, however, there was a persistent negative relationship between floristic quality and agricultural land use (Figure 4). Pasture land cover was negatively correlated with FAQWet value, and the combination of pasture and cultivated land area were negatively correlated with FQAI. Pasture cover also was positively correlated with number of exotic plant species recorded in each wetland, which likely contributed to the negative correlation with vegetation quality index values. All the patterns were evident from 200m out to 1km from the wetland edge.

### *Fish and mussels*

Data representing the earlier time period (1977-1982) indicated no significant correlations between GIRAS land cover and mussels, nor between land cover and fish and mussel collections combined, for any of the three response parameters employed (richness, richness of species ranked 1 or 2, and percent of species ranked at 1 or 2 conservation status). During the later period (2002-2004), analyses of MODIS land cover data extracted from buffers of 50m to 1000m width revealed no correlations with mussels or fish and mussels combined. Similarly, land cover data were uncorrelated with these biota at the sub-watershed scale. Sub-watersheds with the highest numbers of high-conservation-status species were localized within the center of the study area, with no apparent correlation to unique sub-watersheds.

## Discussion

### *Wetland plants*

Results from these analyses give a clear indication that wetland quality—as indicated by the plant assemblages—is related to human land use. More intensively used land cover was associated with higher numbers of non-native species and lower overall quality index values. Likewise, natural land cover seems to have enhanced wetland quality across these sites. What's more, the slopes of those relationships seem to be fairly consistent across buffer distances, indicating potential use of these relationships in efforts at landscape-scale land use planning for the purposes of wetlands conservation.

### *Fish and mussels*

The lack of a significant correlation between mussel community structure and land cover likely results from differences in the time scale of the life history characters most influenced by critical shifts in land use. Because adult mussels within the upper Tombigbee watershed generally are long-lived, only factors that influence adult survival would be apparent in our analysis. If the declines that led to the decline of these species were heavily influenced by juvenile recruitment, either because of the loss of host fishes or because of changes in juvenile survivorship, we would be unable to detect the effects for as much as 50-80 years (the lifespan of some of the longest-lived adults; Haag 2008). We currently are working to reconstruct historical recruitment patterns from museum specimens to evaluate the importance of this temporal influence on our analysis.

While the unexpected results for mussel communities may reflect the limitations of working with exceptionally long-lived species, the incongruence between fish community status and land use may reflect the difficulties associated with parsing terrestrial influences on aquatic communities. Land cover data were extracted based on a series of nested buffers around collection points. Each point represents only a snapshot in the lives of the samples collected; they may have, in fact, ranged widely up and down a given section of the stream in which they were collected. The other method for extracting land cover data was based on sub-watersheds defined topographically, each having a sample point as its outlet. Although these areas were defined based on sampling locations, the areas delineated by each division may still fail to reflect a biological or ecological division of the watershed. Thus, the particular scale at which land cover data were assembled for the present analyses may have been biologically inappropriate. We intend in future efforts to assemble land cover and water quality data at other scales in an effort at better representing environmental characteristics that the organisms may be experiencing.

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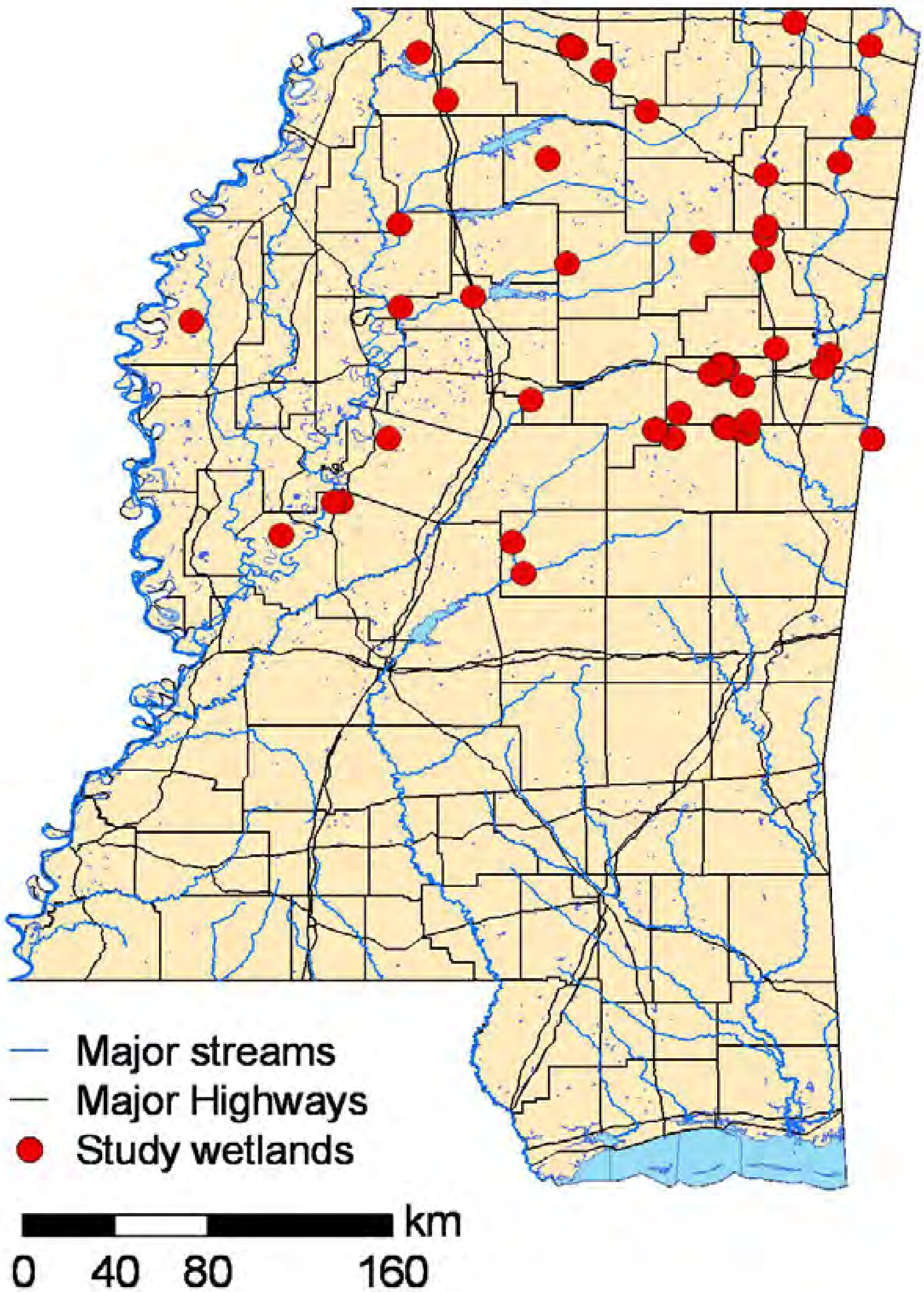


Figure 1. Wetlands included in this study. Plants were surveyed during 2004, in 53 wetlands categorized as depressional, riverine, or lacustrine (Smith et al. 1995).

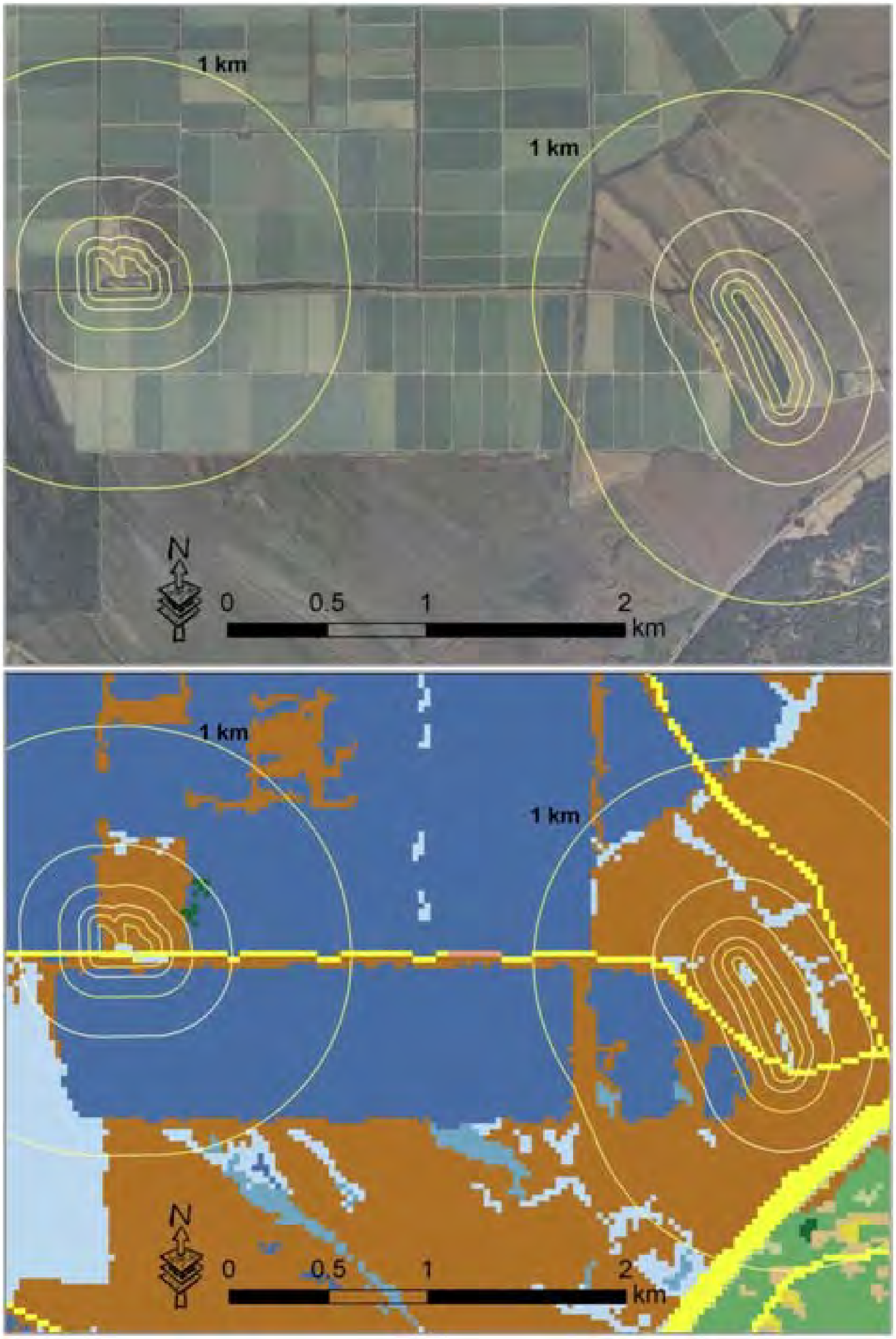


Figure 2. Examples of nested wetland buffers (upper) used to extract land cover data (lower) for vegetation analyses. Shown are two wetlands in Yazoo County, MS.

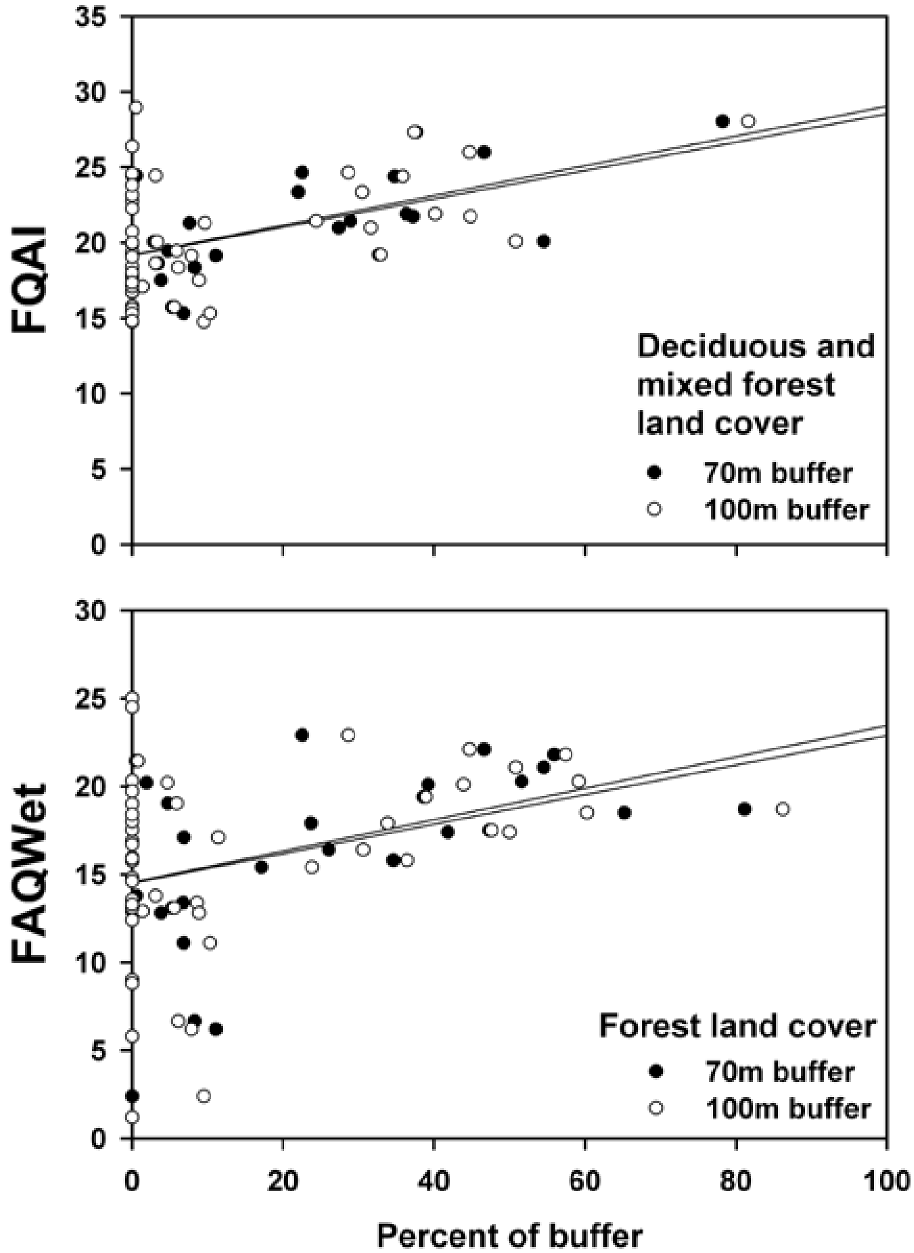


Figure 3. For buffer widths of up to 100m, wetland floristic quality was positively correlated with proportion of forested land area surrounding the study wetlands.

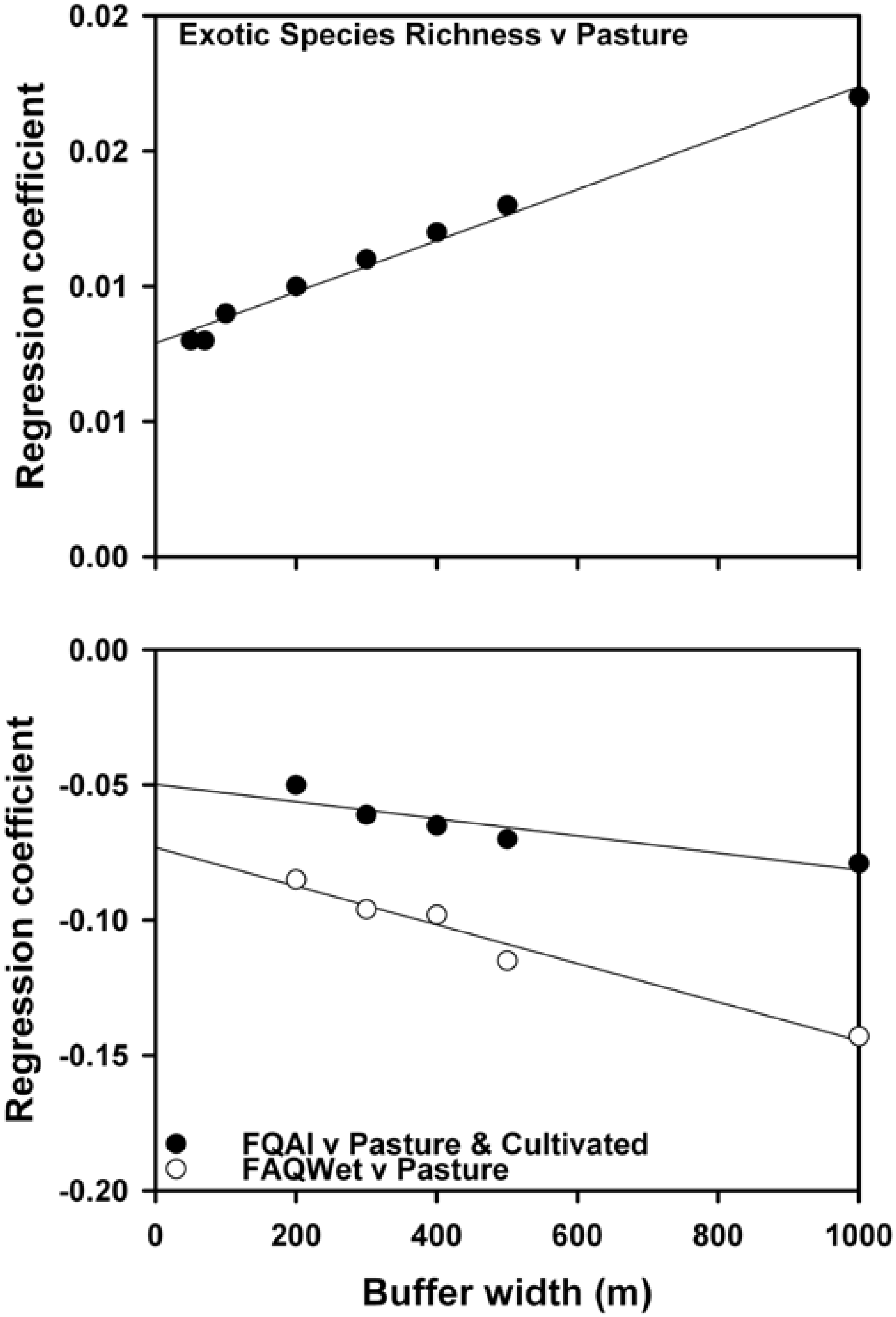


Figure 4. For buffer widths of up to 1000m, wetland floristic quality was positively correlated with exotic species richness and negatively correlated with proportion of intensively used land area surrounding the study wetlands (i.e., agricultural land use categories). These relationships grew stronger as larger buffer areas were included in the comparisons.

# Management of an Abandoned River Channel Wetland for Mitigation of Nonpoint Source Pollution

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Reduction of nonpoint source pollutants, principally sediment and nutrients moving from cultivated fields to surface waters, is a major challenge. Remnants of once-extensive natural wetlands occur across the agricultural landscape, and some workers have suggested that these areas might be managed to yield improved wetland function in terms of trapping and retention of nonpoint source pollutants. An existing wetland in a severed meander bend cut off in the 1940s from the Coldwater River in Tunica County, MS was modified by the construction of weirs equipped with water control structures. The wetland was a segment of old river channel about 500 m long and 14 m wide. Inputs to the wetland cell included sporadic flows due to runoff events from about 350 ha of cultivated fields and less frequent but larger flood events from the river. This type of flood event occurred only once during the study.

Weir drainage structures were operated to retain water during March – November, and were opened to allow flow to and from the Coldwater River during December, January and February. Weir elevation during March – November corresponded to a mean water depth of ~ 0.15 m. Volumes of water entering and leaving the wetland cell were estimated for 18 months using measurements made at weirs and at a culvert. Estimates of loads entering and leaving the wetland cell were computed based on concentrations of grab samples collected at the wetland cell inflow and outflow locations.

Water concentrations of sediment and nutrients were generally lower at the downstream end of the wetland cell than in the major inflow, an ephemeral slough. Mean values of turbidity, suspended sediment concentration, and concentrations of filterable and total phosphorus were 25% to 40% lower at the wetland cell discharge weir than in the slough. Mean concentrations of ammonia were 38% lower, but mean nitrate and nitrite concentrations were essentially unchanged by the wetland cell. Comparison of estimated input and output loads during periods when the wetland cell was not flooded by the river indicated that the wetland cell retained about 18% of input suspended sediment, 24% of phosphorus, and 29% of nitrogen input from cultivated fields. Wetland cell sediment and nutrient retention efficiency was greater for drier months, and declined during wetter periods with frequent runoff events.

Key words: Agriculture, Nonpoint Source Pollution, Nutrients, Sediments, Wetlands

## Introduction

Nonpoint source pollution from cultivated fields has been implicated in extensive and chronic environmental degradation in aquatic ecosystems ranging from small streams to large estuaries and marine environments such as the Gulf of Mexico. Mitigation and management strategies are needed to address these issues, particularly with regard to sediments and nutrients. Wetland enhancement, creation and management are landscape-scale practices for which USDA conservation practice standards have been developed (Lowrance et al. 2006). Enhancement, restoration and construction are terms that represent a continuum of activities that range from augmenting existing wetland functions through creating wetlands where they did not exist before. Constructed wetlands have been examined as tools for removing nitrogen (N) (Fink and Mitsch 2004, Reinhardt et al. 2006, Kovacic et al. 2006, Sovik and Morkved 2008), phosphorus (P) (Fink and Mitsch 2004, Reinhardt et al. 2005, Braskerud et al. 2005, Kovacic et al. 2006) and pesticides (Bouldin et al. 2005, Moore et al. 2007, Bouldin et al. 2007, Budd et al. 2009, Moore et al. 2009) from agricultural runoff.

Less work has been done on the ability of natural wetlands to attenuate agricultural pollution. Natural riverine wetlands serve as sediment storage zones at the landscape scale (Phillips 1989). Five restored wetlands in Iowa effected an 85% mean reduction in total nitrogen (TN) concentrations in agricultural runoff (Van der Valk and Crumpton 2004), while an instream wetland created by a beaver dam in North Carolina reduced TN by an average of 37% (Hunt et al. 1999). Jordan et al. (2003) reported performance of a restored wetland receiving highly variable inflows of agricultural runoff over a two-year period; although N concentrations were reduced, questions were raised regarding longer-term performance. Large scale restoration of riverine wetlands throughout the Mississippi River basin has been proposed as a solution for hypoxia in the Gulf of Mexico (Mitsch et al. 2005) and for problems of habitat loss (Day et al. 2003). This study seeks to demonstrate how a natural wetland receiving runoff from cultivated fields may be enhanced by adding and operating weirs to trap water and allow time to process sediments and nutrients. Additional findings regarding pesticide retention at the same site have been reported by others (Lizotte et al. 2009).

## Site

An existing 2-ha wetland in a severed meander bend cut off in the 1940s from the Coldwater River in Tunica County, MS was modified by the construction of weirs equipped with water control structures (Figure 1). The weirs divided the old bendway channel into two segments or cells: a shallow lake and a wetland cell. The wetland cell was about 500 m long and 14 m wide. Inputs to the wetland cell included sporadic flows due to runoff events from about 350 ha of cultivated fields and less frequent but larger flood events from the river. Soils were primarily poorly drained Alligator (40%) or Sharkey clays (47%) with the remainder being Tensas silty clay loam. During the period of interest, crops were limited to soybeans (Glycine max) grown using no-till or minimum tillage. Field runoff was concentrated in a network of ditches feeding a slough that was tributary to the wetland cell through a 0.6-m diameter pipe culvert.

Weirs consisted of low earthen embankments placed at right angles to the old river channel and covered with stone riprap (Figure 2). Each weir included a water control structure that consisted of a 0.3-m diameter pipe that penetrated the embankment bisected by a flashboard riser "manhole." Flash boards (also called stoplogs) could be added or removed through the manhole to adjust the controlling elevation of the drainage structure (Figure 2). Weir water control structures were operated to retain water during March – November, and were opened to allow more frequent connection to the Coldwater River during December, January and February. Weir elevation during March – November corresponded to a mean wetland cell water depth of ~ 0.15 m. Wetland cell water surface elevation (and thus water depth) reflected local precipitation and runoff as well as flooding from the river (Figure 3).

**Methods**

Hydrologic and water quality data were collected from the wetland cell and its major inflows and outflows over an 18-month period between 15 June 2007 and 27 November 2008. Precipitation records were obtained using a rain gage on site, and missing data were replaced with daily totals from nearby stations. During this period of time, river stages in the reach adjacent to the wetland cell were generally below the level needed for flow from the river into the wetland cell. Self-contained loggers measured water pressure (converted to water surface elevation using surveyed data) at 15-min intervals and basic water quality variables including pH, turbidity, and dissolved oxygen at 4-hr intervals. The inflow rate of agricultural runoff into the wetland cell was measured at 5-min intervals using an acoustic Doppler device placed in a pipe that connected the tributary slough to the wetland cell. Relatively small inflows that occurred in gullies were not measured. Weekly grab samples of water were collected from the wetland cell and the three main adjacent water bodies: the Coldwater River, the lake cell and the tributary slough (Figure 1).

Water samples were preserved via chilling and transported to the laboratory for analysis. Physical and chemical water parameters including turbidity, total solids (TS), dissolved solids (DS), $NH_4$-N, $NO_3$-N, $NO_2$-N, TN ($NO_3$-N + $NO_2$-N + total Kjeldahl N), soluble (filterable) P, total P (TP), chlorophyll a were analyzed using standard methods (Table A1). Wetland cell flora was sampled using a visual, qualitative survey along seven transects in October 2008.

Time series for flow through the tributary slough pipe and water surface elevations in the wetland cell and adjacent river, lake cell and tributary slough were constructed using interpolation and subsampling to obtain time series with a frequency of 0.05 day$^{-1}$. Wetland cell water surface area and volume were computed at each time step using formulas that were derived from a digital elevation model constructed using survey data. Flows into and out of the wetland cell were computed at each timestep. Flows over the stone weirs were estimated based on broad-crested weir formulas and head differences, while flows through the water control structures were estimated using a rating curve based on data provided by the manufacturer. Noise in the 0.05 day-1 time series of wetland cell storage volume and flows was damped by computing daily averages. A water budget was constructed by setting up the following equation at each daily time step:

$$\Delta S(t) = [Q_{evap}(t) + a_1 Q_{pipe}(t)^{b_1} + a_2 Q_{lstone}(t)^{b_2} + a_2 Q_{ldrain}(t)^{b_3} + a_4 Q_{wstone}(t)^{b_4} + a_5 Q_{wdrain}(t)^{b_5}]$$

Where $\Delta S(t)$ is the change in wetland cell water volume (m$^3$) during timestep t, which is of length $\Delta t$ (1 day = 86,400 s); $Q_{evap}$ is the rate of evaporation, $Q_{pipe}$ is the discharge through the pipe, $Q_{lstone}$ and $Q_{wstone}$ were the flows over the stone-plated weirs at the upstream and downstream ends of the wetland cell, respectively and $Q_{ldrain}$ and $Q_{wdrain}$ were the flows through the water control structures at the upstream and downstream ends of the wetland cell, respectively. Each discharge, *Qi*, is in units of m$^3$s$^{-1}$. Evaporative losses ($Q_{evap}$) were assumed equal to observed pan evaporation values in m s$^{-1}$ (data from personal communication, C. Wax, 2009) times the mean daily wetland cell water surface area in m$^2$. Since the left hand side of the equation is known at each timestep, the adjustment coefficients, $a_i$ and exponents, $b_i$ were computed using the Solver utility within Microsoft Excel. Linear interpolation was used to obtain time series of water quality variables (concentrations) at a daily interval. Loads of sediment and nutrients entering and leaving the wetland cell were computed at each daily timestep by multiplying the corresponding concentration times the adjusted flowrate.

Concentrations of all water quality analytes sampled at the primary wetland cell inflow (the tributary slough) and at the downstream end of the wetland cell were compared using a Mann-Whitney rank-sum test. Parametric tests were not used because concentrations were not normally distributed.

**Results**

Plant populations were dominated by grasses, sedges and duckweed (Table 1). Mature forest lined the banks of the old river channel that comprised the wetland cell, and woody species occasionally occurred in the wetland cell itself.

Rainfall was below local monthly norms for 14 of the 18 months of the study period. Total precipitation during the study period (1070 mm) was about 60% of normal. Daily total rainfall was greater than 63.5 mm (2.5 inches) for only five days. Wetland cell stage fluctuated in response to runoff events; flooding from the river was almost nonexistent during the study period. The only connection of the river with the wetland cell occurred for 6 hrs on July 8, 2008 and contributed about 650 $m^3$ of water to the wetland cell. Results of the water budget computations for the 18-month period of interest are summarized in Table 2 below. About 84% of the estimated inflow was comprised of runoff from the adjacent cultivated fields that were drained by the tributary slough. Limited center pivot irrigation occurred during the study period, but runoff from irrigation was never observed.

Continuously monitored water quality constituents displayed characteristics typical of wetland conditions (Table 3). Relatively low mean and median dissolved oxygen concentrations are due to nighttime respiration during algal blooms. Concentrations of all grab-sampled water quality constituents except for $NO_2$-N, $NO_3$-N and chlorophyll a were higher in the tributary slough than in the downstream end of the wetland cell (Figure 4). Except for these three constituents, median values were significantly different ($p < 0.021$). Medians of $NO_2$-N, $NO_3$-N and chlorophyll a were not significantly different between the two water bodies. Mean values for tributary slough concentrations were 86% (chlorophyll a) to 166% (suspended solids) of the wetland cell means.

Net fluxes of solids and nutrients over the period of interest are presented in Table 4. Inflow from the tributary slough dominated loading to the wetland cell. Yields of TN, TP and NO3-N from the ~350 ha of cropland that were drained by the tributary slough were about 0.49, 0.24, and 0.054 tonnes $km^{-2}$ $yr^{-1}$, respectively. Our estimates indicate that the wetland cell retained about 18% of the sediment, 24% of the N and 29% of the P that reached it via inflows from the lake, tributary slough or river. Examination of monthly flux values indicate that the wetland cell was most efficient during drier months when loading rates were lower and retention times were longer; performance deteriorated during wetter winter and spring periods when most runoff occurred.

**Discussion**

A high level of uncertainty attends the values in Tables 2 and 4 due to two reasons:

1. Flow computations were subject to bias caused by slight errors in measuring water surface elevations, particularly the differences in water surface elevations occurring over the stone weirs. The major inflow to the wetland cell, which occurred through the 0.6-m pipe draining the tributary slough, was not subject to such error as it was measured using an acoustic Doppler flow meter.
2. We did not collect water quality samples during actual runoff events. Water samples were collected at regular, weekly intervals whether or not water was flowing into or out of the wetland cell. We assumed that the concentrations and values we measured were representative of levels occurring during flow events; this assumption was supported by time series plots of flow and water quality. Sediment and nutrient concentrations were not influenced by antecedent flow conditions: for example, TP levels in the tributary slough were not higher immediately after storm events (Figure 5).

The loads of nutrients entering the wetland cell through the tributary slough were converted to annual yields for comparison with work by others. Our estimates for TN and TP yields were about 0.49 and 0.24 tonnes $km^{-2}$ $yr^{-1}$, respectively, and these values are similar to six-year means of 4.2 and 2.1 tonnes $km^{-2}$ $y^{r-1}$ for N and P respectively, from Delta lands growing conventional till cotton (McDowell et al. 1989) and to a three-year mean of 3.2 tonnes $km^{-2}$ $yr^{-1}$ for N from Delta lands growing conventional till cotton and soybeans (Schreiber et al. 2001). About 24% of the TN and 29% of the TP were retained in the managed wetland cell during our study period; these values are in line with an observed 37% mean retention of TN by an instream wetland created by a beaver dam in North Carolina (Hunt et al. 1999). We note that the wetland cell:watershed area ratio for our site was ~1:200, which is likely too small and resulted in excessive loading rates, especially during wet periods. Standard practice for constructed wetland design for this region results in a wetland cell:watershed area ratio of about 1:70 (personal communication, Paul Rodrigue). Our average hydraulic loading rate was 0.027 $m^3 s^{-1} ha^{-1}$. In contrast, a set of four experimental wetlands along the Des Plaines River in Illinois experienced hydraulic loading rates of 0.0013 to 0.0066 $m^3 s^{-1} ha^{-1}$ with removal rates of 92%, 84%, and 85% for suspended solids, $NO_3$-N and TP, respectively (Sather 1992). Mitsch et al. (2005) reported loading rates of 0.006 to 0.010 $m^3$ s ha for two 1-ha wetlands receiving pumped inflow from the Olentangy River in Ohio and 0.0005 to 0.004 $m^3 s^{-1} ha^{-1}$ for a 260 $km^2$ wetland receiving pumped inflow from the Mississippi River in southern Louisiana. The higher loading rate for our site was not a result of a design error; the location for the boundary between the lake cell and the wetland cell was selected to use the existing landscape features to protect lake cell size and quality.

Although ecologically rich features of the riverine corridor, instream wetlands such as the one described here are nonideal for treatment of polluted waters due to highly variable inputs of water and pollutants. Our study did not examine conditions during seasons when frequent overflow from the river into the wetland cell occurs; we anticipate that sediment and nutrient retention during those periods is complex due to the rapid change in wetland cell volume, surface area and water quality that occurs during inundation. Interestingly, Mitsch et al. (2008) reported that three floodplain wetlands subjected to steady inflow and pulsed inflow during successive years exhibited similar or higher levels of nutrient retention during the year with pulsed inflow.

**Conclusions**

The modified natural wetland described here retained about one fourth of the TN input and one third of the TP input during an 18-month period with minimal river flooding. It also retained about one-fifth of the suspended sediment input. Soluble nutrients were reduced more than total nutrients: nitrate and filterable P loads leaving the wetland were 43% less and 34% less, respectively than those entering. Additional study is needed to assess managed wetland performance during flooding and over longer periods of time.

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Table 1. Results of plant survey in managed wetland, October 2008.

| Transect (upstream to downstream) | Dominant species | Remarks |
|---|---|---|
| 1 | *Ludwigia peploides (HBK) Raven Commelina communis L.* | Ground cover was almost 100% |
| 2 | *Leersia spp.* | About half mixed tall herbaceous annuals and shrubs, and half grasses and low herbs. |
| 3 | *Leersia spp., Agrostis sp.* | Predominantly grassy except at the outer edges |
| 4 | *Rumex crispus L. and Amaranthus sp.* | Woody species along banks |
| 5 | *Leersia spp., Commelina communis L.* | Diverse mix of low herbaceous and woody species |
| 6 | *Leersia spp., Cyperus sp., Carex spp., Commelina communis L.* | |
| 7 | *Ludwigia sp., Mimulus ringens L., Leersia spp., Cyperus sp., Carex sp., Amaranthus sp., Xanthium strumarium L., Polygonum spp.* | |

Table 2. Water budget for wetland cell. Positive values indicate net flow into wetland cell, and negative values indicate flows out of wetland cell.

| Term, $m^3$ | Sum, $m^3$ | Maximum $m^3 day^{-1}$ | Mean $m^3 day^{-1}$ | Median $m^3 day^{-1}$ | Adjustment coefficient, $a_i$ | Adjustment exponent, $b_i$ |
|---|---|---|---|---|---|---|
| $\Delta S$ | 259 | 22,400 | 0.33 | -5.28 | | |
| $Q_{evap}\Delta t$ | -3,620 | 0 | -6.8 | -5.83 | | |
| $a_1 Q_{pipe}(t)^{b_1}\Delta t$ | 900,800 | 77,070 | 1,710 | 1,740 | 1.00 | 0.98 |
| $a_2 Q_{lstone}(t)^{b_2}\Delta t$ | 168,000 | 172,800 | 310 | 0 | 2.00 | 0.00 |
| $a_3 Q_{ldrain}(t)^{b_3}\Delta t$ | -47,600 | 50 | -90 | 0 | 1.00 | 1.00 |
| $a_4 Q_{wstone}(t)^{b_4}\Delta t$ | -98,800 | 0 | -190 | 0 | 2.00 | 0.50 |
| $a_5 Q_{wdrain}(t)^{b_5}\Delta t$ | -925,000 | 637 | -1740 | 0 | 1.00 | 1.00 |

Table 3. Summary statistics for wetland water quality constituents measured using in-situ logger.

| Variable | N | Mean | Median | Standard Deviation |
|---|---|---|---|---|
| DO (mg/L) | 3127 | 4.71 | 3.98 | 3.72 |
| pH | 3127 | 6.72 | 6.74 | 0.43 |
| Turbidity (NTU) | 3127 | 28.0 | 12.7 | 66.3 |
| Specific Conductivity (uS/cm) | 3127 | 128 | 123 | 51 |
| Temperature (°C) | 3127 | 21.99 | 24.59 | 7.16 |

Table 4. Flux of water, solids and nutrients for wetland cell. Net percentages > 0 indicate retention.

| Constituent | Tributary slough into wetland cell | Lake cell | | River | | Wetland cell (net) |
|---|---|---|---|---|---|---|
| | | Into wetland cell | From wetland cell | Into wetland cell | From wetland cell | |
| Water, $10^3$ $m^3$ | 901 | 170 | 53 | 0.6 | 1,020 | 0.3 |
| Total solids, kg | 199,558 | 22,536 | 7,433 | 129 | 176,173 | 38,618 (+17%) |
| Dissolved solids, kg | 76,974 | 9,349 | 4,315 | 43 | 68,305 | 13,926 (+16%) |
| Suspended solids, kg | 122,584 | 13,187 | 3,297 | 86 | 107,868 | 24,692 (+18%) |
| TN, kg | 2,551 | 425 | 75 | 1 | 2,194 | 708 (+24%) |
| $NH_3$, kg | 22.1 | 1.0 | 0.6 | 0.0 | 18.10 | 4.4 (+19%) |
| $NO^3$, kg | 283.6 | 20.7 | 8.7 | 0.1 | 164.5 | 131 (+43%) |
| TP, kg | 1,239 | 99 | 29 | 0.4 | 916 | 384 (+29%) |
| Filterable P, kg | 272 | 25 | 9 | 0.1 | 187 | 102 (34%) |


Figure 1. Managed wetland on west side of Coldwater River, Tate and Tunica Counties, MS. Inset photo shows wetland prior to construction of weirs used to manage water levels, which are shown as red bars on aerial photo. Blue arrows along drainage ditch and slough (shown in yellow) indicate the flow in the channels of run-off from about 100 ha of cultivated lands. Wetland topography shown on contour map to right; elevations are in m referenced to NAVD 88. Site location shown on map to left.

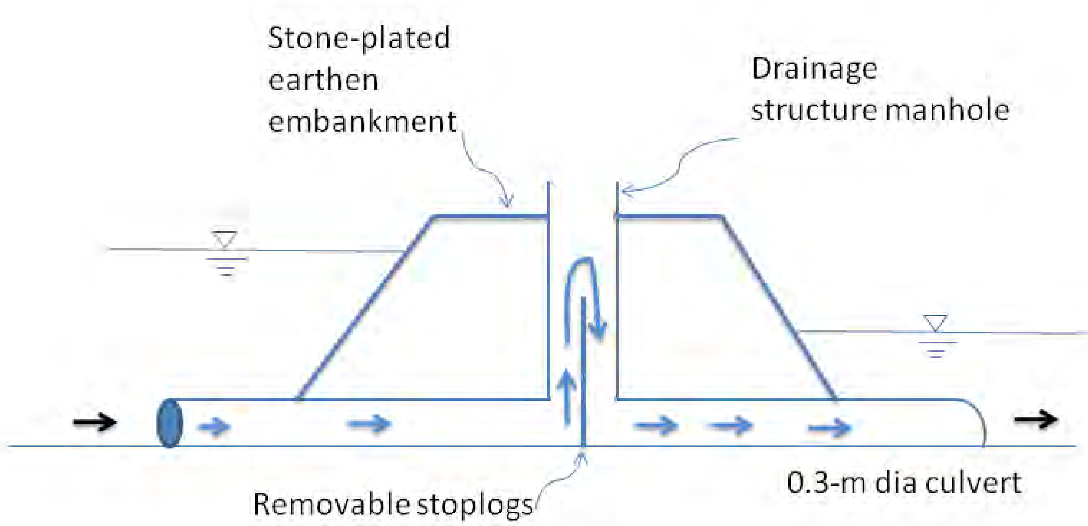


Figure 2. Schematic of drainage structures and weirs shown as red bars in Figure 1.

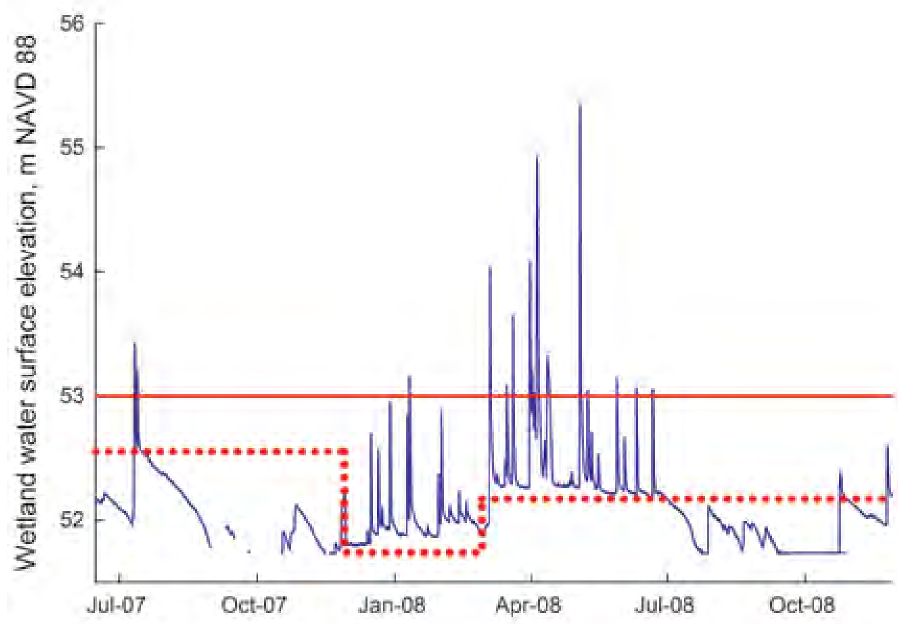


Figure 3. Stage hydrograph for wetland during period of interest. Crest of weir at downstream (river) end of wetland is shown as solid red line, and the elevation of adjustable stoplog crest is shown as the red dotted line.

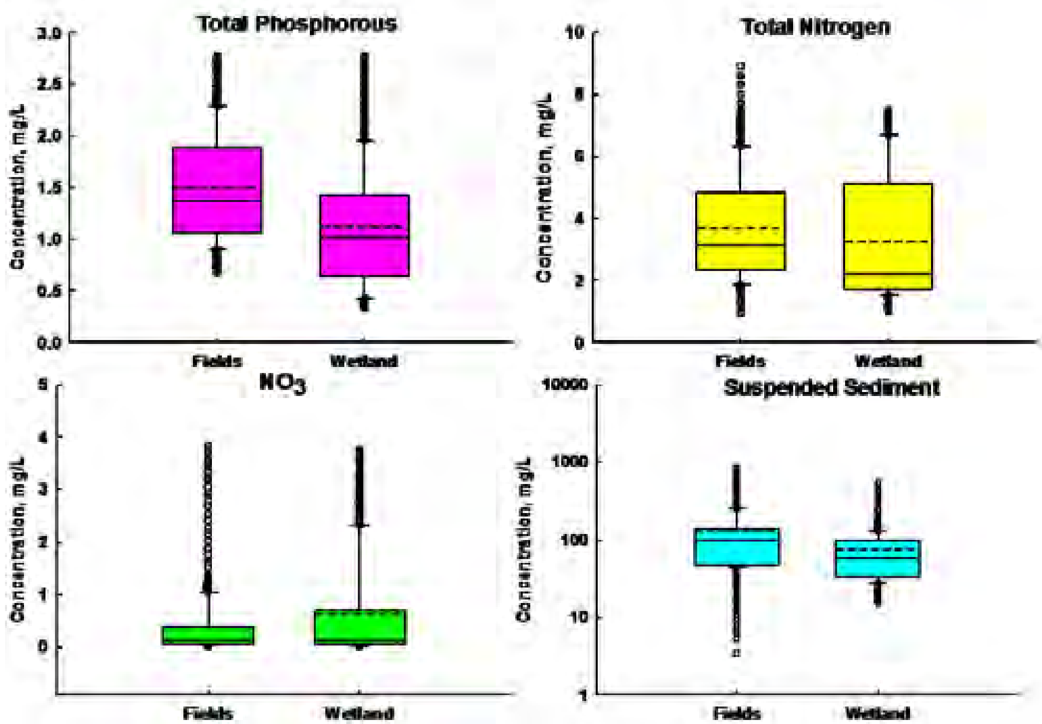


Figure 4. Box and whisker plots for selected water quality constituent concentrations of samples collected from the primary inflow to the managed wetland, a slough that conveyed runoff from about 100 ha of cultivated fields (labeled "Fields"), and for samples collected from the downstream end of the wetland (labeled "Wetland"). Medians of all constituents except for NO3-N were significantly different ($P < 0.013$)

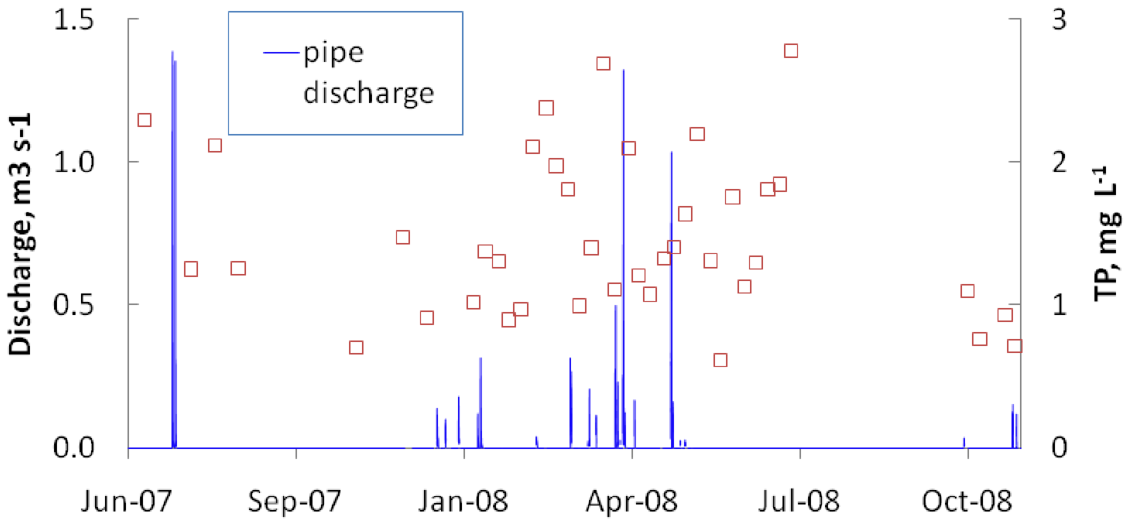


Figure 5. Discharge through tributary pipe versus date and total phosphorus concentration in tributary slough during study period.

**Appendix**

Table A1. Methods Used in Water Quality Analyses

| Parameter | Method Used | Standard Method (APHA 1998) |
|---|---|---|
| Turbidity | Calibrated Hach electronic turbidimeter | N/A |
| Total Solids | Dried @ 105 °C | 2540 B |
| Dissolved Solids | Dried @ 105 °C | 2540 B |
| $NH_4$-N | Phenate method | 4500-NH3 D |
| $NO_3$-N | Cadmium reduction method | 4500-NO3- E |
| $NO_2$-N | Colorimetric method | 4500-NO2- B |
| TN ($NO_3$-N + $NO_2$-N + TKN) | Block digestion & flow injection analysis | 4500-Norg D |
| Soluble P | Ascorbic acid | 4500-P.E. |
| Total P | Persulfate digestion; ascorbic acid | 4500-P B; 4500-P E |
| Chlorophyll a | Pigment extraction & spectrophotometric determination | 10200.H |

# A Study of Seagrass at Grand Bay National Estuarine Research Reserve, Mississippi

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Seagrass beds provide nursery and foraging habitats for marine life, help improve water clarity, help reduce coastal erosion, and buffer wave energy. Therefore, temporal changes in their distribution and abundance indirectly reflect changes in the habitat quality and environmental health status. *Ruppia maritima*, the most abundant and common species in the Mississippi seagrass beds, is an opportunistic, pioneer species that is highly dependent on sexual reproduction. In order to provide information needed to identify areas that can support seagrass growth and to understand the temporal variations in the seagrass structures within the areas, we conducted biannual surveys at *Ruppia maritima* and *Halodule wrightii* beds in Grand Bay National Estuarine Research Reserve (NERR), Mississippi. We hypothesized that there were significant spatial and short-term fluctuations in the coverage of *Ruppia/Halodule* beds. Three-way ANOVA was used to analyze seagrass depth distribution and abundance, which we surveyed along water depth gradients and shoreline orientation. Other pertinent water quality parameters - turbidity, [chlorophyll $\alpha$], dissolved color, dissolved oxygen, pH, salinity, temperature, sediment, nutrients, and water level were monitored *in-situ* or obtained from the NERR monitoring data. The coverage and distribution of the beds dominated by *R. maritima* and the *Ruppia – Halodule* mixed beds of the tidal bay area (the estuarine area) in the reserve vary substantially primarily due to changes in *R. maritima* abundance between summer and fall. Our results on site variation in SAV coverage suggest that shore orientation and wind-driven energy within the estuarine system might be contributing factors to the spatial difference in the shallow estuary. The estuarine *Ruppia* population that grows in the shallow, high wave energy environment has an annual growth pattern: seedling growth in early spring, rapid vertical growth in April, producing abundant inflorescence and seeds in May and June, and senescence in the fall. On the other hand, *R. maritima* that occurs in the bayous and marsh in the reserve area, where tides and wind-driven wave actions are less severe, rarely flowers and sets seeds. Our results also suggest that consistent SAV survey efforts are needed to reduce errors in assessments of disturbance/restoration impacts and long-term trend, which will provide a useful tool for management and research.

Key words: Ecology, Water Quality, Wetlands

**Introduction**

Submerged aquatic vegetation (SAV) is a unique group of flowering plants that have adapted to live fully underwater. Seagrasses are the SAV species that are adapted to live in marine environment. Seagrasses represent critical ecosystems, with a much higher biomass compared to plankton-based oceanic communities, with relatively complex physical structures. Seagrass beds provide combination of food and shelter that enables high biomass and productivity of commercially important fish species; an important nursery area for many species that support offshore fisheries and for adjacent habitats such as salt marshes, shellfish beds, coral reefs, and mangrove forests. Healthy seagrass beds also enhance shoreline stabilization:

the leaves of SAV reduce waves and currents; root and rhizome system bind sediments. Nutrient uptake and particulate sedimetnation effectively improve water quality.

In Northern Gulf of Mexico, freshwater and brakish water SAV communitites occur mainly in large, shallow bays and flats formed at the river mouths along the Gulf coast. Seagrasses, or salt water SAV species, are the most extensive SAV system in the area. There are a few species occurring in this region: turtlegrass (*Thalassia testudium*), manateegrass (*Syrigodium filiforme*), stargrass (*Halophila engemanii*), paddlegrass (*Halophila decipiens*), and Shoalgrass (*Halodule wrightii*). Wigeongrass (*Ruppia maritima*) has a broad salinity tolerance and also occur abundantly in the seagrass beds.

In the Mississippi Sound, seagrass beds had been declining more than 50 percent since the 1969 Hurricane Camille according to the early 1990's studies (Moncreiff, 2006). The more significant declines occurred in stable, climax community seagrasses such as *T. testudinum* and *S. filiforme*, which have resulted in the increased relative abundance of opportunistic species such as *R. maritima* and *H. wrightii* in estuaries and barrier islands of the northern Gulf of Mexico (Eleuterius 1987). The primary causes for this general decline in SAV habitat and the loss of species are likely water quality degradation and physical disturbances such as hurricanes. SAV distribution maps presented in the aforementioned reports and publications have been used as a critical indicator of the general long-term trends of SAV habitat in Mississippi Sound. However, seasonal and annual variations have become more pronounced in the Mississippi seagrass beds due the dominance of *R. maritima* (Cho and May 2008). *R. maritima* areal coverage and biomass are known to fluctuate considerably seasonally and annually elsewhere.

**Objectives**

The overall objective of this research is to develop an ecological model that links the spatial and temporal variability in the seagrass structure/competitive advantage with key environmental factors through a long-term study at the seagrass beds in Grand Bay National Estuarine Research Reserve (NERR). Our specific objective for this report was to identify the optimal growth conditions and areas for the seagrass species by studying temporal/spatial variations in the seagrass abundance, species composition, and biomass.

**Methods and Materials**

***Biannual SAV survey***

Five sites in Middle Bay, Jose Bay, Grand Bay of Grand Bay NERR were surveyed biannually (in July and in October) using transects since 2005. These sites represent gradients of species composition and abundance, shoreline type and aspect, shoreface slope (gradual—steep), and sediment composition, and tidal (or wave) fluctuation. At each site, we ran three 200-m transects perpendicular to the shoreline; and the each transect was surveyed by snorkeling and raking from a boat to record linear SAV coverage, species, density, and the corresponding depths. Water depth were calibrated to the mean water level; data were normalized whenever needed using appropriate data transformation methods. Differences in the SAV coverage (Ruppia, Halodule, mixed) were tested using ANOVA with fixed variables of season, year, and site.

Monthly SAV Biomass Sampling: Four replicates of core (an inside diameter of 7.5 cm diameter) samples were collected monthly at three of the sites: Middle Bay, Grand Bay, and Jose Bay. The samples were processed in a laboratory to assess seasonal, spatial (among sites and depths) variations in root (below-ground part) to shoot (above-ground part) dry biomass ratio.

**Results and Discussion**

Only two SAV species are currently present in the seagrass beds at Grand Bay NERR: *Ruppia maritima* and *Halodule wrightii*. The areal coverage and biomass of these two species change significantly monthly, between summer and fall, and annually (Figs 1 and 2). The temporal fluctuation is more prominent in *R. maritima* than in *H. wrightii*, but there is a general natural temporal cycle that can be induced from our datasets (Figs 1 and 2 and Table 1). In early spring, the *Ruppia* above ground shoot biomass and coverage increase rapidly until they reach their maximum values in July (Figs. 1 and 2). Then the *Ruppia* population dwindles after reaching the maximum growth, the above ground biomass decreases rapidly in August (Fig. 2) and the areal coverage are reduced in the fall. Below ground biomass shows much less changes throughout the time period (Fig. 2), therefore, *Ruppia* shoot to root biomass ratios were as great as 13 in the spring and summer. This can partially explain the substantial annual variation in the summer *Ruppia* coverage (Fig.1) because we have observed the most significant loss of *Ruppia* shortly after severe spring and summer storms that uprooted the shallow-rooted SAV. The storm-related loss and recovery of above and below biomass have been documented elsewhere (Preen et al. 1995; Di Carlo and Kenworthy 2008). Unlike *R. maritima*, *H. wrightii* abundance showed much less temporal variations in their coverage. According to our ANOVA results (Table 1), *Halodule* abundance at a given site was not changed significantly among the years or even between July and October.

Despite the significant fluctuation in the coverage, species dominance, and biomass of the overall seagrass community in Grand Bay NERR, our study demonstrates that there are seasonal and annual biological cycles; and the unpredicted temporal/spatial variations probably are resulted by physical/chemical factors that interrupt the biological cycles. It is important to identify the key factors that prevent/limit SAV growth in the areas with no or less vegetation in order to set feasible restoration strategies and goals.

**Acknowledgements**

This research is supported by grants from the National Oceanic and Atmospheric Administration (NOAA) (Grant No.NA17AE1626, Subcontract # 27-0629-017 to Jackson State University), NOAA through National Estuarine Research Reserve System, Mississippi Department of Marine Resources, and MS-AL Sea Grant Consortium.

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Table 1. Results of a three-way Analysis of Variance (ANOVA) to compare SAV coverage among survey sites, between two season (summer and fall), and survey years (2005-2008).

| **Source** | **P** | |
|---|---|---|
| | ***Ruppia maritima*** | ***Halodule wrightii*** |
| Site | <0.001 | <0.001 |
| Season | <0.001 | <0.001 |
| Year | <0.001 | <0.001 |
| Site x Season | <0.001 | 0.572 |
| Site x Year | <0.001 | <0.001 |
| Season x Year | <0.001 | 0.013 |
| Site x Season x Year | <0.001 | <0.001 |

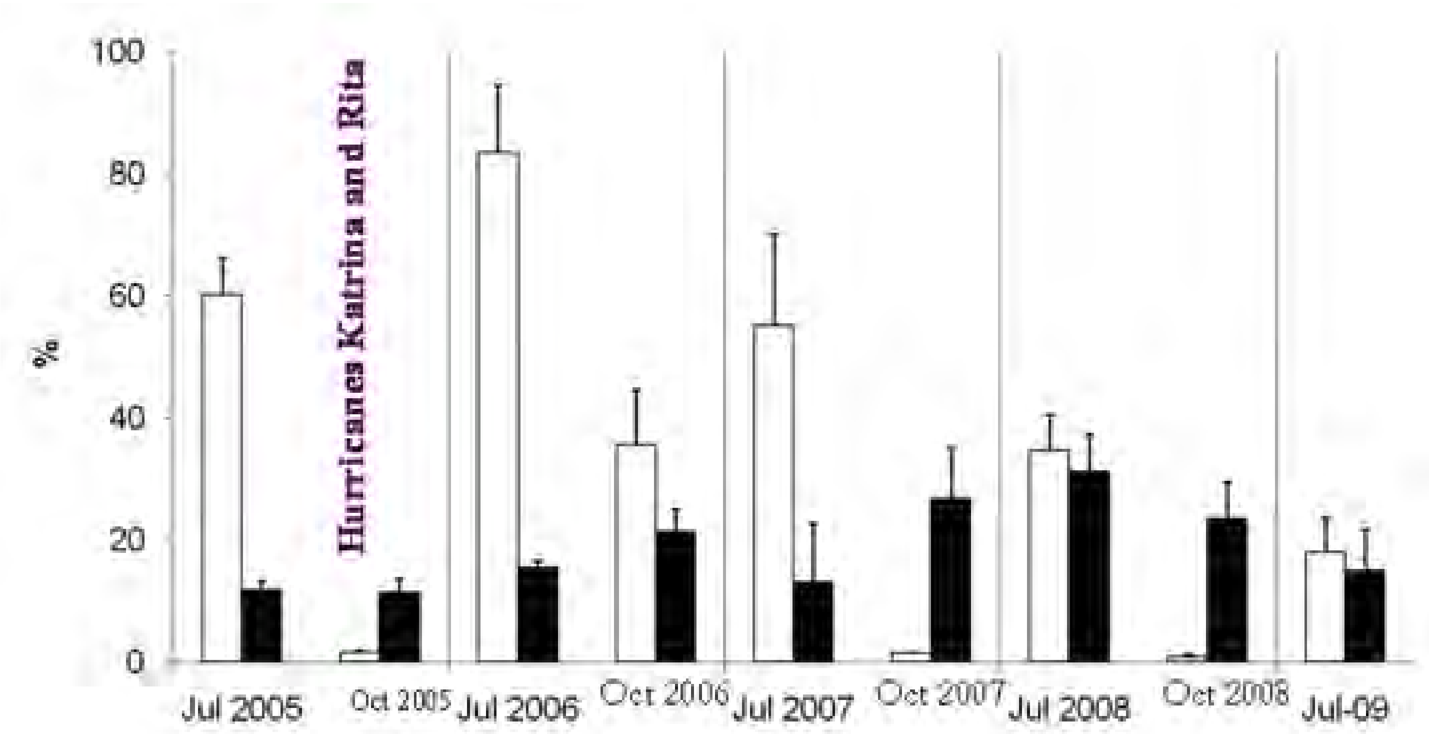


Figure 1. Percent Transect Portion Covered by Seagrass. The white bars represent the Ruppia maritima coverage and the black bars represent Halodule wrightii coverage. The error bars represent standard errors.

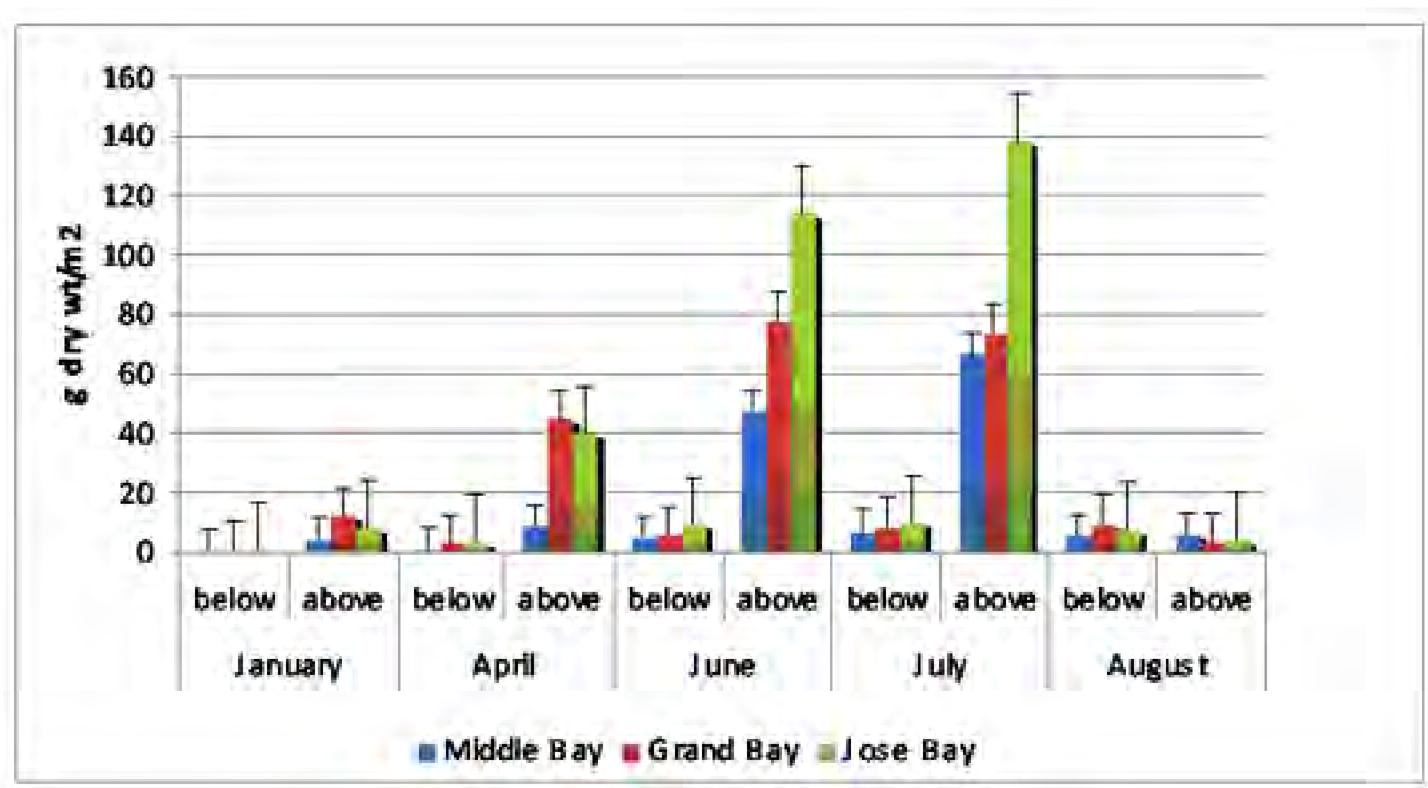


Figure 2. Monthly mean below and above ground biomass of seagrass beds at three sampling sites in Grand Bay National Estuarine Research Reserve. The error bars represent standard deviations.

# Flooding or Precipitation: What is the Dominant Source of Moisture Sustaining a Backwater Bottomland Hardwood Forest?

David R. Johnson, U.S. Army Corps of Engineers

When modeling the potential impact of the Yazoo Backwater Pump Project on the Bottomland Hardwood Wetlands, the Corps assumed the precipitation played an insignificant role in the sustenance of these wetlands. That assumption will be examined through the use of a water budget equation and groundwater monitoring wells.

The dominant water demand in forested areas is from evapotranspiration. It is generally presented that a forested area will be a wetland if precipitation exceeds evapotranspiration. A wetland water budget is actually much more complicated than that. Forested wetlands have four potential sources of moisture: precipitation, surface water, groundwater, and tidal, and four potential methods to lose water: evapotranspiration, surface runoff, infiltration into groundwater and tidal. Yazoo Basin wetlands are not affected by tides and are disconnected from the alluvial aquifer by a confining clay layer. Thus there are only two remaining sources of moisture: precipitation and surface water (riverine flooding). This presentation will compare the relative roles of these two sources of moisture to the forested wetlands in the Yazoo Backwater Area.

Key words: floods, ground water, surface water, hydrology, wetlands

# Transport of Non-Point Source Contaminants Through Riparian Wetlands in the Mississippi Delta Region

Elizabeth Noakes, University of Mississippi
Gregg R. Davidson, University of Mississippi
Daniel G. Wren, USDA ARS National Sedimentation Laboratory
Steven G. Utroska, University of Mississippi

A joint research group at the University of Mississippi and the USDA ARS National Sedimentation Laboratory has been investigating the fate and transport of non-point source contaminants entering riparian wetland systems from agricultural lands. Results to date suggest that short-term studies documenting sequestration of chemically persistent contaminants in riparian wetlands are not sufficient to document long-term containment of these substances. In previously reported work, elevated concentrations of Pb and As were found at particular depths in open-water sediments in Sky Lake, but not in contemporaneously deposited sediments in the surrounding wetlands. Depositional dates of the zones of elevated concentration, based on 210Pb and 137Cs measurements, were consistent with the timing of lead arsenate use in the vicinity. The absence of similar concentration spikes in the wetland sediments led to the working hypothesis that contaminants such as Pb and As may be initially scavenged from water flowing through a riparian wetland, but over time are flushed out into adjacent lakes or streams. Within the wetland, seasonal inundation and aeration results in decomposition of litter, remobilization of contaminants bound to organic matter, and redistribution by rising and falling water levels. Permanent sequestration occurs only with burial in the perennially flooded open water environment. The study has been expanded to additional lake-wetland systems in the Mississippi Delta region to determine if evidence of long-term flushing of contaminants from riparian wetlands is a common occurrence.

Key words: Hydro Geochemistry, Nonpoint Source Pollution, Sediments, Surface Water, Wetlands

Delta Water

**Charlotte Bryant Byrd**
*Mississippi Department of Environmental Quality*

Hydrogeology of the Central Delta

**Paul C. Parrish**
*Mississippi Department of Environmental Quality*

Ground Water-Surface Water Interaction in the West-Central Delta (Washington County)

**James E. Starnes**
*Mississippi Department of Environmental Quality*

Mississippi River Bluff Line Streams

**Olivier Bordonne**
*U.S. Geological Survey*

Interaction of the Mississippi River with the Mississippi River Valley Alluvial Aquifer in Northwestern Mississippi

**Pat Mason**
*Mississippi Department of Environmental Quality*

Recharge in the Water Budget of the Delta's Alluvial Aquifer

# Hydrogeology of the Central Delta

Charlotte Bryant Byrd, Mississippi Department of Environmental Quality

For the last several years there has been growing concern regarding the declining water levels in Mississippi River Valley alluvial aquifer (MRVA) in the central Delta. Analysis of water levels alone does not answer the question of how much water is actually remaining in the aquifer. The only way to determine this is to know where the base of the aquifer is in relation to the water level at any one site. Therefore, in the summer of 2004 staff of Mississippi Department of Environmental Quality's Office of Land and Water Resources (OLWR) began a drilling program to gather this type of information.

Twice each year, staff of the Yazoo-Mississippi Delta Joint Water Management District (YMD) collects water level data from wells screened in the MRVA throughout the entire Delta. Most of the drill sites for this project have been very near some of these wells. The minimum depth drilled at all the sites has been 300 feet. This depth allows not only the entire thickness of the MRVA to be penetrated, but a portion of the underlying formation, as well. Data collected from the water level measurements and drilling enables changes in the saturated thickness of the aquifer at each of these MRVA well sites to be monitored through time.

Throughout the Delta, the surface of the formation(s) underlying the MRVA is an erosional surface; therefore, the contact between the two is an unconformity, resulting in an extremely variable MRVA thickness. Most publications report that the average thickness is approximately 135 to 140 feet. In the project area the average depth of the base of the aquifer is 131 feet below ground surface, with the range of depth between 90 and 166 feet. The water level in the MRVA is approximately 50 feet below ground surface. As most irrigation / catfish culture wells have 40 feet of screen, the most serious scenario is where these wells are screened where the MRVA base is less than 100 feet below ground surface. At these sites, the static water level is either only a very few feet above the top of the well screen or at the top of the screen; and during periods of pumping, the water level is below the top of the screen.

Continued investigation of the geology is an important key to understanding the hydrology of the alluvial aquifer in this area. A better understanding of how this aquifer system works will allow officials to properly and effectively manage this tremendous resource.

Key words:

# Ground Water-Surface Water Interaction in the West-Central Delta

Paul C. Parrish, Mississippi Department of Environmental Quality

From the end of the 2008 irrigation season to the beginning of the 2009 irrigation season, measurements were made at eleven Mississippi Delta irrigation wells. The measurements were made along a profile in Washington County. This profile extended from the Longview community to just west of Hollandale, MS. All of the wells lie on a general West to East trend.

The purpose of this study was to evaluate the interaction between surface water of the Mississippi River and ground water of the Mississippi River Valley Alluvial Aquifer (MRVA) along a specific profile. The study also allowed for pinpointing of the localized ground water divide. Data from 2008-2009 was then compared to data from a 1992-1993 study along the same profile. The question that must be asked is whether the ground water divide and the Mississippi River's influence shifted over the last 15-16 years. If the answer is yes, then more study will be needed to determine if this is localized and to determine what factors may have contributed to the shift.

Key words: Ground Water, Surface Water, Irrigation

# Mississippi River Bluff Line Streams

James E. Starnes, Mississippi Department of Environmental Quality

A multitude of deeply incised, distinctive streams drain the Mississippi Loess Bluffs from Memphis southward to Natchez. These hydrologic features (and supported biota) are strongly influenced and controlled by complex Quaternary and Tertiary lithologic layers. These "bluff line streams" support unique, complex, and delicate sets of aquatic ecosystems, some of which are considered to be ice-age relics. Locally, these dendritic systems support the recharge of the Mississippi River Alluvial Aquifer (MARVA) as their trunk streams enter into the Mississippi River Alluvial Plain across copious, low relief, alluvial fans. These streams are threatened by in-stream mining, oil and gas production activities (shallow salt water injection, evaporation pits, and spills), industrial and housing development, deforestation, nonpoint source pollution such as agricultural runoff, solid waste dumping, and stream-bed alteration. Such activities can have profound negative impacts; degrading water quality, threatening aquatic/terrestrial biology, amplified erosion, localized excessive sedimentation, and spoiling sensitive, natural eco-system balances. Heightened awareness, study, and understanding of integrated and interdependent processes (geology, hydrology, biology) is essential to maintaining and sustaining delicate, unique, bluff line stream environments.

Key words: Nonpoint Source Pollution, Agriculture, Sediments, Hydrology

# Interaction of the Mississippi River with the Mississippi River Valley Alluvial Aquifer in Northwestern Mississippi

Olivier Bordonne, National School for Water and Environmental Engineering, France
Jeannie R.B. Barlow, U.S. Geological Survey
Richard H. Coupe, U.S. Geological Survey

The Mississippi River Valley Alluvial Aquifer (MRVA) in northwestern Mississippi is in direct connection with the Mississippi River, discharging into the River at times of base flow and being recharged by the Mississippi River at times of high flow. Modeling studies have indicated that over the long term, there is a net zero exchange of water between the Mississippi River and the MRVA. However, because of increased groundwater withdrawals for agriculture over the past few decades, groundwater levels have been declining in the MRVA; this decline has likely changed the interaction between the Mississippi River and the MRVA. Changes in surface- and groundwater interactions are important to understand, especially as local agencies attempt to implement policies to use the MRVA in a sustainable manner. In order to quantify the exchange between the Mississippi River and the alluvial aquifer, continuous data collected over the last decade from wells located near the Mississippi River were used to identify recharge and discharge periods and to estimate the net balance between the river and aquifer. Historical water-level data were also used to determine if the relation has changed over time.

Key words: Agriculture; Ground Water; Irrigation; Water Quantity

# Recharge in the Water Budget of the Delta's Alluvial Aquifer

Pat Mason, Mississippi Department of Environmental Quality

The Missisippi River Valley Alluvial Aquifer (MRVA) is a highly productive aquifer which supports vast amounts of Delta agriculture and commerce. Maintaining an adequate future water supply requires understanding of the water budget. Stated simply: current water levels + recharge - discharge = future water levels. Focusing on the recharge term in the equation, existing evidence about recharge to the MRVA is reviewed, and current active research is described.

Normal direct recharge by precipitation is extremely restricted in the MRVA because of a widespread impermeable unit just below the soil profile. Direct recharge is, however, active in localized areas, particularly through the conduit of the alluvial fans along the eastern boundary of the Delta plain. An estimated 220 square miles of land surface is covered by fans, with vertical relief ranging from 4 to 66 feet. Drilling reveals much greater thicknesses of alluvial fan deposits occur below the surface, coeval with deposition of the MRVA.

Recharge from streams is also a significant factor in the bluff margin area, where streams cross fan sediments which lie in connection with the MRVA. In summer, many smaller streams can be observed to lose flow and disappear as they traverse fans. Direct discharge measurements of larger streams have recorded every condition as streams cross the fans, from gains on clay dominated fans, to significant losses over sandy materials, suggesting that the variable source geology of the reworked sediment making up each fan tends to control the amount of gain or loss of flow from any given stream to the aquifer.

Efforts are underway to characterize and quantify water heads and pathways along the Bluff Hills boundary for use in a large flow model. These include data collection regarding the size and hydraulic conductivity of the alluvial fans, the role of Yazoo headwater streams and other surface watersheds, and the involvement of the several geologic formations adjacent to the MRVA.

Key words: Water Quantity, Water Supply, Groundwater, Geomorphological Processes

**Sediments**

| | |
|---|---|
| **Trey Davis**<br>*Mississippi State University* | A Study of the Effectiveness of Various Sedimentation Solutions and Practices |
| **Christopher L. Hall**<br>*Mississippi State University* | Modeling Fluid Mud |
| **Michael S. Runner**<br>*U.S. Geological Survey* | Turbidity as a Surrogate for the Estimation of Suspended-Sediment Concentrations in Mississippi Streams |
| **John J. Ramirez-Avila**<br>*Mississippi State University* | Sediment Budget Analysis for Town Creek Watershed, MS |
| **Byoungkoo Choi**<br>*Mississippi State University* | Headwater Hydrologic Functions in the Upper Gulf Coastal Plain of Mississippi |

# A Study of the Effectiveness of Various Sedimentation Solutions and Practices

Trey Davis, Mississippi State University

This report will show the effectiveness of various types of solutions and practices used to reduce, prevent or change sedimentation patterns within areas of navigational interest. Most modern shipping facilities maintain deeper depths than occur naturally to accommodate the size of the world's ever growing merchant vessel. Deepening of such facilities such as anchorage basins, ship channels, etc are usually met with sediment deposition, which must be removed or prevented to maintain efficient shipping operations. Maintenance dredging has become the primary tool for the upkeep of underwater navigation dimensions, but it also has a number of downfalls in its operation, which has become more prevalent over the years. Likely, the most obvious problem with dredging is the lack of a permanent solution, for maintenance dredging removes unneeded sediment rather than addressing the processes creating deposition. Many other concerns are associated with maintenance dredging such as: expensive operation costs, difficulty to secure small contracts, downtimes in shipping operations and worries of ecological distress. These problems have created interest in solutions or practices to reduce or prevent the amount of sediment deposition within maintained depth facilities and ultimately reduce the amount of maintenance dredging needed, which may result in significant economic benefits.

Key words: sediment, economic, ecology

# Modeling Fluid Mud

Christopher L. Hall, Mississippi State University

Fluid mud is defined as a high concentration aqueous suspension of fine-grained sediment in which settling is substantially hindered. Fluid mud occurs in many ports and channels around the world. It can severely affect navigation due to the sharp increase in sediment concentration returning a false bottom to sonar systems, and the fluid mud can fill in channels faster than it can be dredged, restricting port access. Fluid mud can also suffocate benthic organisms or contribute to eutrophication. This study is designed to further advance the field of fluid mud modeling to aid in the prediction of fluid mud formation and movement. Most available hydrodynamic models do not include a fluid mud routine. The addition of fluid mud equations to these existing models could greatly enhance sediment process modeling in areas that experience fluid mud. These equations calculate formation, dissipation, flow, and consolidation to adequately describe the physical processes affecting fluid mud. Modeling results using these equations compared with field data as well as laboratory experiments will determine their usefulness. Laboratory experiments include measuring the flow of fluid mud under shear stress and on a slope. With accurate prediction of the physical processes governing fluid mud, dredging alternatives could be developed to reduce dredging requirements and improve port access.

Key words: sediments, modeling, management and planning

# Turbidity as a Surrogate for the Estimation of Suspended-Sediment Concentrations in Mississippi Streams

Michael S. Runner, U.S. Geological Survey
Shane J. Stockes, U.S. Geological Survey

The U.S. Geological Survey currently collects suspended–sediment concentration data at more than 25 hydrologic monitoring stations in Mississippi. Data are collected to describe suspended-sediment concentrations and loads over the range in discharge for these stations and to determine if trends in the sediment-discharge relation exist, as well as describe changes in those trends. Where sufficient data are collected, they can be used to compute the load of sediment transported in suspension during storm events.

Traditional methods for obtaining suspended-sediment concentration data require the collection of water samples that are shipped to a laboratory for analysis.  Depending on a variety of factors, it can take up to 6 months from the time of sample collection to receipt of laboratory results. To expedite the availability of these data to the cooperators, which will allow decisions to be made in a timely manner, the U.S. Geological Survey began a study to develop a method to estimate suspended-sediment concentrations using a surrogate. The method is based on the success of previous studies, which indicated that for streams with certain hydrologic and sediment characteristics, site-specific relations between turbidity and suspended-sediment concentrations could be developed, which allow the estimation of the sediment concentration.

For this study, turbidity data are being collected by using two methods. First, in situ water-quality monitors are installed at two continuous-record stations where discrete suspended-sediment concentration data are collected. Turbidity data are collected on a regular time interval, generally every 15 minutes, by water-quality monitors deployed in the water at these stations. The measured turbidity values are compared with the suspended-sediment concentrations in water samples collected by using automatic pumping samplers. Second, water samples collected at locations without continuous water-quality monitors are analyzed for turbidity by using a bench-top turbidity meter prior to the samples' shipment for analysis. Water samples collected at stations with continuous water-quality monitoring are also analyzed using the bench-top meter so that comparisons can be made between the two methods.

Preliminary results indicate that reasonable turbidity-sediment relations can be developed for many of the stations that are currently being tested as part of this program. These relations could provide a means to estimate suspended-sediment concentration for water samples collected by automatic pumping samplers, as well as provide a means to reduce the costs associated with collecting data necessary for the evaluation of environmental projects.

Key words:  Methods, Sediments, Surface Water, Water Quality

# Sediment Budget Analysis for Town Creek Watershed, MS

John J. Ramírez-Avila, Mississippi State University
Jeremy Sharp, Mississippi State University
William H. McAnally, Mississippi State University
Sandra L. Ortega-Achury, Mississippi State University

The Town Creek watershed is located in the Northeast area of Mississippi. It covers 1,769 $km^2$ and represents approximately 50% of the upper Tombigbee River basin area contributing to the Aberdeen Pool on the Tennessee-Tombigbee Waterway. The sediment yield from the watershed attributes to the estimated 320,000 ton/yr of deposition in Aberdeen pool, where annual dredging averages 310,000 ton/yr. To produce remedial measures for reducing water quality impairment, and dredging costs (expressed in terms of a percent reduction of sediment loads), and future BMP's in Town Creek watershed, it is necessary to know the sediment sources and loads currently transported within the watershed. A sediment budget for a partial sub-basin within Town Creek watershed is investigated by means of experimental and modeling methods, including HEC-RAS and the Sediment Impact Analysis Method (SIAM). SIAM is a rapid assessment screening tool used to evaluate the impacts of sediment management activities and determine trends in sedimentation. The tool is incorporated in the latest version of the U.S. Army Corps of Engineers HEC-RAS model as a design module. Local sediment sources/sinks (e.g. tributary inputs, landuse practices) as well as the upstream and downstream boundary conditions are defined by using computational tools, field surveys, and sediment sampling The analysis performed is expected to provide a general assessment of the sediment budget components within a representative watershed within the Tombigbee River Basin.

Key words: Sediment Budget, Sediments, Models, Water Quality, HEC-RAS, SIAM

# Headwater Hydrologic Functions in the Upper Gulf Coastal Plain of Mississippi

Byoungkoo Choi, Mississippi State University
Andrew W. Ezell, Mississippi State University
Janet C. Dewey, Mississippi State University

Headwater streams are often considered to be contributors of nonpoint source sediment in forested watershed areas and are a key component of overall hydrologic processes because they comprise more than 60-80% of stream networks and watershed land areas. However, the relationship between silvicultural practices in the uppermost portions of headwater systems characterized by ephemeral-flow areas and their downstream linkages is poorly understood. In Mississippi's forestry best management practices (BMPs) manual, streamside management zones (SMZs) have specific guidelines for perennial and intermittent streams, but ephemeral streams are rarely considered in forest resources management. This study is being conducted in Webster County, Mississippi to (1) examine the influence of ephemeral-flow portions of headwaters on downstream hydrology and water quality, and (2) evaluate silvicultural BMPs effectiveness of ephemeral streams in protecting downstream water quality. Specific objectives of this study are to test effects of four levels of harvest in ephemeral-flow areas on (1) in-stream water quality and total suspended sediment (TSS), (2) surface erosion and deposition in pre- and post-harvest conditions, and (3) the responses in subsurface hydrology. This study is installed as a randomized complete block (RCB) design consisting of three replicates of four treatment watersheds (No BMP, BMP1, BMP2, No harvest) representing a range of potential BMPs for ephemeral-flow portions of headwater streams. Results consisting of one year of pre-treatment data and two years of post treatment data will be presented. This study will increase our understanding of effectiveness of the headwater BMPs in mitigating timber harvesting impacts on water quality in riparian areas as well as providing information on the relationship between hydrological connections between perennial and ephemeral streams, and overall water quality.

Key words: Hydrology, Nonpoint Source Pollution, Water Quality, Sediments

Water Quality

## Water Quality

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| **Richard Rebich**<br>*U.S. Geological Survey* | Sources and Transport of Total Nitrogen from Major River Basins of the South-Central United States, 2002 |
| **Zhengzhen Zhou**<br>*University of Southern Mississippi* | Composition and Size Distribution of Colored Dissolved Organic Matter in River Waters as Characterized using Fluorescence EEM and Field-Flow Fractionation Techniques |
| **Billy Justus**<br>*U.S. Geological Survey* | Fish and Invertebrate Assemblage Relations to Dissolved Oxygen at 35 Sites in Southern Louisiana |
| **Bonnie Earleywine**<br>*Mississippi State University* | The Effects of Land Use on Streams along the Natchez Trace Parkway Using Rapid Bioassessment Protocols |
| **Alison Kinnaman**<br>*University of Mississippi* | The Use of Microcosm Studies to Determine the Effect of Sediments and Nutrients on Fecal Indicator Bacteria in Lake Water |

# Sources and Transport of Total Nitrogen From Major River Basins of the South-Central United States, 2002

Richard Rebich, U.S. Geological Survey

A spatially-referenced regression on watershed attributes (SPARROW) model was developed for a 2002 base year for streams in the Lower Mississippi, Arkansas-White-Red, and Texas-Gulf River basins to describe total nitrogen loadings to the northwestern Gulf of Mexico. Ultimately, model results may be used to help develop water management plans to reduce, control, and mitigate nutrient inputs throughout the study area. Total nitrogen loads and yields generally were highest near streams in the eastern part of the study area in the Lower Mississippi basin and along reaches near the Texas and Louisiana shoreline. The highest individual source of nitrogen for the study area was from wet deposition of total inorganic nitrogen, which accounted for 36 percent on average of total nitrogen in streams from the study area. Land application of manure from confined feedlots and manure generated in pastures accounted for 22 percent, nitrogen fixation from fertilizer applications accounted for 17 percent, and nitrogen from commercial fertilizers accounted for 12 percent on average of total nitrogen in streams from the study area, which combined totaled 51 percent from agricultural and pasture land uses. Urban sources of nitrogen totaled about 13 percent on average of total nitrogen in streams from the study area, of which urban nonpoint runoff accounted for 9 percent and municipal and industrial point sources about 4 percent.

For the Yazoo River basin in northwestern Mississippi, preliminary estimates of total nitrogen load and yield were about 21,300 metric tons and about 0.64 metric tons per square kilometer, respectively, both of which agree with literature estimates for the sampling station located near the mouth of the Yazoo River prior to release into the Mississippi River. The total nitrogen load from the Yazoo represents about 2.2% of the total nitrogen load of the Mississippi River near its mouth. Nitrogen from atmospheric deposition accounted for about 25 percent of the total load leaving the Yazoo River basin. Agricultural sources accounted for about 67 percent of the total load: 31 percent by commercial fertilizers, 30 percent by nitrogen fixation from fertilizer applications, 5 percent from pastures, and 1 percent from land application of manure from confined feedlots. Urban sources of nitrogen accounted for the remaining 9 percent of the total load from the Yazoo River, of which about 5 percent came from municipal and industrial point sources and 4 percent came from urban nonpoint runoff.

Key words: Water Quality, Models, Nutrients, Nonpoint Source Pollution, Surface Water

# Composition and Size Distribution of Colored Dissolved Organic Matter in River Waters as Characterized Using Fluorescence EEM and Flow Field-Flow Fractionation Techniques

Zhengzhen Zhou, University of Southern Mississippi
Bjorn Stolpe, University of Southern Mississippi
Laodong Guo, University of Southern Mississippi

Colored dissolved organic matter (CDOM) is an active organic component in natural waters, and can have an effect on environmental and water quality in aquatic systems. In order to examine the composition and size-distribution of CDOM in the Mississippi and Pearl rivers and the effect of flooding, monthly water samples and flood samples were collected from the lower Mississippi River at Baton Rouge and the Pearl River at Stennis Space Center, followed by size fractionation using ultrafiltration and flow field-flow fractionation (FlFFF) and measurements of dissolved organic carbon (DOC), specific UV absorbance (SUVA) and fluorescence excitation emission matrix (EEM). Concentration of DOC varied from 2.8 to 3.9 mg-C/L in the Mississippi River, but was much higher in the Pearl River, ranging from 3.9 mg-C/L in Mar-2009 to 13.6 mg-C/L during the Apr-2009 flood event. Average value of SUVA (254 nm) was 0.035±0.003 L/mg-C/cm in the Mississippi River and 0.045±0.006 in the Pearl River. In the Mississippi River the SUVA254 was fairly constant, indicating similar DOM sources between seasons, while the SUVA254 in the Pearl River varied with DOC concentration and discharge, indicating variable DOM composition. Colloidal organic matter (1-450 nm) from the Pearl River had a $SUVA_{254}$ value of 0.889 compared to 0.0029 for the < 1 nm dissolved fraction, showing that CDOM is mostly present in the colloidal fraction and enriched in microbially-derived humic substances (SUVA at 370 nm). The colloidal size spectra of CDOM determined by FlFF with UV absorbance detection show that the majority of CDOM is found in a population of small (1-4 nm hydrodynamic diameter) colloids in both rivers although the relative proportions of CDOM in the range of 1- 4 nm, 4-20 nm, and >20 nm varied between samples. Fluorescence index (FI), which is the ratio of the emission intensity at 450 nm to that at 500 nm under excitation of 370 nm, shows a more terrestrially derived CDOM in the Pearl River (1.29-1.36), but more microbially derived CDOM in the Mississippi River (1.47-1.49). Based on the integration of fluorescence intensity in the FlFFF fractograms, the ratio of DOC-normalized protein-type fluorophores (Ex/Em 276/340 nm) (proFL/DOC) and humic-type fluorophores (Ex/Em 350/450 nm) (humFL/DOC) exhibits more amino-acids and humic-substance components of CDOM in the Pearl River (7.7-16 and 1.0-3.6) than in the Mississippi River (6.5-9.4 and 0.2-1.3). Moreover, the humFL/DOC value during flooding in the Pearl River was three times higher than normal sample values, suggesting more humic substances during the flooding event. In the EEM measurements, the Ex/Em wavelength at maximum fluorescence intensity shifted from 330/445 nm in normal samples to 338/451nm in flood samples, suggesting an increased input of humic substances that are less transformed by photochemical or microbial processes during the flooding event in the Pearl River. The SUVA and fluorescence EEM coupled with FlFFF and ultrafiltration can be used to effectively investigate the source and composition of CDOM in natural waters.

Key words: CDOM, composition, size distribution, river

# Fish and Invertebrate Assemblage Relations to Dissolved Oxygen at 35 Sites in Southern Louisiana

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From 2005 to 2007, the U.S. Geological Survey sampled fish and invertebrate assemblages and monitored dissolved oxygen during critical summer conditions at 35 stream sites in southern Louisiana. The purpose of the study was to assess relations between fish and invertebrate assemblages and dissolved oxygen, and to provide information that could be used to validate or refine existing aquatic life use categories and dissolved-oxygen criteria (5 milligrams per liter) for streams in southern Louisiana. Sites with a range of ecological conditions were selected for sampling by the U.S. Environmental Protection Agency Region VI, and nine sites were considered to be least impaired. Dissolved-oxygen concentrations were standardized to 0800, a time when concentrations were near the daily minimum, and were compared to approximately 370 biological metrics. Piecewise regression was used to evaluate biological metrics for break points to indicate a minimum (biological) threshold concentration for dissolved oxygen. Preliminary data indicate a biological threshold exists between 2 and 3 milligrams per liter of dissolved oxygen. This finding indicates that fish and invertebrate assemblages in low-gradient streams have adaptations that enable them to withstand low dissolved-oxygen concentrations.

Key words: dissolved oxygen, criteria, biological metrics, threshold

# The Effects of Land Use on Streams along the Natchez Trace Parkway Using Rapid Bioassessment Protocols

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Stream quality is commonly assessed using the Environmental Protection Agency's rapid bioassessment protocols for the habitat, fishes, and benthic macroinvertebrates. These assessments are useful to evaluate impacts that land use may have on streams. We conducted bioassessments in eighteen streams, identified land uses, and compared water quality parameters of forty-four streams along the Natchez Trace Parkway. We measured for potential land use effects by sampling water quality metrics (April 2008-February 2009), benthic macroinvertebrate and habitat assessment protocols (June 2008), and fish protocols (February 2009) to demonstrate differences across six subregional watersheds. The three dominant land uses were deciduous forest, pasture/hay, and evergreen forest respectively. Deciduous forest was most abundant in the Upper Cumberland, Lower Cumberland, and Tennessee watersheds while evergreen forest covered more area in the Mississippi, Pearl, and Tombigbee watersheds. Habitat assessment scores averaged highest in the deciduous forest-dominant watersheds and lowest in the blackwater stream watersheds dominated by evergreen forests. The Pearl watershed, comprised mostly of evergreen forest land, had the lowest average dissolved oxygen, alkalinity, conductivity, pH, and nitrate. Turbidity and total suspended solids decreased as latitude increased. Fecal *E.coli* colony estimates were highest in Mississippi and Upper Cumberland watersheds. Latitudinal differences were also observed in the macroinvertebrate assemblages. Tennessee, Lower Cumberland, and Upper Cumberland watersheds had more shredders and were the only watersheds with Plecoptera. Relationships between fish and macroinvertebrate integrities are discussed for each stream and watershed.

Key words: Ecology, Nutrients, Water Quality, Nonpoint Source Pollution

# The Use of Microcosm Studies to Determine the Effect of Sediments and Nutrients on Fecal Indicator Bacteria in Lake Water

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Field and laboratory experiments were conducted to determine the effects of sediments and nutrients on the persistence of the fecal indicator bacteria (FIB) groups total coliforms and *Escherichia coli (E. coli)* in lake water using samples collected in the field and laboratory-based microcosms. Samples were collected at a discharge point of Thompson Creek into Lower Sardis Lake in northern Mississippi. Samples were tested for total coliforms, *E. coli*, dissolved oxygen, temperature, dissolved organic carbon, nitrate, phosphate, and phenols. Following initial sample testing, seven microcosms were created in the laboratory: (1) lake water, (2) lake water and sediment, (3) lake water and sterilized sediment, (4) sterilized lake water and sediment, (5) sterilized deionized water and sediment, (6) sterilized lake water (control), and (7) sterilized deionized water and sterilized sediment (control). Each microcosm had a function to test a different hypothesis related to whether sediment affected FIB concentrations in water and vice-versa. Samples from each microcosm were collected approximately every 12 hours for two days and 24 hours for the subsequent five days. FIB concentrations from the microcosms were plotted against time, and first-order decay constants were obtained. In addition, correlations were run between FIB decay constants and water quality parameters to assess the dependence of FIB die-off on nutrients. Preliminary results show that FIB decay rates were lower when sediment was present and that high dissolved organic carbon concentrations were associated with a temporary increase in FIB concentrations. The data found on die-off rates and on FIB dependence on nutrients is useful to determine parameters for numerical modeling in lakes.

Key words: Nonpoint Source Pollution, Nutrients, Recreation, Sediments, Methods

Non-Point

**Non-Point**

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| **Scott Perry**<br>*Ibrium Systems Corporation* | Urban Stormwater Runoff Phosphorus Loading and BMP Treatment Capabilities |
| **Maifan Silitonga**<br>*Alcorn State University* | Watershed Assessment and Education |
| **Sandra L. Ortega-Achury**<br>*Mississippi State University* | Water Quality Assessment in the Town Creek Watershed, Mississippi |
| **Marvin Washington**<br>*Jackson State University* | Development of Water Correction Algorithm for Underwater Vegetation Signals |
| **Cristiane Surbeck**<br>*University of Mississippi* | Monitoring and Statistical Analysis of Fecal Indicator Bacteria in Lower Sardis Lake, Mississippi |
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| **Renee Clary**<br>*Mississippi State University* | Gulf Coast Watersheds and Water Education: Outreach Alignment and Best Practices |
| **Michael S. Runner**<br>*U.S. Geological Survey* | Collection of Hydrologic Data on Tidally Affected Streams |
| **Kenny Langley**<br>*Mississippi State University* | The Effect of Policy and Land Use Change on Water Quality in a Coastal Watershed City: An Analysis of Covington, Louisiana |
| **Nathaniel Jourdan**<br>*Mississippi Transitional Recovery Office* | Drainage Improvement Project Development for Successful Hazard Mitigation Funding |
| **Casey DeMoss Roberts**<br>*Gulf Restoration Network* | Protecting Water Quality in Your Community |

# Urban Stormwater Runoff Phosphorus Loading and BMP Treatment Capabilities

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Continued land development through urbanization is deteriorating surface water quality. A significant concern with our limited global fresh water resources is the onset of toxic algae blooms and reduced dissolved oxygen due to continued, uncontrolled phosphorus loading from an ever increasing source, urban development. This is leading to negative ecologic, economic, and human health impacts. As a result, regulators are beginning to acknowledge the impairment of fresh water bodies, and have begun implementation of Total Maximum Daily Loads (TMDLs). However, applying phosphorus related TMDLs specifically to urban stormwater runoff may not be effective without first understanding the available mechanisms and limitations involved in phosphorus treatment for stormwater applications.

To achieve high levels of permanent phosphorus removal, review of the fate and transport of Phosphorus, including both particulate-bound and dissolved phosphorus, in urban stormwater runoff is necessary. Significant field monitoring data of various stormwater Best Management Practices (BMPs) exists which illustrates advantages and disadvantages of removal mechanisms, and ranges of performance variance in both conventional Best Management Practices (BMPs) as well as newer Low Impact Development (LID) applications.

Advances in phosphorus treatment technologies have recently become available and better understood, providing the ability to capture high levels of both particulate-bound and dissolved phosphorus. Amending both conventional BMPs and LID applications with engineered solutions offers increased ability to achieve existing and future phosphorus based TMDLs. These concepts, performance data and design amendments are discussed as a potential means to protect our fresh water resources from remaining eutrophication.

Key words: Non Point Source Pollution, Nutrients, Water Quality, Treatment, Solute Transport

**Introduction**

Phosphorus is an essential nutrient for life, and comprises roughly 10% by mass of the Earth's crust. It is not found in free elemental form in nature, but is widely distributed in minerals, primarily in magmatic, sedimentary rocks and ocean sediments. Phosphorus naturally complexes with other molecules to form organic and inorganic phosphates. It is present in both the dissolved phase (commonly measured as orthophosphate, and referred to as bio-available or Soluble Reactive Phosphorus (SRP)), and particulate-bound phase (adsorbed to sediment particles). Like most chemical constituents present in the environment, phosphorus is cyclic. Under natural conditions phosphorus migrates slowly from rock and sediment deposits, with a portion metabolized into the tissues of living organisms, to be released upon excretion and decay back into the soil and water. Human activities have significantly short-circuited and accelerated this naturally slow phosphorus cycle through agricultural practices, industrialization, land development and urbanization. Some research suggests land development activities account for a 300% load increase in the phosphorus cycle (Howarth et.al., 2005) compromising surface water quality.

Commonly phosphorus is the limiting fresh water nutrient, and when present in excess can quickly lead to significant water quality degradation. Trends in agricultural practices, energy use, and population growth indicate that eutrophication of lakes, streams, rivers, and bays are an expanding problem globally (WRI, 2008). Eutrophication is the result of excess nutrient availability and over enrichment, often identified by toxic algal blooms or oxygen depletion (hypoxia). Algal blooms can result in fish kills, shellfish poisoning and human illness, and even death of mammals and birds. An extreme result of algal blooms is hypoxia, which occurs when algae and other organisms die and begin decomposing, consuming dissolved oxygen (DO) from the water column. As DO levels drop, oxygen required for native species is not available and aquatic ecology suffocates. By monitoring increases in orthophosphate levels (dissolved phosphorus) in the water column, algal blooms can be predicted (EPA, 1997). Though orthophosphate is not the only source of phosphorus in a water body, it does function as the "quick sugar" for algae formation as it is highly bio-available, therefore if untreated or uncontrolled water quality degradation can be anticipated.

Water quality degradation as a result of continued phosphorus loading is beginning to be acknowledged by North American policy decision makers. In the U.S., this is pursued in the Clean Water Act section 303(d), waters listed as impaired by pollutant(s). In Canada, the Ontario Ministry of the Environment is in the process of developing the Lake Simcoe Act to similar effect. To effectively address these impairments it is important to strengthen connections between two key federal programs under the Clean Water Act – the TMDL program and the NPDES stormwater permitting program (EPA, 2008). However, applying TMDLs specifically to stormwater treatment practices (e.g. Total Phosphorus effluents of < 0.1 mg/L) may not be effective without first understanding the available mechanisms and limitations involved in phosphorus treatment for stormwater applications.

Before implementing BMPs to mitigate impaired water bodies and achieve necessary pollutant reductions, a thorough understanding of the problem is required, including: 1) the transport and fate of the specific root-cause pollutant; 2) the effects of continual loadings to the watershed if gone untreated; and 3) assessing the functional mechanisms and limitations of available treatment practices.

**Transport and Fate of Phosphorus in Stormwater Runoff**

The transport and fate of a pollutant describes the migration and possible altered chemistry resulting from prevailing chemical conditions. To determine which mechanisms will be effective in removing a given pollutant, its transport and fate in stormwater runoff must be understood. Considerable hydrologic variation exists when considering stormwater runoff characteristics during a rain event or between successive rain events. Transport of sediment becomes rather complex when considering the resulting variable rain intensity, runoff rate and volume, and pollutant load generation during antecedent conditions. Considering this variability, research over the decades have provided a better understanding on how best to treat sediment in stormwater runoff through a variety of practices. Sediment has been generally thought of as the surrogate of stormwater pollutants, and is identified and is often quantified as Total Suspended Solids (TSS), or Suspended Sediment Concentration (SSC). Sediment fate remains virtually unchanged as it is not impacted through water chemistry changes typical in stormwater.

However, when considering phosphorus transport, water chemistry adds an additional level of complexity that alters the fate and ability to capture and retain this critical pollutant.

Phosphorus is commonly quantified in two forms: Total Phosphorus (TP) and Dissolved Phosphorus (DP). TP accounts for both particulate-bound phosphorus and all forms of DP. DP comprises a large portion of the bio-available phosphorus, also known as soluble reactive phosphorus or the "quick sugar" for algal blooms. Measurements of orthophosphate,

$HPO_4^{-2}$ and $H_2PO_4^{-1}$ are commonly used to quantify DP. The TP and DP speciation are site, watershed, land use, water chemistry and time sensitive. This sensitivity results in an even more dynamic transport and fate of phosphorus from site to site, event to event, and water body to water body. Partitioning of TP in rainfall runoff between the particulate-bound and DP fractions can vary from 20% to more than 90% (NYS DEC, 2008). Phosphorus partitioning from urbanized settings (residential and commercial) where characterized within the New York State Department of Environmental Conservation Stormwater Management Design Manual as listed in Table 1. Table 1 quantifies the partitioning of phosphorus by land use, suggesting that generally half of the phosphorus load in runoff from residential and commercial sites is particulate-bound, with slightly larger particulate-bound fractions likely in runoff from industrial and open space areas.

Other research has quantified the transport of particulate-bound phosphorus by the particle size of suspended solids in runoff. The outcome of the research identified that particulate-bound phosphorus is largely concentrated on the finer fraction of suspended sediment from 1 to 25 µm (Madge, 2004 and Vaze et al., 2004). Research conducted by Vaze (2004) on an urban road surface suggested that less than 15% of TP was attached to sediment particles greater than 300 um, while 20% to 30% was in DP form. Results from testing of a residential site (Madge, 2004) found that the majority of phosphorus was attached to particles in the range of 5 to 20 um. The DP fraction made up only 20% of the TP load, with 96% of the dissolved phosphorus being determined to be bio-available. Both studies concluded that BMPs capable of removing and securing smaller sized particles provide effective TP treatment by capturing a high percentage of particulate-bound phosphorus. Additionally, the research indicates that treatment focused on capture of particulates does not address DP removal nor the bio-availability of phosphorus.

It is important to recognize that phosphorus fate will shift speciation as water chemistry conditions (pH, alkalinity, temperature, redox potential, concentration, etc…) naturally change in stormwater runoff and treatment systems. These shifts in speciation may occur both during the transport and/or storage of particulate-bound phosphorus within the conveyance and treatment structures, such as piping, detention/retention facilities, settling basins, and filtration/infiltration treatment practices. Speciation shifts may result in particulate-bound phosphorus re-solublizing into DP and becoming readily bio-available. Despite having been previously captured in the particulate-bound form, phosphorus that has transitioned to a dissolved form has high propensity to be carried downstream into a surface water body to feed algal growth.

**Current Phosphorus Removal Targets**

Several State-level stormwater guidelines suggest an effective stormwater treatment practice, considered a “stand-alone practice”, captures a minimum 80% TSS and a minimum 40% TP on an average annual basis (MDE 2000, MOE 2003, NYS DEC 2003). New regulatory requirements have begun to be adopted that specify a higher degree of phosphorus removal. For example, Maine and specific regions in New York State are targeting 65% TP removal, but neither specifically addresses DP removal. Virginia is more aggressively addressing nutrient capture from stormwater by working towards implementation of a post-development TP pollutant load limit of 0.28 pounds per acre, per year. Nonetheless, these requirements may be inadequate to improve the quality of threatened or impaired water bodies if the ratio of particulate-bound and bio-available dissolved phosphorus is not considered.

A compilation of previous stormwater research on many conventional stormwater treatment practices commonly implemented to achieve 80% TSS removal (dry ponds, wet ponds, wetlands, filtrating and bioretention practices) were extracted and analyzed from the National Pollutant Removal Performance Database (CWP, 2007) in Table 2, and presented in Figure 1. The information data set for each of these practices demonstrated variable phosphorus removal rates, and highlighted difficulty in achieving greater than 65% TP removal. Additionally, median performance reviewed indicated *all practices excluding wet ponds and infiltration indicated variable or even negative soluble phosphorus removal.*

**Conventional Phosphorus Removal Mechnisms**

Through analyses of hydrology, it has been recognized that small storm hydrology naturally dominates the volume of runoff accumulated on an annual basis. For treatment practices to be effective they need to address smaller storms as these generally contribute the majority of the annual pollutant load (Pitt, 1999). Most current North American stormwater treatment regulations drive towards treating a required water quality volume ($WQ_v$) of 80% to 90% based on local historical rainfall records. This provides comfort that the majority of the pollutant load (sediment basis) will be treated to the maximum extent practicable (ASCE and WEF, 1998; USEPA, 2004, MOE, 2003).

Considering the dynamic transport and fate of phosphorus, relying solely on these water quality volume principles will not provide effective results. To achieve high levels of phosphorus removal required to address a TMDL for an impaired water body, not only does the water quality volume need to be considered, but so do several other parameters which impact phosphorus removal, such as: (1) the mechanisms, capacities, and limitations of unit operations and processes (UOPs) of treatment practices; (2) recognition that the transport and fate of phosphorus is dynamic and speciation changes over time; and (3) ensuring regular maintenance to remove sediment and particulate-bound phosphorus, not only to ensure systems are functioning as designed, but also to help mitigate phosphorus from re-solublizing into DP and transporting downstream.

Well-recognized mechanisms employed to capture particulate-bound phosphorus are UOPs of sedimentation and filtration. Sedimentation has been heavily studied, and when using this mechanism alone in stormwater treatment practices significant limitations are encountered in regards to removal of finer particulates, especially with under-sized facilities. Limitations can be mitigated through proper basin design, or within proprietary practices through proper sizing and accounting for a realistic particle size distribution (PSD) that includes the finer fraction of sediment. For sedimentation practices to be effective they need to demonstrate capture of a finer fraction of particles and be able to retain the material and prevent re-suspension. The preventative design feature of incorporating an effective sedimentation basin bypass is often overlooked with smaller conventional and proprietary practices, to the detriment of overall performance and system capability.

BMPs with UOPs of filtration, including infiltration, are generally more effective for capturing the finer fraction of particulates in addition to the coarse fraction. However, system design needs to consider clogging or plugging of the filtering surfaces. Pretreatment using sedimentation can be effectively implemented to remove settleable solids and gross pollutants prior to the filtration and infiltration practice, improving performance while extending the maintenance interval. Overall, filtration practices generally have a higher TP removal rate as compared to sedimentation practices, but most do not effectively remove DP.

Management and maintenance of all unit operations, including physical, chemical and biological processes, are critical to ensure removal of phosphorus from stormwater (Strecker et al., 2005). Without regular removal of phosphorus-laden particles, a system may be vulnerable to a phosphorus speciation shift, and release of DP downstream.

**Evaluating Dissolved Phosphorus Removal Performance**

In order to address impaired water bodies, higher levels of phosphorus removal are necessary to begin to make a positive impact. Establishing effluent load reduction targets are more appropriate for achieving the objective, however many State requirements dilute the impact of such targets by simply requiring a higher % TP removal, while neglecting to address removal of the bio-available DP fraction.

A method that has been considered for increasing TP removal is increasing the required treated annual $WQ_v$, with the assumption that treatment practices are appropriately sized to manage the runoff peaks and total volume. This action will incrementally treat additional volume and incrementally increase particulate-bound phosphorus removal. In many cases, this action may not be viable and may be a costly solution due to land availability, capital costs and maintenance feasibility. Increasing the annual treated $WQ_v$ does not change the removal mechanism, and does not impart a mechanism to directly address DP removal. Additionally, there is risk with the increased volume, if detention and storage is part of the practice, that these systems will undergo natural water chemistry changes which can transform captured particulate-bound phosphorus to the dissolved phase, which will then be carried downstream, worsening the situation.

The earlier referenced studies by Madge, 2004 and Vaze et al., 2004 suggest that in order to consistently achieve higher levels of TP removal (> 65%), treatment practices need to not only remove particles as small as 11 µm, but must also capture and retain a significant fraction of the DP. In order to address the dissolved phase of phosphorus, advanced mechanisms must be implemented as part of, or in addition to, conventional stormwater treatment practices.

One advanced mechanism for treating DP is sorption, which is beginning to be incorporated into some proprietary and non-proprietary stormwater treatment practices.

Sorption is a combination of physio-chemical interactions including; adsorption, absorption and surface complexation, often referred to as adsorption. The sorption mechanism has been utilized for decades in industrial air and water treatments. Materials, or media, utilizing sorption have pollutant removal capacities that are specific to a given pollutant under defined conditions, and such capacity must be thoroughly understood in order to predict media performance and service life. A rigorous media performance analysis is required and should be based on in-depth testing of adsorption isotherm, reaction kinetics, breakthrough, and desorption (Wu et.al., 2008).

Media characteristics such as specific surface area, porosity, organic content and gradation are also important, but do not indicate a media's ability to capture and retain dissolved pollutants. To properly and successfully implement the use of sorption-based materials all four descriptive performance parameters (adsorption isotherm, reaction kinetics, breakthrough, and desorption) must be understood, as each are interlinked.

Adsorption isotherm quantifies the available sorption capacity of media for a given pollutant for a known quantity of media and volume of solute over a fixed period of time. Testing is performed under controlled conditions over a wide variety of pollutant concentrations, allowing for an isotherm model to be generated. Often for water treatment media, the Freundlich isotherm is utilized to model media performance due to the heterogeneous nature of the material. This performance indicator assessed alone will be misleading as contact time for this test parameter is fixed and maximized, which is certainly not the case in stormwater treatment.

Reaction kinetics illustrates performance over a variety of contact times. This evaluates how fast pollutant sorption takes place with a given media mass, known volume of solute and pollutant concentration. Without sufficiently fast kinetics, a material may have high available sorption capacity but still requires a very large volume of media to achieve its removal due to poor kinetics. This may not be a practical or cost effective solution as larger volumes of media will consume significant land space to treat swiftly flowing runoff.

Breakthrough indicates the volume of polluted water that can be treated by a quantity of media while still providing the target degree of pollutant removal. In more practical terms, breakthrough illustrates long-term performance and determines the service life of the media. Water containing a known pollutant concentration is passed through a known mass of media at a given surface loading rate. Samples are analyzed for pollutant removal efficiency as the total treated water volume increases. Breakthrough is best quantified by the volume of pollutant laden solute which has passed through a given volume of a media bed, known as Bed Volumes (BV). One liquid BV equals an equivalent volume of media. Performance can then be quantified by the number of BVs, or total volume passed through the media before pollutant removal efficiency drops below a pre-specified level. For example, 50% breakthrough would indicate the number of BVs of solute treated before a single BV of media no longer achieved 50% pollutant removal. The breakthrough evaluation should be taken to exhaustion (0% removal), as this indicates how long the media can last and the rate of performance decline.

Desorption demonstrates the tendency for a given media to desorb, or release, a given pollutant that is naturally occurring in the media, or to desorb the pollutant of interest (e.g. phosphorus) after the media reached its full capacity. This test can be conducted by extending the breakthrough evaluation beyond exhaustion and determining if the effluent concentration of the pollutant increases above the influent.

Without this full array of performance metrics clearly defined, claiming the ability to remove a given dissolved pollutant such as phosphorus may lead to false expectations of performance. Often filtration media are marketed by highlighting a media's capacity value (mg/g) to retain a dissolved pollutant. A capacity value (mg/g) is meaningless if the testing conditions are not stated, and if breakthrough (longevity) and kinetics are not evaluated and clearly understood. Additionally, relying only on surface area or porosity data is misleading as well.

For example, many stormwater practices have incorporated granulated filtration media such as perlite, blends of perlite/zeolite/carbon, organic-based media, expanded aggregates, slag-based materials or other by-products such as recycled tires, and even bioretention soil mixes to filter out sediment and sediment-associated pollutants, while claiming the ability to also capture phosphorus. However, these materials have been found to have very limited phosphorus treatment performance as they lack either sufficient DP sorptive capacity, kinetics, or phosphorus capture longevity, BVs (Wu et.al., 2008). It is possible for a media to have sufficiently high sorption capacity as indicated by an isotherm and sufficiently fast kinetics, but poor breakthrough (e.g. expanded shale, bioretention soil media), which renders the media unacceptable from a longevity standpoint. It is also possible to have a high specific surface area but virtually no capacity at all for dissolved phosphorus (e.g. granulated carbon, zeolite, or perlite).

Some filtration materials have demonstrated desorption of phosphorus from the fresh filtration media (e.g. some composts, organics and expanded aggregates). Other media such as slag-based materials and granulated tires are known to have a tendency to leach other pollutants of concern (e.g. metals, pH). Recycled media, which are often waste by-products and sometimes marketed as "green technology", may contain debris or potentially leach toxic pollutants that become apparent when tested in stormwater of typically low background pollutant concentration (Minton, 2005). One study documented activated aluminum and expanded shale leaching heavy metals or changing the pH (Patel, 2004) of the effluent. These materials have been found not to be effective in addressing the higher phosphorus removal standards (> 65% TP), nor a phosphorus TMDL.

Current and newer stormwater practices are generally designed to maximize the hydraulic surface loading rates of BMPs to effectively manage and treat the prescribed $WQ_v$. To achieve this while still physically filtering or straining sediment from runoff, high flows are often hydraulically loaded through filtration media (1 mm to 10mm) such as perlite, blends of perlite/zeolite/carbon, ASTM C-33 sand (0.1 mm to 10mm) or through practices that use sandy soils. Soils and agricultural research have identified that sandy soils have low adsorptive capacity for phosphorus, and have greater tendency to desorb phosphorus that is adsorbed below the root zone into surface water through subsurface flow when saturated (Havline, J. . 2004). Similar findings have been found for some clay soils through transport in macropores (Djodjic et al., 1999; Laubel et al., 1999).

Low capacity, desorption and leaching of phosphorus from these filtration media types are a significant limitation on current practices. An alternate mechanism to capture phosphorus has been biological uptake used for design of wetlands, and recently for bioretention cells. Limitations exist with biological uptake, such as dissolved phosphorus migrating past the limited root zone, or from lack of vegetative maintenance. As vegetation grows, pollinates, and dies, this cycle takes nutrient rich vegetation and re-emits these nutrients back into the growth media. These practices commonly use a sand-soil with limited to no dissolved phosphorus sorption capacity, hence there is a limited net impact if the vegetation is not continually harvested and managed. A combination of a wide variety of bioretention mixes, soil types and chemistry, and this vegetative cycle begins to explain the large variance in phosphorus removal performance, and at times phosphorus export from bioretention cells (Dietz et al., 2005, Hunt et al., 2006, Davis et al., 2006).

**Ameding Stormwater Practices**

Faced with an escalating number of eutrophied water bodies, and knowing that common stormwater treatment practices and system designs continue to provide insufficient phosphorus removal, it is sensible that proven high-performing sorption-based amendments should be applied to both new and existing BMPs to capture and retain dissolved phosphorus. Employing such amendments will drive elevated phosphorus removal performance, design requirements and improve water quality.

For many media, well-described behavior exists for phosphorus removal. Media that can cost effectively capture dissolved phosphorus commonly contain oxides of iron and aluminum, with aluminum oxides typically outperforming all other materials for dissolved phosphorus capture and retention (Wu et al., 2008). Amending treatment practices by incorporating proven sorption-based media into conventional stormwater treatment practices and LID applications will enhance phosphorus removal and elevate overall performance. As long as the performance description is well understood based on in-depth analyses of adsorption isotherms, reaction kinetics, breakthrough and desorption tendency, a system can be easily and properly designed to incorporate these advanced media types, with the ability to predict performance and maintenance frequency. Without a full performance description, stakeholders are "flying blind" when trying to use a filter media or material to capture dissolved phosphorus.

For example, sand has limited to virtually no sorption capacity for dissolved phosphorus. Amending a sand filter by displacing a sand layer (6-inches to 18-inches in depth) with a sorptive media of the same ASTM C-33 gradation would significantly compliment this treatment practice. Amendment by incorporating an advanced removal mechanism provides a tool to achieve significant enhancement of TP and DP removal, while maintaining hydraulic conductivity of the filtration bed. This eliminates the need to treat additional runoff volume with costly enlarged systems that take up more land area. Amending a conventional stormwater treatment practice provides elevated phosphorus removal performance while also fitting within the concept of LID, better site design (BSD), and environmental site design principles (ESD).

Another example would be to use a multi-inch layer of sorptive media as part of the bioretention cell or similar filtration cell to address the known DP capacity limitations of sandy-soils. Commonly these systems employ an under drain and do not capture DP. Sorption-based media can also be employed downstream of the under drain system to allow DP treatment of the bioretention cell's effluent after it has filtered alternate pollutants. This treatment train approach cost effectively takes advantage of the conventional treatment practice, but provides a tool for dissolved phosphorus removal. This treatment amendment may be necessary if trying to achieve a phosphorus TMDL of less than 0.1 mg/L.

This same amendment concept can be employed as part of a pervious pavement system, utilizing the sorptive media as part of the sub-base, or with permeable interlocking concrete pavers, utilizing this media as the joint fill and bedding layer. Alternatively, lightweight sorption-based media can be considered for green roof media, or incorporated into other landscaping features used to treat runoff.

These advanced sorption-based medias can be used in radial cartridge systems to capture TP, as well as DP. One study using aluminum oxide based sorption filtration media inside multiple radial cartridges demonstrated over 85% sediment capture, 70% TP removal and greater than 40% DP removal over a series of storm events, while being able to consistently achieve a TMDL of less than 0.1 mg/L TP (Liu et al, 2007). Additionally, retrofitting pre-existing stormwater infrastructure, including replacement of low-performance media in underground filtration cartridges and other filter systems is a viable option to address bio-available dissolved phosphorus.

**Conclusion**

Phosphorus induced eutrophication continues to degrade freshwater resources globally, as evidenced by increasing incidents of toxic algae blooms, hypoxic conditions, and aquatic ecosystem stress. Phosphorus loading in runoff has not been adequately addressed by conventional treatment approaches. Common stormwater treatment practices, designs and regulations are deficient in regards to capturing bio-available dissolved phosphorus.

To make the necessary progress in protecting our recreational and drinking water resources, and to have the ability to achieve a phosphorus TMDL of 0.1 mg/L or lower, the use of high-performance sorption-based media should be considered for incorporation into conventional and proprietary stormwater treatment practices, further driving the concepts of LID, BSD, ESD. Aluminum oxide-containing media, supported by well-defined performance testing, shows particular promise for cost-effective total and dissolved phosphorus removal. Without addressing bio-available dissolved phosphorus through practice, amended design and regulatory requirements, our water resources will continue to degrade.

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Table 1. Phosphorus Concentrations in Runoff by Land Use (NYS DEC, 2008).

| | Residential | Commercial | Industrial | Open Space |
|---|---|---|---|---|
| Average TP, mg/L<br>(Number of Observations) | 0.41<br>(963) | 0.34<br>(446) | 0.45<br>(434) | 0.59<br>(46) |
| Average DP, mg/L<br>(Number of Observations) | 0.20<br>(738) | 0.18<br>(323) | 0.16<br>(325) | 0.16<br>(44) |
| Approximate % TP | 51 | 47 | 64 | 73 |
| Approximate % DP | 49 | 53 | 36 | 27 |

Table 2. BMP Removal Efficiency Statistics from the Analyses of data from the National Pollutant Removal Database, Version 3 (CWP, 2007).

| Pollutant Median Removals | Dry Ponds | Wet Ponds | Wetland | Filtering Practices | Bio-retention | Infiltration Practices | Open Channel |
|---|---|---|---|---|---|---|---|
| TSS %<br>(number of observations) | 49<br>(10) | 80<br>(44) | 72<br>(37) | 86<br>(18) | 59<br>(4) | 89<br>(4) | 81<br>(17) |
| TP %<br>(number of observations | 20<br>(10) | 52<br>(45) | 48<br>(37) | 59<br>(17) | 5<br>(10) | 65<br>(8) | 24<br>(16) |
| Soluble P %<br>(number of observations | - 3<br>(6) | 64<br>(28) | 25<br>(26) | 3<br>(7) | -9<br>(5) | 84<br>(4) | -38<br>(14) |

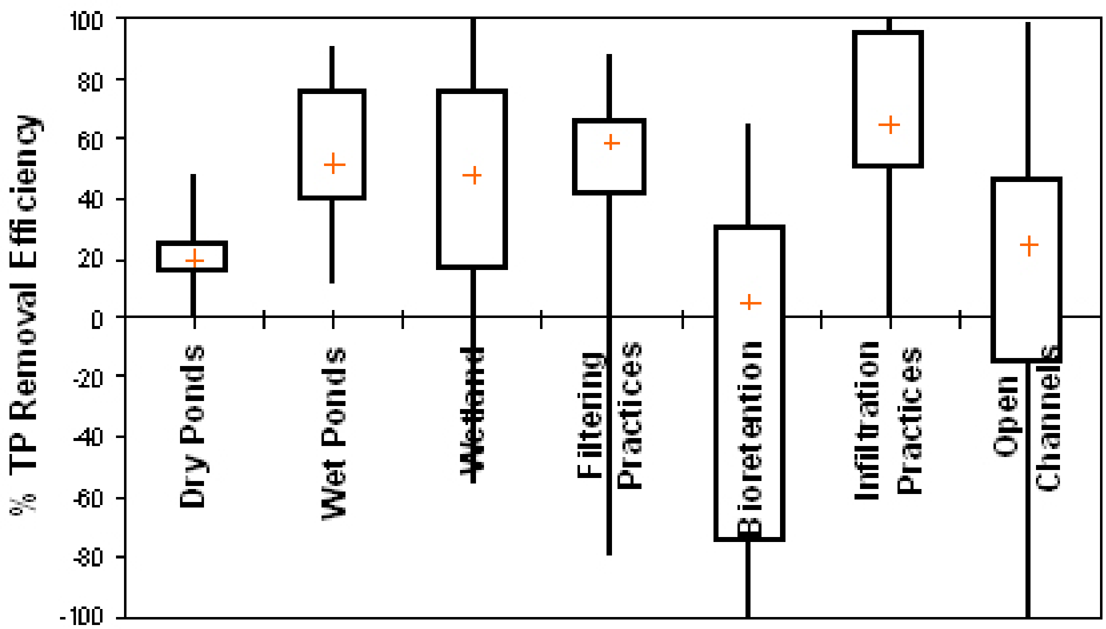


Figure 1. BMP Total Phosphorus Removal Efficiency Analyses of data from the National Pollutant Removal Database, Version 3 (CWP, 2007)

# Watershed Assessment and Education

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The Coles Creek Watershed, located in the southwestern quadrant of the state of Mississippi, is listed under the US EPA impaired water section 303(d). Degradation of the ponds/lakes and streams/creeks in this watershed is caused mostly by biological impairment, followed by nutrients, organic enrichment or Low Dissolved Oxygen, sediment/ siltation, pesticides, and pathogens (US EPA, 2007). Water samples will be collected from waterbodies in the Coles Creek watershed for physical, chemical, and biological analysis. Sampling will be conducted every month over a 12- month period to evaluate the spatial and temporal variability of water quality. Positions of sample locations will be geo-referenced to be displayed on a map using ArcView. In addition, soil and rainfall data will be used to study the correlation between land-use and water quality. The analysis of the results will help us to better understand the quality of water in the watershed. Results will also help us to determine the best alternative management practice(s) to be adopted and implemented in the community. Based on the results and findings, educational materials will be developed and disseminated to the communities. This effort will help increase the community awareness of their environment and encourage them to adopt and implement BMPs on their land which will lead to promoting environmental health and its sustainability, thereby, having good water quality to support the economic development in the area.

Key words: Education, Non-point Source Pollution, Nutrients, Surface Water, Water Quality

# Water Quality Assessment in the Town Creek Watershed, Mississippi

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William H. McAnally, Mississippi State University
James L. Martin, Mississippi State University

Surface water quality is deteriorating around the world at an increasingly alarming pace. The majority of the incidences from nutrient impacts are primarily occurring in areas with increased development. Town Creek Watershed is located within the Tombigbee River Basin representing 50% of the Upper Basin and is approximately 10% of the entire Tennessee-Tombigbee Waterway Watershed. Town Creek watershed directly contributes to the Aberdeen pool on the Tennessee-Tombigbee Waterway. Data relating sediment and nutrients concentrations and discharges after 1994 are not available for most of the watersheds within the Tombigbee River Basin. The objective of this study is to provide valuable water quality data for the upper Tombigbee Watershed. The study area included four of the five sub-basins within Town Creek that according to the EPA and MDEQ are biologically impaired due to sediment and nutrients. The study monitored the water quality conditions in the major tributaries of Town Creek Watershed. Grab samples and *in situ* measurements of water quality parameters (dissolved oxygen (DO), temperature (T), electric conductivity (EC), turbidity, and pH were taken at 24 stations with 7 along the principal channel within the study area. The collected water samples were analyzed for total phosphorus (TP), dissolved reactive phosphorus (DP), and suspended sediment concentration (SSC). Preliminary results for the monitoring period of May 2008 to February 2009 showed mean values for T, pH and EC of 23 ºC, 8, and 343 mS $cm^{-1}$, respectively. DO concentrations and turbidity levels showed mean values of 6.4 ppm and 14 NTU, respectively. Phosphorus and sediment concentrations presented mean values of 0.07 mg $L^{-1}$, 0.12 mg $L^{-1}$, and 19 mg $L^{-1}$ for DP, TP and SSC, respectively. Significant levels of impairment on water quality were observed at sampling stations surrounding and receiving water from the urban area (City of Tupelo and Plantersville plants of water treatment). The most important source of SSC was the area under construction for the Toyota Assembly Plant at Blue Springs, MS. Tributaries downstream of the Town Creek at the Brewer Rd site were not important contributors of sediments and P; however, they do contribute a significant volume of flow allowing for a dilution effect that kept constant the mean SSC. Considering the 0.1 mg-TP $L^{-1}$ water quality criteria, the headwater areas were not impaired by P concentrations, while the tributaries near and after the urban areas presented P impairment showing mean concentrations values up to 1.2 mg-TP $L^{-1}$.

Key words: Water Quality, Non-point Source Pollution, Sediments, Nutrients

# Development of Water Correction Algorithm for Underwater Vegetation Signals

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The unique spectral characteristics of green vegetation, low reflectance in red and high reflectance in Near-Infrared (NIR), have been used to develop vegetation indices, such as Normalized Difference Vegetation Index (NDVI). Our preliminary studies suggest that NDVI was not a useful indicator for submerged aquatic vegetation (SAV), even in clear water, due to energy absorption by water in the NIR region. In order to improve the use of the vegetation indices, we modeled the depth-induced water absorption and scattering through a controlled indoor experiment. We used a GER 1500 spectroradiometer to collect spectral data over an experimental water tank (70cm tall, 50cm wide) that was deployed with a black panel or a white panel at a time; the panels were cut to fit the bottom of the tank. Our assumptions were: (1) the black bottom panel absorbs 100% incoming light; (2) the white bottom panel reflects 100% incoming light; and (3) the water volume scattering and absorption remains the same for the two conditions (black and white bottoms) at a given depth. The measured upwelling radiance was converted to % reflectance. We developed correctional algorithms for water scattering and absorption using the reflectance data. After finding the contribution of these features, we were able to remove the water effects from the measured data. The SAV reflectance that was corrected using the algorithm produced a spectral signature more closely resembling those of terrestrial vegetation. The application of the algorithm significantly improved the vegetation signals, especially in the NIR region. Our results suggest the conventional NDVI: (1) is not a good indicator for submerged plants even at shallow waters (0.3 m); and (2) the index values can significantly improve once the water effects are modeled and removed.

Key words: Methods, Models, Surface Water

## Introduction

Over the past three decades, satellite/airborne sensors have been utilized to collect land cover information as well as to provide insight into the objects and processes that occur within water bodies. In order to collect information and data through remote sensing, a substantial amount of electromagnetic radiation (EMR), either reflected or emitted from a target under investigation, need to be detected and recorded by the sensor.

When your target is an underwater object, the process becomes more complicated as the light energy (EMR) is absorbed by pure water. The water absorption increases with wavelength, which makes it virtually hard to detect signals within the Near-Infrared (NIR) regions. In addition, EMR signals from a natural water body contain information on the pure water properties (i.e. water surface reflectance, water column scattering), suspended inorganic/organic solids, phytoplankton chlorophyll and other pigments, colored dissolved organic carbon, and water bottom backscattering.

The unique spectral characteristics of green vegetation, low reflectance in red and high NIR, have been used to develop vegetation indices, such as Normalized Difference Vegetation Index (NDVI). Our preliminary studies suggest that NDVI was not a useful indicator for submerged aquatic vegetation (SAV), even in clear water, due to energy absorption by water in the NIR region. In this study, we applied a water correction model that was developed using our experimental data in an image taken over seagrass beds to see if the algorithm application would improve the benthic signals.

**Objective**

The objective of this study was to test our water correction algorithm using a hyperspectral airborne image for its preliminary validation. The algorithm was developed based on experiment-driven water absorption and scattering coefficients.

**Methods and Materials**

***Algorithm Description***

Indoor controlled experiments were conducted to collect water depth-variant spectral information over an experimental water tank (70cm tall, 50cm wide) that was deployed with a black panel or a white panel at a time; the panels were cut to fit the bottom of the tank. The data were collected using a GER 1500 Spectroradiometer, made by Spectral Vista Corporation. The unit has a spectral range from 350 nm to 1050 nm, internal memory of 500 scans, and a field of view (FOV) of 4° and 23° option with fiber optic. Our assumptions were: (1) the black bottom panel absorbs 100% incoming light; (2) the white bottom panel reflects 100% incoming light; and (3) the water volume scattering and absorption remains the same for the two conditions (black and white bottoms) at a given depth. The measured upwelling radiance was converted to % reflectance. Water volumetric reflectance (%) was calculated using the data collected over the black panel (bottom reflectance = 0); and the water absorption (%) was calculated using the reflectance values measured over the white panel (measured reflectance = incident light – total water absorption + bottom panel reflectance + water volumetric reflectance). As a result, we obtained the absorption and volumetric reflectance correction coefficients (%) within a depth range from 0 to 70 cm and within a wavelength range from 400 to 900 nm (Cho and Lu, in press).

***Algorithm Application***

In order to apply the algorithm in an image, we selected an area of Mission-Aransas National Estuarine Research Reserve in Texas, where seagrass is abundant and water is generally shallow (< 2 m). The image data were obtained by AISA Eagle Hyperspectral Sensor and preprocessed and distributed by University of Nebraska at Lincoln Center of Advanced Land Management Information Technology (CALMIT) in the fall of 2008. After preprocessed for atmospheric and geographic corrections, the image data had 63 bands within a spectral range from 400 to 970 nm with a spectral resolution of 2.9 nm and a spatial resolution of approximately 1 m. The general coordinates for the image subset that we used are 685627.21 E and 3089698.35 N meters in the UTM Zone 14 North.

We conducted a spectral subset to include only the five hyperspectral bands that have been proven to contain critical vegetation information from our previous studies (Cho et al. 2008). The five bands are centered at 553.9, 694.6, 722.9, 741.7, 808.8 nm. In the ERDAS Imagine 9.1. Model Builder, we separated the five bands from the input (original) image, applied the correction algorithm using the appropriate coefficients for each of the wavelengths, then re-stacked the bands to create the output (water effect corrected) five-band image (Fig. 1). Using ENVI 4.1, the two images were opened and linked to compare the spectral profiles of the seagrass beds.

**Results and Discussion**

The original and the corrected images are shown in Fig. 2. The images are shown using the color infrared composite (Red: 722.9 nm; Green: 694.6 nm; Blue: 553.9 nm). The dominant color of the original image is blue (Fig. 2), indicating that the energy reflected at 553.9 nm much exceeded that at 722.9 nm or at 694.6 nm. The pink dominated colors of the corrected image indicated the relative reflectance of the bands have been changed. When spectral profiles of selected seagrass pixels were viewed (Fig. 3), it is evident that the application of the algorithm improved the vegetation signals, especially in the red and NIR regions. The digital number (DN) values for the original bands were % reflectance X 10 and the corrected image has the DN values representing % reflectance. Our results suggest the red and NIR signals from benthic features of a relatively clear, shallow water body can be improved significantly once the water effects are modeled and removed.

**Acknowledgements**

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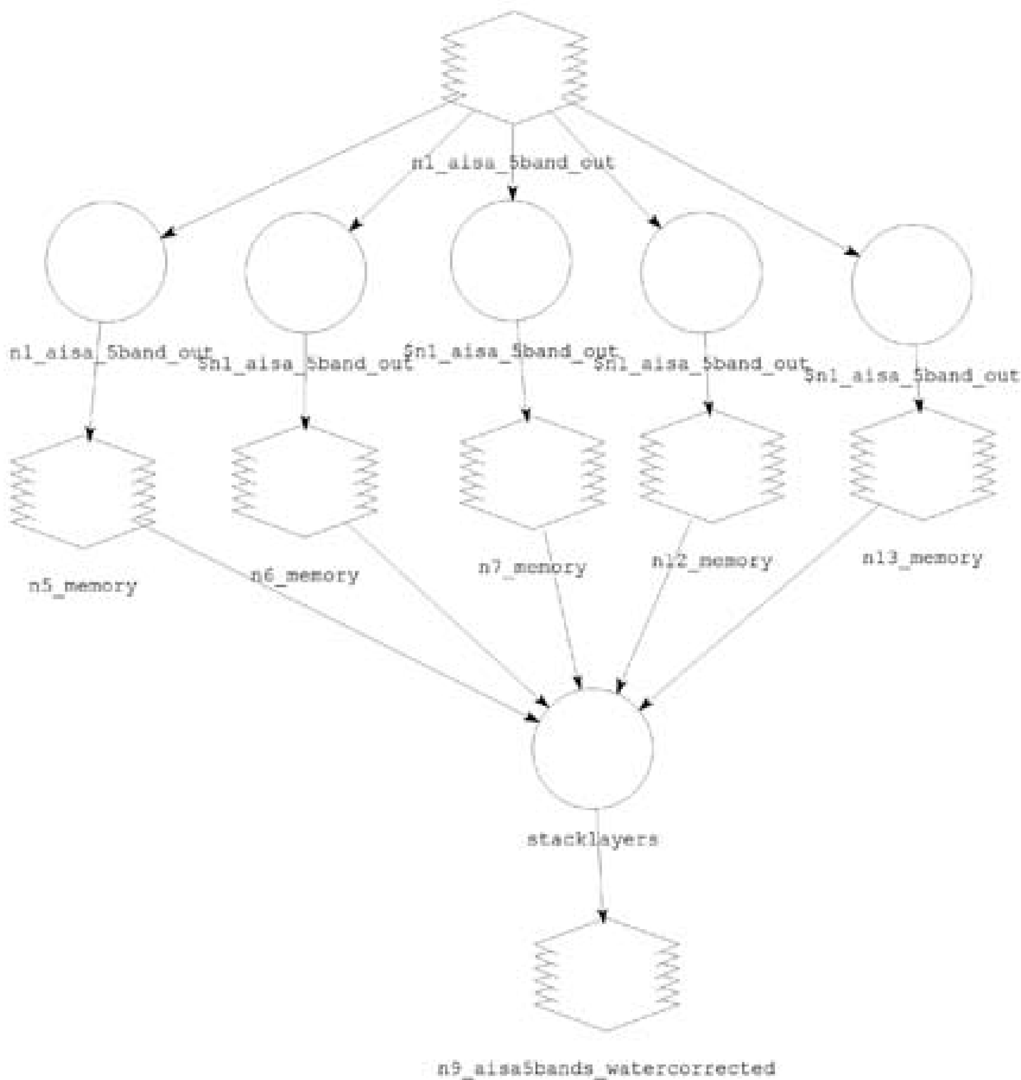


Figure 1. A schematic algorithm application using a five band image data in Model Builder of ERDAS Imagine 9.1.

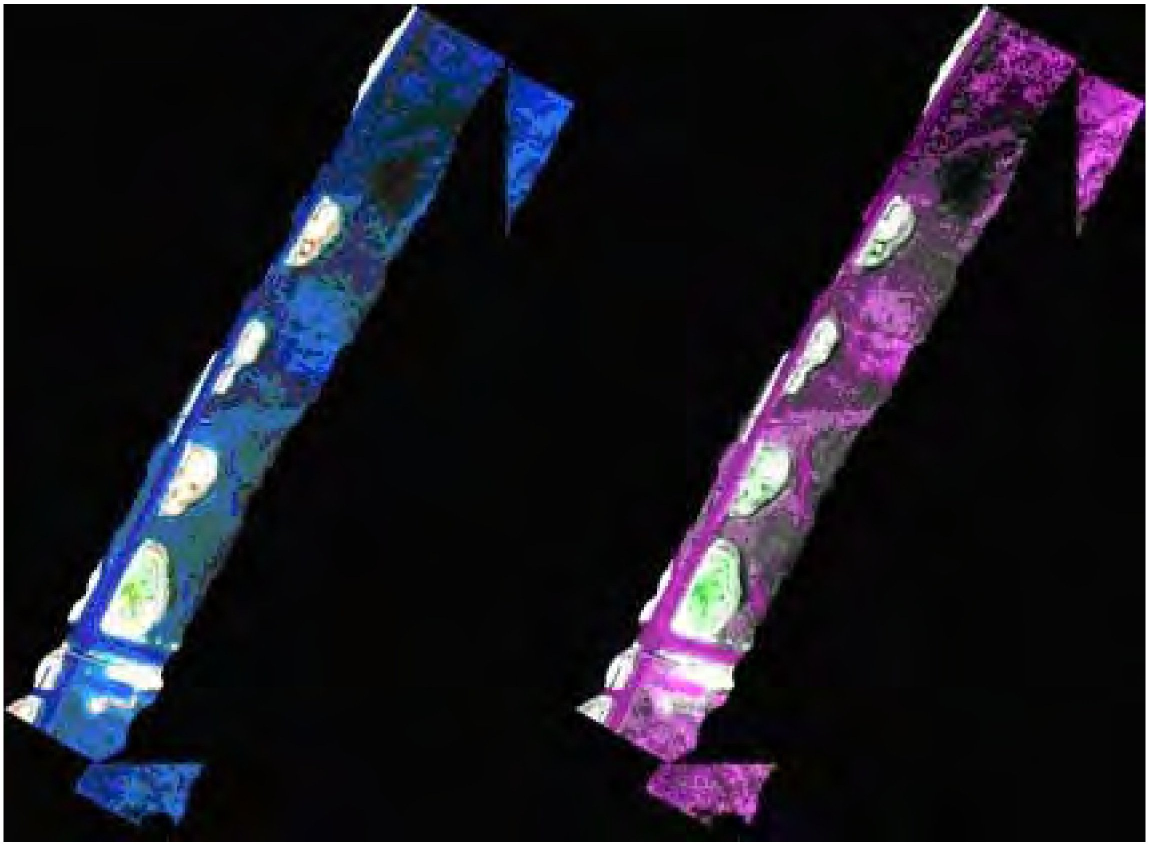

Figure 2. The original (left) and the corrected (right) subset image of airborne AISA data obtained over seagrass beds in Mission-Aransas National Estuarine Research Reserve, TX.

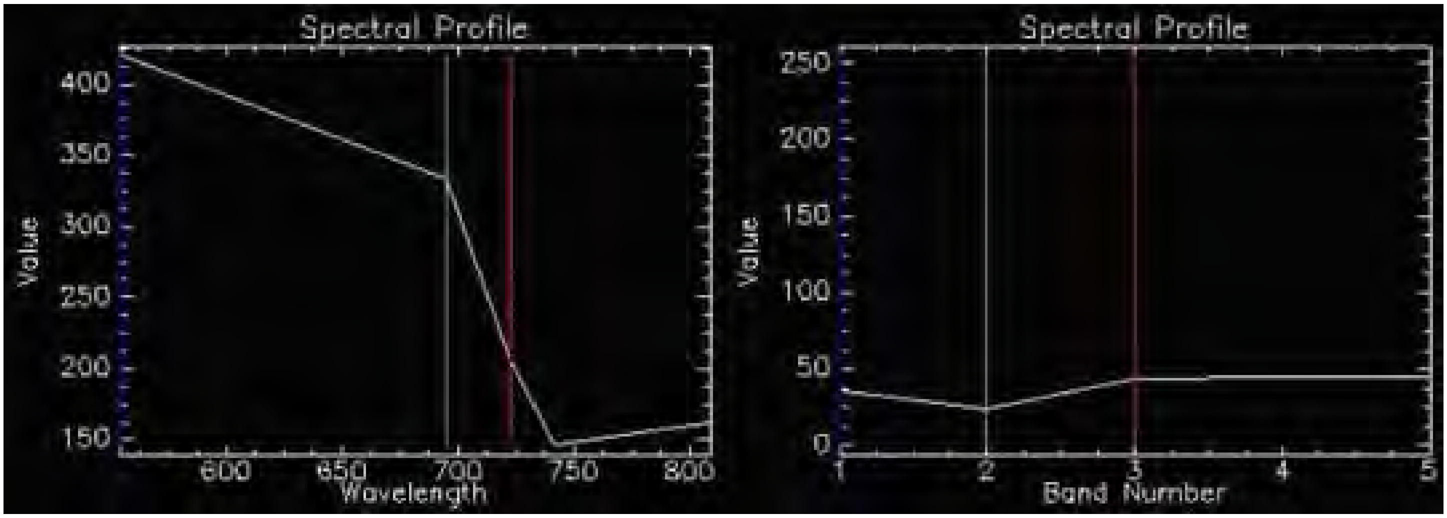


Figure 3. Spectra profiles of a selected seagrass pixel. The left is the original spectra profile and the right shows the profile after the correction using the algorithm.

# Monitoring and Statistical Analysis of Fecal Indicator Bacteria in Lower Sardis Lake, Mississippi

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The quality of a recreational water body is usually assessed by quantifying fecal indicator bacteria (FIB) in the water. FIB are groups of bacteria that together may indicate the presence of pathogens and have been strongly correlated with diseases contracted by swimmers in recreational waters. A two-week monitoring event was conducted in the summer of 2008 at 10 locations in the Lower Sardis Lake in northern Mississippi. Samples at selected beaches and embayments were collected and analyzed for total coliforms, *E. coli*, temperature, dissolved oxygen, nitrate, phosphate, and phenols. Concentrations of the FIB *E. coli* were generally below the U.S. Environmental Protection Agency (EPA) criterion of 126 per 100 mL for swimming freshwaters, which is consistent with previous research that attributes high FIB concentrations to large urban centers and not rural areas, such as the field location of this study. However, higher concentrations than the EPA criterion were found in lake water near a residential area and at an embayment with presence of wildlife. Further, results from creek sampling at a nearby town indicate consistently high *E. coli* concentrations at a geometric mean of 424 per 100 mL. Given the incidences of higher than standard FIB concentrations, statistical analyses were conducted to relate FIB concentrations to days of high-swimmer visits, presence of nutrients, and location.

Key words: Methods, Nonpoint Source Pollution, Nutrients, Recreation, Water Quality

# Runoff Modeling of the Luxapallila Creek Watershed Using Gridded and Lumped Models

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The Northern Gulf Institute is funding a project focus in improving watershed-wide decision support for resource management agencies; one of the tasks in this project is define the sensitivity of rainfall-runoff results to use of advanced tools, such as the Corp's distributed hydrologic model Gridded Surface Subsurface Hydrologic Analysis (GSSHA) and the EPA Hydrologic Simulation Program – FORTRAN (HSPF). GSSHA is a physics based watershed model simulating 2D overland flow, 1D channel flow, and surface water/groundwater interaction. The HSPF software is a conceptual, continuous, lumped parameter watershed model that has been extensively used around the world since 1980. This study evaluates the GSSHA and HSPF runoff performance in the Luxapallila Creek watershed, Alabama and Mississippi. The 1,851 $km^2$ watershed drains into the Tombigbee River. Six NOAA raingauge stations are used as hourly input precipitation. Land use distribution using the 1980 GIRAS database shows 73% forest, 20% agricultural land, and 6% wetlands. USGS 30-m resolution digital elevation models (DEMs) are used to delineate and calculate physiographic parameters (e.g., area, slope, and length of slope). The State Soil Geographic (STATSGO) database depicts mainly sandy loam soils. The GSSHA model grid size is 100 m x 100 m, resulting in 185,816 grids. The HSPF model is divided in 50 subwatersheds. Daily streamflow data collected by the USGS at the 02443500 station are used for model evaluation. The Web-based hydrograph separation system (WHAT) is used to calculate runoff and baseflow from observed streamflow data. Observed and simulated runoff data are evaluated using the following statistics: peak error, volume error, flow error, and peak time error. Four storm events are analyzed for the period 01/01/1989 to 03/31/1989. GSSHA peak, volume, and flow errors were around half of HSPF results. Both models showed ahead peaks of one day. However, the GSSHA model results matched the peak of two out of four storm events. The HSPF model runs faster than GSSHA (5 seconds vs 20 hours). GSSHA and HSPF groundwater modules will be setup and evaluated.

Key words: Hydrology, Models, Surface Water

# Gulf Coast Watersheds and Water Education: Outreach Alignment and Best Practices

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Robert F. Brzuszek, Mississippi State University

Previous research (Fulford, Brzuszek, & Roberts, 2008) assessed the impact of ordinances, outreach, and enforcement on the resiliency of the northern Gulf Coastal watersheds. Four watersheds in Louisiana, Mississippi, Alabama, and Florida were selected, and 22 non-governmental organizations (NGOs) in the target watersheds were surveyed with regards to water quality monitoring, environmental education, and watershed management. Detrended Correspondence Analysis (DCA) revealed that the most relevant programs for each watershed varied. Whereas Tchefuncte/Bogue Falaya's NGOs (LA) tended towards a management plan, the Biloxi River Watershed (MS) focused upon conservation easements and managing land restoration. The Fish River Watershed (AL) exhibited more centralized efforts with a tendency toward conservation, partnerships, and policy. The New River Watershed (FL) was strongest toward development review and education. Our current research extended the results of this initial study to investigate how the focus of each watershed reflected or paralleled its state's educational goals, benchmarks, and grade level expectations. The educational programs were also analyzed for correspondence to the National Science Education Standards. We included those educational outreach programs aimed toward K-12 students, and analyzed the NGOs' educational products for alignment with state curricula and national science standards. Additional investigation of other watersheds' educational programs (e.g., Chesapeake Bay) provided benchmarks against which the northern Gulf Coast watershed programs were compared. Our research resulted in the identification and development of best practices for the implementation of effective Water Education programs that include ecology, water management, and water quality focus.

Key words: Conservation, Ecology, Education, Water Quality

## Introduction

Water education is important for all citizens, including school-age children who will undoubtedly interact with surface water, groundwater, pollution, and water conservation within their lifetimes. For citizens of Mississippi, water education topics also intertwine with the agriculture, aquaculture, and industry of the state. How well is water education represented in our state, in our neighboring Gulf Coast states, and across our nation? Are our 5th-grade students, 7th-grade students, or even 11th-grade students well informed so that, upon reaching adulthood, they can actively participate within their communities and make sustainable decisions with respect to pollution, storm water run-off, and groundwater extraction?

This research began as a collaborative effort between a landscape architect and a geoscience educator, who sought to determine the quality of water education in the Gulf Coast states of Mississippi, Louisiana, Alabama, and Florida. Our investigation probed the curricula in public schools that directly addressed water education, and the alignment of water education curricula with the National

Science Education Standards. Gulf Coast states' curricula and water education programs were compared also with benchmark programs in other states, including the Chesapeake Bay Foundation. A resultant model for best practices and effective water education within the public school system was developed.

**NGOs and Gulf Coast Watersheds: Relevant Programs**

Previous research on effective water quality programs underscores the role of non-governmental organizations (NGOs) in successful regional watershed programs (Wiley & Canty, 2003; Koehler, 2001). Beyond the US, NGOs also assume a role toward sustainable development and environmental education (Tilbury et al, 2003), and are viewed by some researchers as the organizations that may best counter the destructive features of modern society (Haigh, 2006). NGOs have been cited as "highly significant factors" in regional resolution of environmental problems (Hirono, 2007), and have become increasingly important within developing countries (Nomura et al, 2003).

Brzuszek et al (2009) investigated the role of NGOs within Gulf Coast watersheds. In Mississippi, Louisiana, Alabama, and Florida, four watersheds were identified (Figure 1), and 22 non-profit groups were surveyed. Five groups were surveyed in each state except Mississippi, which contributed seven NGO groups to the survey. Detrended Correspondence Analysis of the survey participants' responses, using CANOCO 4.55 software, revealed that NGOs' efforts varied across the Gulf Coast region.

Although the sample was not large enough to be conclusive, the researchers noted that relevant associations emerged for each watershed. While the New River Watershed (FL) focused on development review and education, the Fish River Watershed (AL) was more centered, with a tendency toward conservation, partnerships, and policy (Brzuszek et al, 2009). The Florida watershed included Apalachicola National Forest and Tates Hell State Forest, while the Alabama watershed includes a large national estuarine preserve. However, the Mississippi and Louisiana watersheds are primarily in private ownership. Therefore, differences emerged in the areas of concentration of the NGOs of these states. Biloxi River Watershed (MS) NGOs focused on managing land, restoration, and conservation easements, while the Tchfuncte/Bogue Falaya watershed (LA) efforts tended towards a management plan. Although the work of the NGOs is important in public education and sustainable development, several recommendations made by the Center for Watershed Protection (2006) in the Smart Watershed Benchmarking Tool were not employed or implemented by the Gulf Coast watershed NGOs. Importantly, one recommendation went unfulfilled: NGOs did not partner with schools to build watershed education into the curriculum.

**Science Reform and the National Science Education Standards**

How important is a science curriculum when educating our future citizens about the importance of water conservation and preservation? The American Association for the Advancement of Science (AAAS) initiated Project 2061 in 1985, when Halley's Comet last passed near Earth. The AAAS (1989) identified a core set of knowledge for science, mathematics, and technology that our next generation will need for scientific literacy upon Halley's return. The resultant Benchmarks for Science Literacy (AAAS, 1993) identified the science curriculum needed for all future Americans at the conclusion of grades 2, 5, 8, and 12.

The National Science Education Standards (NSES) grew from the AAAS' Science for All Americans and the Benchmarks for Science Literacy (National Committee on Science Education Standards and Assessment, 1996). Based on the learning theory of constructivism, the science education standards promote building scientific literacy on pre-existing knowledge, and rally against teaching isolated, memorized facts. Eight categories of science content standards were identified and developed, and include 1) Unifying concepts and processes in science, 2) Science as inquiry, 3) Physical science, 4) Life science, 5) Earth and space science, 6) Science and technology, 7) Science in personal and social perspectives, and 8) History and nature of science. These National Science Education Standards guide the science education for all students enrolled in US public schools. Whether water education enters the classroom in US schools is partially determined by how well any water education program aligns with these standards. Shepardson et al (2007) successfully illustrated how watershed study can be aligned with the NSES.

An examination of the content categories of the NSES revealed that there were several portals through which water education can be incorporated in US public schools. At all grade levels (categories K-4, 5-8, and 9-12), the Unifying Concepts and Processes category addresses systems, order, and organization into which the hydrologic cycle and subsequent study can be implemented. The Science as Inquiry category, by promoting "skills necessary for our students to become independent inquirers about the natural world" can also be a portal for teachers to incorporate water education in their classrooms. Both biological and geological sciences (Life and Earth and Space science categories) address some form of water education at various grade levels. In Life Science, early grades (K-4) study organisms and the environment, middle grades (5-8) investigate populations and ecosystems, while high school students (9-12) focus upon matter, energy, and organization in living systems. In the Earth and Space Science category, the youngest students (K-4) learn about the properties of earth materials, while the oldest students (9-12) focus upon geochemical cycles.

Not surprisingly, the best-fit category for water education within the NSES appears to be Science in Personal and Social Perspectives. Within this category, water education is a natural fit in the science curriculum at *all* grade levels: K-4 classrooms study types of resources and changes in environments; 5-8th graders study populations, resources, and environments, and 9-12th graders investigate natural resources and environmental quality.

### State Educational Competencies and Learning Expectations

Although the NSES provides the overriding science education content standards for the US public school system, the No Child Left Behind (NCLB) Act of 2001 required each US state to develop content standards. NCLB addresses accountability, teacher quality, and public reporting, with the directive that each state develop and establish a state-wide accountability system. While Reading/Language Arts and Mathematics were the first disciplines identified with NCLB, a newer law mandated "challenging science content standards by 2005-06." While the National Science Education Standards still provided the overriding guidelines, each US state developed individual science content standards, and was accountable for each student achieving at the proficiency level.

Therefore, we researched and examined each Gulf Coast state's curriculum, searching for classroom opportunities through which water education could be addressed in Louisiana, Mississippi, Alabama, and Florida. Were the efforts of the 22 NGOs surveyed in the original Gulf Coast watershed research (Brzuszek et al, 2009) finding a statewide classroom portal for dissemination of water education? The state curricula were retrieved online, and searched for any reference to water education. Through initial research, we discovered grades K-4 addressed only basic water concepts, and therefore we focused primarily on grades 5-8 and 9-12. Our search terms included aquatic organisms, aquifers, coastal loss, flooding, groundwater, infiltration, pollution, quality of water, run-off, soil erosion, Surf Your Watershed (EPA, 2009), urban development, total maximum daily loads (TMDLs), and any state-specific water feature we thought—and hoped—might be addressed in the public school classroom.

### Louisiana Grade Level Expectations

Of the four Gulf Coast states reviewed in this research, Louisiana rated an "adequate" science curriculum approach to water education. Several topics were addressed at the middle and high school levels, including aquifers, coastal loss, flooding, groundwater, pollution, water quality, and soil erosion (Table 1). Aquifers, groundwater, pollution, and soil erosion were covered in grades 5, 6, 7, and 8 for a reinforced curriculum on these topics, in the spirit of the constructivist learning theory which suggests building upon existing knowledge. Groundwater was also addressed in the biology core curriculum as well. Although Louisiana's benchmarks in grades 9-12 cover most of the water education information, there is also a disclaimer: "Warning: Benchmarks 9-12 need to be addressed if Earth Science is not offered at the high school level" (Louisiana Department of Education, 2008). Earth Science is not a required science in Louisiana schools.

**Alabama Science Standards**

Alabama's science curriculum standards focus upon only four of the water education topics we searched, although a few state-specific topics peripherally addressed water (Alabama Department of Education, 2006). In particular, Alabama content standards included coastal loss, flooding, groundwater, and water quality (Table 2). A curriculum search failed to reveal that any topics were covered at more than one grade level, so it appears that topics are introduced, but not re-addressed. Alabama incorporated the hydrosphere as part of the science curriculum in grade 6, included in Alabama's Content 5. Another Alabama-specific topic was "weather phenomena", addressed in grade 3 as part of Content Standard 12.

**Florida Sunshine State Standards**

Florida science content standards incorporate water education in the public schools using at least six content topics, including flooding, groundwater, pollution, water quality, soil erosion, and aquatic organisms (Table 3). Additionally, the topics of water quality and soil erosion are introduced and reinforced in more than one grade level. However, there is a 3-grade gap between the soil erosion content that is addressed in grades 4 and 7, and a 2-grade level gap between water quality content that is implemented in grades 7 and 9. Florida, like Alabama, also includes state-specific content on the water cycle at grade 5, and again at grade 6 (Florida Department of Education, 2005).

**Mississippi Science Competencies and Suggested Teaching Objectives**

How does Mississippi fare with water education in the school science curriculum? At first perusal, there appear to be nine topics that are introduced in Mississippi public schools from grade 4 through grade 12 (Table 4).

Additionally, state-specific topics in Mississippi include using maps to identify local watersheds and run-off patterns in grade 4 (Competency 5b, Mississippi Department of Education, 2001). Also in grade 4, conservation of water resources is included in the science curriculum (Competency 7b). Another Mississippi-specific topic is included in Aquatic Science: Competency 7c relates the contribution of aquatic technology to industry and government. Although Mississippi does not have a reinforced water education curriculum—topics that are addressed within one grade level are not reinforced in another grade level—the inclusion of many water education topics is encouraging at first appearance.

Unfortunately, Aquatic Science, Environmental Science, and Spatial Information Science are courses that are not required for students. Additionally, these courses are not offered in every public school district in the state of Mississippi. Although some water education topics are addressed with suggested objectives, the objectives are not required to be taught in Mississippi public schools. While competencies are required, objectives are only alternatives available to a teacher if 1) s/he has time within the curriculum to implement them, and 2) s/he is interested in implementing these specific objectives.

Therefore, in order to gain a more realistic view of water education in the state of Mississippi, we omit those topics that are not required as part of a competency, or topics that are only included as competencies in non-required science elective courses that are not taught in every school district in the state. Table 5 is the disappointing result.

**The Gulf Coast and Benchmark Water Education Programs**

Our review of the Gulf Coast states' science curricula revealed that, in the required science standards addressing water education content, Louisiana's curriculum is better than most. Not only are several water education topics addressed (7, when compared with 4 topics in Alabama, 5 in Florida, and only 1 topic required in Mississippi's science curriculum), but Louisiana's design has overlapping content in three topic areas for reinforcement of science content at different grade levels. However, even in Louisiana, several topics in water education are not addressed, and not all water content is reinforced through the grade levels.

We can conclude that the work of NGOs to promote healthy watersheds and environmental awareness is not affecting statewide changes in these Gulf Coast states. Although NGOs may make an impact locally with educational programs, this impact is in isolated areas, and is not being translated into a required state curriculum. Only with required grade level expectations, competencies, or state standards can we ensure that water education is being implemented in our public school systems. The requirements of No Child Left Behind leave public school teachers with few opportunities for scheduling alternative curriculum content and activities.

An idealized model for water education feedback (Figure 2) would involve the local watershed, communication of best practices and environmental awareness by the NGOs, implementation of water education into the public school classrooms, and educated students—our future citizens—who are aware of best water practices for their communities. What appears to be occurring, however, is lack of communication between the NGOs and the state educational systems, or a lack of translation between the effects of the NGOs and implementation of water education into required science content standards. We turned our investigation to the other states' curricula, and water education programs with national recognition.

### Chesapeake Bay Foundation

The Chesapeake Bay Foundation is recognized as one of the premier partnerships with water education as a goal. Established in 1998, the foundation includes formalized educational partnerships between Maryland, Pennsylvania, Virginia, Delaware, New York, West Virginia, Washington, D.C., and the US Environmental Protection Agency (EPA). An increase in K-12 watershed education programs that support watershed restoration protection efforts in each state is one of the foundation's main goals. Other goals include the creation of interagency education groups within each jurisdiction and a biennial education summit for non-profit and higher education institutions to share and develop formal assessment standards. The Chesapeake Bay Program partners, the National Park Service (NPS) and the National Oceanic and Atmospheric Administration (NOAA) develop strategies for both formal and informal education across the Chesapeake Bay watershed.

For K-12 students, the Chesapeake Bay Program partners provide curriculum-based environmental education programs throughout the watershed for traditional and field excursions (Chesapeake Bay Program, 2009). This is a three-pronged effort that 1) provides technical and financial assistance; 2) ensures that schools utilize the available expertise and resources for Meaningful Watershed Education Experiences (MWEEs); and 3) improves MWEEs through technological advances and Chesapeake Bay education summits. The MWEE is based on active-learning strategies, and seeks to provide experimental or investigative experiences for students that result in enhanced critical thinking. The Chesapeake Bay watershed and associated issues are incorporated in the participating state partners' curricula. Maryland's curriculum, for example, includes the evaluation of the interrelationships between humans, watersheds, and water quality (Table 6).

### Illinois Learning Standards Performance Descriptors

During the investigation of the state standards for water education, the Illinois' model revealed some excellent features that should inform the development of water education standards in the Gulf Coast states. The Illinois learning standards in science content addressed 5 topics in water education, including groundwater, pollution, soil erosion, Surf Your Watershed, and TMDLs (Table 7). Although only 5 topics are addressed, there is extensive overlapping of topic coverage in the various grade levels through which students matriculate.

Therefore, the Illinois Performance Descriptors (Illinois State Board of Education, 2001) are not notable for the total amount of water education content they address, but in the manner in which science content is covered in the classroom. The Illinois Performance Descriptors define stages, or performance levels, for the science standards that teachers have to address in their classroom. From Stages A through J, the performance levels increase in content rank from early elementary to late high school. Stages E, F, and G are covered in grade 6, while grade 7 includes stages F, G, H. Grade 8 reviews stage G, and implements stages H and I. Grades 9 and 10 cover stages H, I, and J, while grades 11 and 12 implement stages I and J. If the science curriculum is implemented in the manner in which it is written, Illinois teachers are expected to 1) review older content, 2) introduce new content and implement with saturation, and 3) scaffold to a higher level of content within one school grade. The subsequent grade level will review the previous year's content saturation level, and expand the content in an in-depth examination of the next stage (Figure 3).

**Model: Water Education Best Practices**

We originally identified search terms for water education incorporation in the curriculum. Thirteen search terms, and a state-specific features category were investigated in each Gulf Coast state's science content curriculum. The original 13 terms were not meant to be completely inclusive for water education, but were what we considered to be the most relevant terms for citizen understanding of water quality. Other than Louisiana, the Gulf Coast states we investigated did not incorporate even 50% of our "foundation knowledge" for water education. Water science content is notably absent from Gulf Coast states' science curricula.

Also absent in our research of Gulf Coast states' curricula, and even within our expanded research of water education curricula within all 50 US states, was consistency of water education study. The Illinois model offered a good method for reinforcement of water content in the public school system, but this method appears to be an exception rather than the consensus for water content implementation.

While there are notable organizations working diligently to address watershed and water quality education, we noted that the efforts of the initial 22 Gulf Coast NGOs had not resulted in a developed science curriculum for the individual Gulf Coast states. Some NGOs have, however, been quite successful for water education implementation, and a prominent exception is the Chesapeake Bay Foundation. Through the consortium of collaborating states and government agencies, a noticeable water education component is included in the science curriculum in the participating states.

From our exploratory research, we propose that a model for water education in public school systems should incorporate the best practices that we uncovered in this study, and focus upon three C's: Collaboration, Content, and Consistency. Watersheds and their partnering NGOs should collaborate with other watersheds, other states' NGOs, and science educators to develop appropriate water education curricula that can provide meaningful learning opportunities for their public school students. For example, all Gulf Coast states should be concerned with coastal erosion. A consortium of Gulf Coast states could produce a highly effective model for addressing the National Science Education Standards through water education—and particularly coastal erosion—which could be implemented in all coastal states.

It is productive for individual states to focus upon water issues relevant to their local communities, and implement these issues in the classroom through state science education standards. Place-based learning and incorporation of local environments tap into students' previous experiences and existing knowledge (Clary & Wandersee, 2006). However, we also think that a broad base within water education is important, and the content introduced in K-12 science classrooms should address multiple issues in water education content. Our 13 original search terms were not meant to be comprehensive for water education, and we were disappointed that most states incorporated fewer than half of these topics in their curricula. Water education that proceeds through only one or two isolated topics probably will not result in a well-educated citizen with respect to water quality. Our science classrooms will require a more in-depth approach to water education, and more inclusive water content.

While implementation of several water topics in the classroom will be an improvement in water education, we further advocate consistency in implementation of water content, across several grade levels. Following an introduction to science content, greater sustained learning for our future citizens will result when content is reviewed, and reinforced. The Illinois model seems to adopt this strategy.

**Discussion and Concluding Remarks**

Although water education is important for all citizens, it is not being adequately addressed in school science curricula by the vast majority of US states we investigated. For the Gulf Coast states, only a small amount of water education content is mandated through the state-required science content standards. Louisiana's students fared better than the other coastal states, but there is still important content in water education that is not being addressed: Louisiana only implements 7 of the 13 water topics we initially identified, or about 54%.

NGOs of the Gulf Coast watersheds had differing areas of concentration, which may be related to the types of properties included in their watersheds. However, regardless of each watershed's focus, the NGOs' efforts appear to be unrealized in more inclusive water education content, as part of their states' science curriculum standards, benchmarks, or competencies. While the efforts of NGOs may be contributing greatly to individual schools, counties, or parishes with respect to watershed and water quality education, there is little mandated water education inclusion at the state level. Without mandatory science content directives, water education is not assured of being included in all public schools within a state. More research is needed to ascertain the effects of NGOs on water education science content outside the Gulf Coast states.

We advocate that future efforts of watersheds, their associated NGOs, and interested environmentalists and educators include collaboration for implementation of water education in public schools through required science content standards. The National Science Education Standards should serve as the guiding policy for content implementation via the eight identified science content strands. Not only should water education be addressed with sufficient content, but the implementation of water education should be consistent over various grade levels for reinforcement. The collaboration, content, and consistency model may facilitate water education within our public schools, and perhaps result in greater scientific literacy of the general public toward water quality, watersheds, pollution, and other associated issues. For all interested in water education, this research indicates that our work is just beginning.

**Acknowledgements**

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Table 1: Water Education Content in Louisiana. Several water education topics are included in Louisiana's Comprehensive Curriculum (Louisiana Department of Education, 2008). Topics that are covered and reinforced at more than one grade level are highlighted in blue.

| Topic | Grade Level | Standard |
|---|---|---|
| Aquifers | 5-8 | ESS-M-A-10 |
| Coastal Loss | 8 | GLE 20 |
| Flooding | 6 | |
| Groundwater | 5-8, Biology core | ESS-M-A10 |
| Pollution | 5-8 | |
| Quality | 9-12 | SE-H-C1 |
| Soil Erosion | 5-8 | ESS-M-B3 |

Table 2: Water Education Content in Alabama. Only four of our water education search terms were included in Alabama's curriculum (Alabama Department of Education, 2006). The curriculum search revealed that each topic was only covered at one grade level, and was not subsequently reinforced.

| Topic | Grade Level | Standard |
|---|---|---|
| Coastal Loss | 6 | Content 2 |
| Flooding | 6 | Content 3 |
| Groundwater | Biology Core (9) | Content 14 |
| Quality | Biology Core (9) | Content 14 |

Table 3: Water Education Content in Florida. Six water education topics are introduced in Florida's state science curriculum (Florida State Department of Education, 2005). Topics that are covered and reinforced at more than one grade level are highlighted in blue.

| Topic | Grade Level | Standard |
|---|---|---|
| Aquatic organisms | 9-12 Life Science | SC.912.L. 17.3 |
| Flooding | 7 | SC.7.L.17.3 |
| Groundwater | 9 | SC.912.L.17.16 |
| Pollution | 7 | SC.7.3.6.6. |
| Quality | 7,9 | SC.7.E.6.6., SC.912.L.17.7 |
| Soil Erosion | 4,7 | SC.4.E.6.4, SC.7.E.6.6 |

Table 4: Water Education Content in Mississippi. An impressive nine water education topics are introduced in Mississippi's state science curriculum (Mississippi Department of Education, 2001). However, items marked with superscript 1 are not required courses, and are not offered in every school system in the state. Objectives are marked with superscript 2. Objectives are suggested for a classroom, but are not required to be taught.

| Topic | Grade Level | Standard |
|---|---|---|
| Aquatic Organisms | Aquatic Science[1] | Competency 2, 4 |
| Coastal Loss | Aquatic Science[1], Environmental Science[1] | Competency 6b,7; Competency 3e |
| Flooding | Aquatic Science[1] | Competency 6b, 7 |
| Pollution | 4, Aquatic Science[1] | Competency 7b, Competency 6a, c |
| Quality | 4 | Suggested objective[2] |
| Run-off | Aquatic Science[1] | Suggested objective[2] |
| Soil Erosion | 4, Aquatic Science[1] | Objective 5a[2], Competency 3 |
| Surf Your Watershed | 4, Aquatic Science[1], Spatial Information Science[1] | Objective[2] Competency 2 |
| Urban Development | Aquatic Science[1] | Competency 6d |

Table 5: Required Water Education Content in Mississippi. After elective courses that are not available in all school districts are removed, as well as those suggested objectives that are not mandated to be taught, the only required water education topic in the state of Mississippi's 2001 curriculum is pollution, at grade level 4.

| Topic | Grade Level | Standard |
|---|---|---|
| Pollution | 4 | Competency 7b |

Table 6: Chesapeake Bay watershed in Maryland's curriculum. Maryland is one of the state partners of the Chesapeake Bay Foundation, and the foundation has been successful in ensuring that some curriculum content standards directly address the watershed and water education. Note that Indicator 6.3.2 of Goal 6, Environmental Science directly addresses the Chesapeake Bay watershed. Content material that is directly relevant to water education is highlighted in yellow. This is one excerpt only from Maryland's state science curriculum. (Maryland Department of Education, 2009)

| **Expectation 6.3** | **The student will analyze the relationships between humans and the earth's resources.** |
|---|---|
| Indicator 6.3.1 | The student will evaluate the interrelationship between humans and air quality. At least—ozone, greenhouse gases, volatile organic compounds (smog) acid rain, indoor air, human health |
| Indicator 6.3.2 | The student will evaluate the interrelationship between humans and water quality and quantity. At least—freshwater supply, point source/nonpoint source pollution, waste water treatment, thermal pollution, Chesapeake Bay and its watershed, eutrophication, human health. |
| Indicator 6.3.3 | The student will evaluate the interrelationship between humans and land resources. At least—wetlands, soil conservation, mining, solid waste management, land use planning, human health. |
| Indicator 6.3.4 | The student will evaluate the interrelationship between humans and biological resources. At least—food production/agriculture, forest and wildlife resources, species diversity/genetic resources, integrated pest management, human health |
| Indicator 6.3.5 | The student will evaluate the interrelationship between humans and energy resources. At least—renewable, nonrenewable, human health |

Table 7: Water Education Content in Illinois. Although only five water education topics are specified in Illinois' Performance Descriptors, the methods by which they are covered in the classroom involved reinforcement through several grade levels (Illinois State Board of Education, 2001) Topics that are covered and reinforced at more than one grade level are highlighted in blue.

| Topic | Grade Level | Standard |
|---|---|---|
| Groundwater | 7,8, 9-12 | 12B Stage G2, 12B Stage J1; 12 B Stage J1 |
| Pollution | 8-10 | 13B Stage H3 |
| Soil Erosion | 6 | 12E Stage E1 |
| Surf Your Watershed | 6, 7-8 | 12E Stage E3, Stage G3 |
| TMDLs | 7-8, 11-12 | 12E Stage &, 13B Stage H |

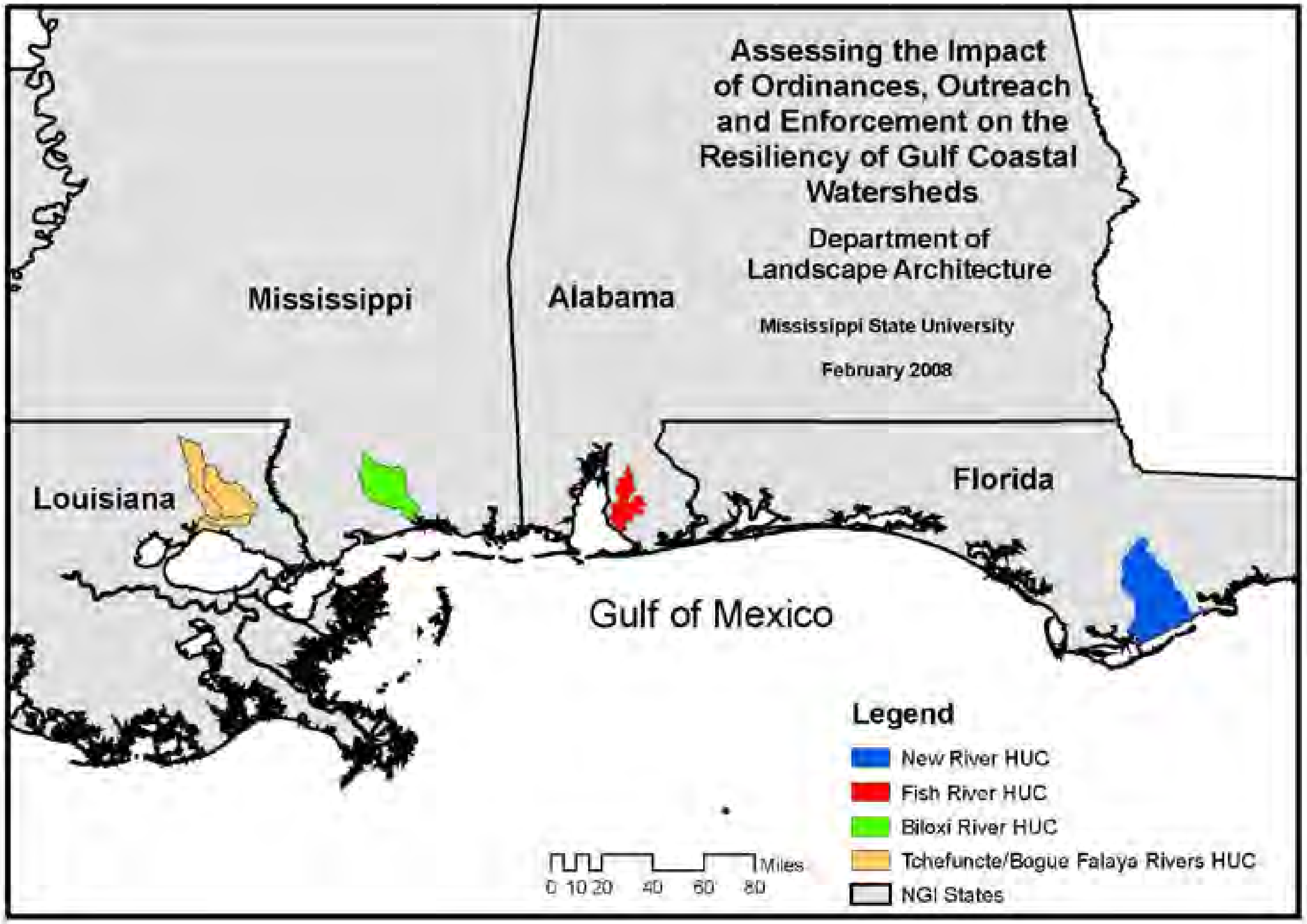


Figure 1: Coastal watersheds in Louisiana, Mississippi, Alabama, and Florida were identified, and NGOs associated with each watershed were surveyed on several topics, including water quality monitoring, environmental education, habitat restoration, conversation easements, and watershed management. (The figure is reproduced courtesy of the Journal of Extension, in which this figure appeared in volume 47, number 6 in 2009.)

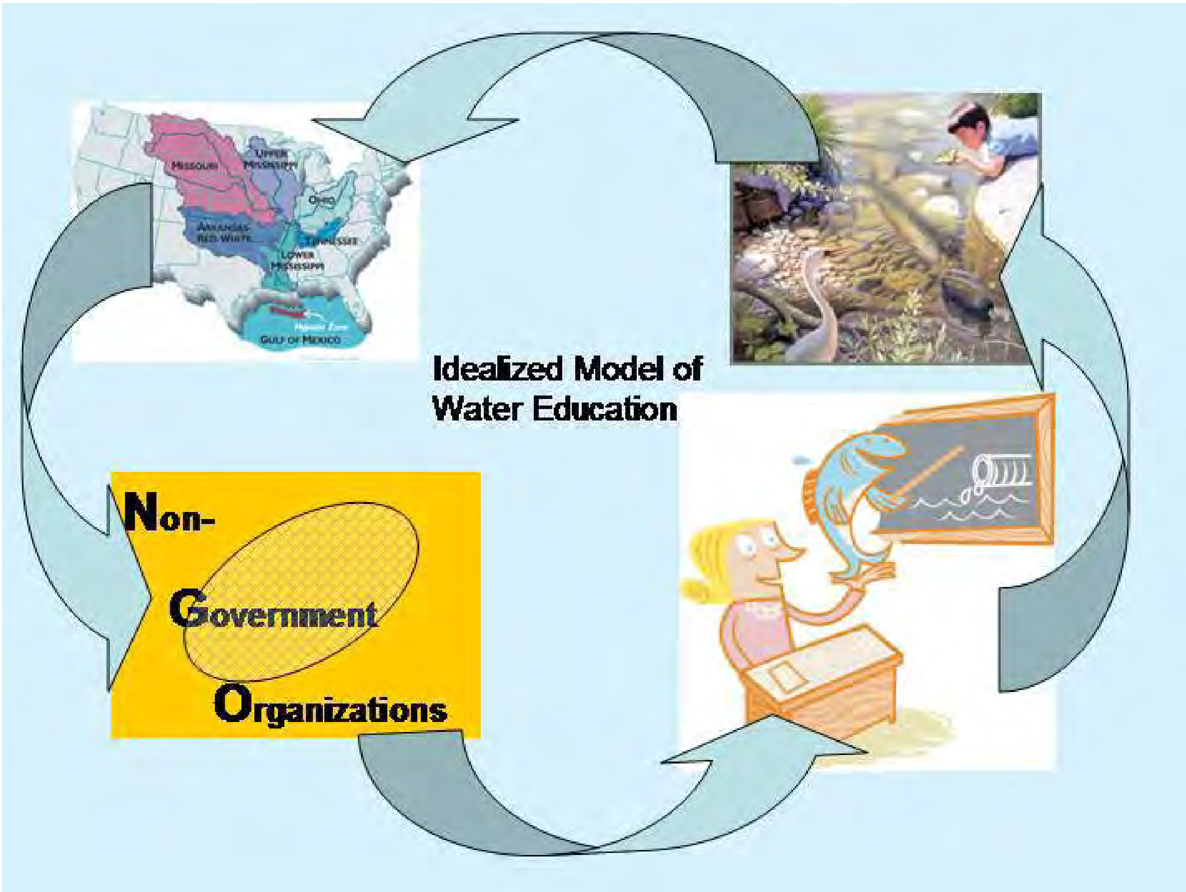


Figure 2: An idealized feedback loop between a watershed, supporting NGOs, classroom water education, and the development of our future concerned citizens. (Original images modified by authors, courtesy of URLs: http://upload.wikimedia.org/wikipedia/commons/b/b3/Gulf-mexico-watershed.gif, , http://ci.santa-rosa.ca.us/SiteCollectionImages/pwstorm_education1.jpg; http://www.co.pierce.wa.us/xml/services/home/environ/ed/teacherandfish2.jpg).

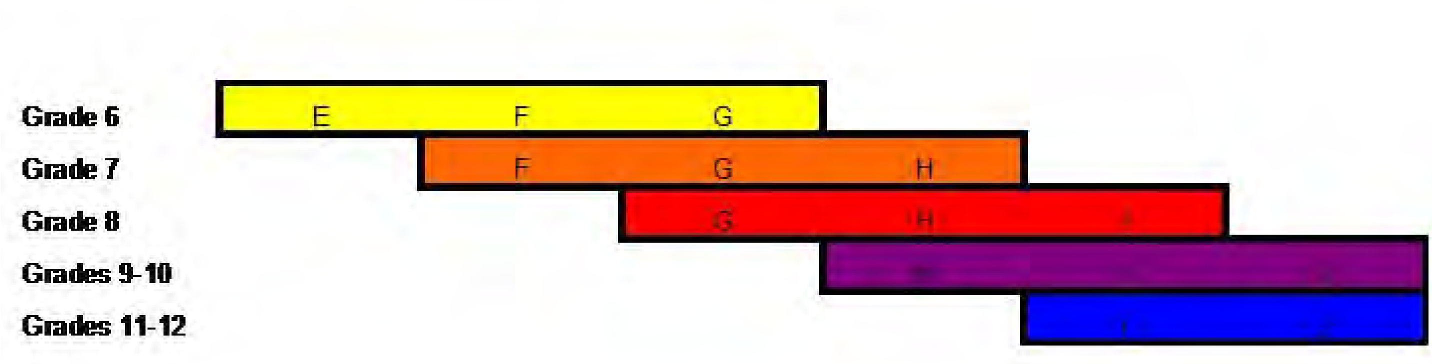


Figure 3: The Illinois' model for science content standards uses the Illinois Performance Descriptors (Illinois State Board of Education, 2001) to review content from a former grade level, implement and thoroughly study content at a higher level, and then briefly introduce the next highest level of content at the conclusion of the topic. If implemented properly, there is substantial overlap as content is reinforced at various grade levels.

# Collection of Hydrologic Data on Tidally Affected Streams

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The U.S. Geological Survey began collecting streamflow and other hydrologic data in Mississippi in the late 1800's. Until recent advances in acoustic technology and its application to hydrologic data collection, it was difficult to collect accurate streamflow data on rivers and streams where stage-discharge relations were affected by varying tide. The greater the tidal affect, the more difficult the data collection. On streams where tides cause the flow to fully reverse, the collection of reasonably accurate continuous data was practically impossible.

By using acoustic technology to collect time-series velocity data and make discharge measurements, the U.S. Geological Survey now operates and maintains four continuous-record surface-water discharge stations, and an additional station where the technology is used to monitor bed scour at bridge piers. At one of these stations, the varying tide primarily affects periods of low flow. At the remaining four stations, the flow fully reverses direction as the tide changes.  The streams range in size from large rivers such as the Pearl and Pascagoula Rivers, to small first order streams such as Bayou Heron in the far southeastern part of the State. Data also were collected at monitoring stations (which are now discontinued) on the Escatawpa and Jourdan Rivers. It has been observed that the smaller the stream and corresponding flow, the greater the effect the tide has on the stream, and not surprisingly, the more difficult the data collection.

The computation of discharge on a tidally affected stream requires the collection of data to develop relations between the stage, or water level, and the cross sectional area, and between an index velocity measured by an in situ velocity sensor and an average velocity computed from a streamflow measurement. It is the collection of these two data sets and the product of the computed area and average velocity that provides continuous discharge values.

Key words: Hydrology, Methods, Surface Water

# The Effect of Policy and Land Use Change on Water Quality in a Coastal Watershed City: An Analysis of Covington, Louisiana

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There is currently a great need to expand the understanding of land use policy's impact on water quality. The purpose of this work is to examine local policy in Covington, Louisiana in order to assess its impact on land use. Land use is then analyzed to reveal effects on water quality. Water quality should then be used to dictate policy in a feedback loop, but that is not currently happening. Methods used include reclassifications of land use categories within a Geographical Information System and analysis of changes over a four year period. Policy is assessed using two instruments. The first is a pre-existing evaluation method devised by The Center for Watershed Protection. The second is by a more flexible and generalized apparatus developed by staff and faculty in the Department of Landscape Architecture at Mississippi State University. Three water quality parameters are examined for impairment due to their known correlation to urban runoff. Nonpoint source pollution from agriculture is also discussed, however, for analysis of policy and land use in the City of Covington, this is less of an issue.

While it has been determined that Covington's water quality related policy is insufficient and surface waters are impaired, there are a great deal of extenuating circumstances that impact water quality both in and around the city. Changes to current monitoring efforts and policy drivers are discussed along with suggested improvements that could be made to altered landscapes and current governance.

Key words: nonpoint source pollution, water quality, and policy

# Drainage Improvement Project Development for Successful Hazard Mitigation Funding

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Over 100 drainage improvement project proposals were considered for Katrina Hazard Mitigation Grant Program (HMGP) funding in 2008 and 2009, by the Mississippi Emergency Management Agency, with assistance from FEMA. Many of these project proposals displayed technical merit and detailed the scope of work and estimated project costs. Completion of these projects could have reduced future flood levels and associated future flood damages in many communities. However, most of these proposals had insufficient damage history data needed to determine the benefits of the mitigation projects. Benefits are defined as avoided damages, disruptions, losses, etc., as a result of the mitigation. For HMGP funding approval, the FEMA Benefit Cost Analysis (BCA) musts show that the benefits of a project are equal to or exceed the project cost. The FEMA Damage-Frequency Assessment (DFA) BCA module is used for localized drainage improvement projects when Flood Insurance Study (FIS) or comparable data are not available. This paper presents an overview of the DFA module and the necessary documentation requirements. Further, suggestions for developing routine collection of the needed documentation to apply the DFA module for drainage improvement projects are outlined. This information will assist communities to be better prepared to successfully apply for HMGP funds that might be available in the event of future disaster declarations.

Key words: Floods, Hydrology, Law, Management and Planning, Models

**Introduction**

The objective of this paper is to assist local communities collect the necessary documentation to successfully compete for HMGP funding for local drainage improvement projects. The drainage improvement projects will be described. The broad scope of Federal Assistance for disaster response and recovery available through the FEMA will be discussed in general. The responsibilities of the each partner in the FEMA-State-Applicant Partnership will be explained. The Hazard Mitigation Assistance (HMA) component of FEMA federal assistance will be discussed in further detail with final emphasis on the HMGP Funding. In similar manner the FEMA BCA methodology will be discussed in detail with emphasis on the BCA DFA module. The MEMA HMGP efforts related to drainage improvements projects, pertaining to Katrina disaster number DR-1604-MS, during 2008-2009, will be presented. The data needed to develop the project scope of work and cost, along with the damage data needed to determine the cost effectiveness employing the DFA module will be covered. Finally a discussion of problems leading to inadequate documentations and suggestions to improve the procedures for routinely collecting damage history documentation will be outlined.

**Drainage Improvement Projects**

One method to reduce future damages from floods is to modify existing drainage or storm water management facilities to reduce the risk of local flooding, i.e.: increase conveyance and capacity; construct new drainage facilities; construct new detention facility; alteration of an existing drainage facility; and construction of a floodwall. Communities fund these projects using local funding, bonds, loans or through various types of grants.

**Federal Disaster Assistance**

One source of grant funding is the federal assistance administered by FEMA if the President declares that a major disaster or emergency exists (www.fema.gov/rebuild/recover/dec_guide.shtm). This response and recover assistance is available through three major grant programs, Individual Assistance (IA) (www.fema.gov/individual/grant.shtm ), Public Assistance (PA) (www.fema.gov/government/grant/pa/index.shtm ) and Hazard Mitigation Assistance (HMA) (www.fema.gov/government/grant/hma/index.shtm ). IA provides assistance to individuals and families in terms of temporary housing, individual and family grants and unemployment assistance. PA provides assistance to states, tribal and local governments, and certain types of Private Nonprofits in terms of debris removal, emergency protective measures, and permanent restorations. HM provides assistance to both individuals and families, and states, tribal and local governments, and certain types of Private Nonprofits in terms of grants for cost-effective measures to prevent or reduce threat of future damage.

IA is for individual assistance and does not apply to the projects under consideration. PA (also know as infrastructure) repairs facilities which could include drainage projects like those addressed and this is the appropriate method to have damages repaired. PA has a form of mitigation that can be applied at the time of repair. PA is important since damage documented by PA determines by formula how much funding is available for the HMGP grant program that will be discussed shortly.

FEMA's HMA grant programs provide funding for eligible mitigation activities that reduce disaster losses and protect life and property from future disaster damages. Currently, FEMA administers the following HMA grant programs: Hazard Mitigation Grant Program (HMGP) (www.fema.gov/government/grant/hmgp/index.shtm); Pre-Disaster Mitigation (PDM) (www.fema.gov/government/grant/pdm/index.shtm); Flood Mitigation Assistance (FMA) (www.fema.gov/government/grant/fma/index.shtm); Repetitive Flood Claims (RFC) (www.fema.gov/government/grant/rfc/index.shtm); and Severe Repetitive Loss (SRL) (www.fema.gov/government/grant/srl/index.shtm).

FEMA's HMA grants are provided to eligible Applicants (States/Tribes/Territories) that, in turn, provide subgrants to local governments and communities. The Applicant selects and prioritizes subapplications developed and submitted to them by subapplicants. These subapplications are submitted to FEMA for consideration of funding.

Although a local drainage improvement project could be eligible for more than one of the HMA grant programs, most likely the HMGP would best assist such projects. The HMGP is authorized under Section 404 of the Robert T. Stafford Disaster Relief and Emergency Assistance Act (as amended) and provides grants to implement long-term hazard mitigation measures following a major disaster declaration. The purpose of the program is to reduce the loss of life and property due to natural disasters and to enable mitigation measures to be implemented during the immediate recovery from a disaster. Further, the program is managed by the state (MEMA).

The amount of funding available for HMGP after a disaster has been declared is limited. The program may provide a State with up to 7.5% of the total disaster grants awarded by FEMA. States that have an approved enhanced state mitigation plan at the time of disaster declaration will qualify to receive up to 15% HMGP funding.

The HMGP program contains a required cost share provision as part of the allowable funding. FEMA can fund up to 75% of the eligible costs of each project. The State or grantee must provide a 25% match, which can be fashioned from a combination of cash and in-kind sources or global match. Cost share is an important aspect of disaster assistance funding. Note that some states contribute a portion of the 25% non-Federal funding. For example FL provides 12.5% and the subgrantees (communities) provide 12.5%. In MS, the state has contributed 20% and the communities must contribute 5%.

As noted previously, applicants eligible for HMGP include: state and local governments; private non-profit organizations or institutions that own or operate a private not-for profit as defined in 44 CFR 206.221(e) and Indian tribes or authorized tribal organizations and Alaskan Native villages. The HMGP applications can come from locals that are not within the disaster declared region. This might lead to less local knowledge of disaster assistance and data documentation requirements.

After a disaster occurs several actions are involved to initiate the HMGP. After the Presidential Declaration, the Standard State Plan must be approved. Then the HMGP Admin plan is updated/ approved. Next, the State solicits program interest and assists applicants in developing applications. These applications must be representative of the State and Local Mitigation Plans. The applicants are responsible for submitting complete and accurate applications. Finally, FEMA reviews applications for eligibility.

There are a number of eligible HMGP activities, including: acquisitions; relocations; elevations; seismic or wind retrofit; drainage, storm shutters, flood proofing, and others. The local drainage improvement projects under consideration fall in the drainage category.

HMGP projects must be in conformance with the State and Local Mitigation Plan, have a beneficial Impact on the designated disaster area, whether or not located in the designated area. HMGP projects must also be in conformance with 44 CFR Part 9 Flood Plain Management and Protection of Wetlands and 44 CFR part 10, Environmental Considerations. HMGP projects must solve a problem independently or constitute a functional portion of a solution where there is assurance that the project as a whole can be completed. Finally, the HMGP projects must be cost effective and substantially reduce the risk of future damage, hardship, loss or suffering resulting from a major disaster. The grantee must demonstrate this by documenting that the project addresses the problem, will not cost more than the anticipated value of the benefits, and has been determined to be the most practical, effective, and environmentally sound alternative after consideration of a range of options.

**Benefit Cost Analysis**

The FEMA BCA Software is the designated methodology to determine cost-effectiveness required by law. States normally arrange for subgrantee training in the proper use of the BCA Software. Reference data is available on the BCA Tool Kit. Data Documentation Templates are a valuable resource in determining required amount of back up data needed for the BCA analysis. BCA Software Version 4.5 is now available (www.bcahelpline.com). A well documented BCA means that a knowledgeable BC analyst can re-create the BCA from supporting documentation provided within the application.

The BCA Software has several modules applicable for all of the eligible HMGP activities listed above (Flood, Hurricane Wind, Earthquake, Tornado, Wildfire, and Damage Frequency Assessment). There are two BCA Methodologies available for Drainage Projects, the Full Data Flood Module and the Damage Frequency Assessment (DFA) Module. The Full Data Flood Module has two components, the Riverine Flood Module and the Coastal Flood Module. The Full Data Flood Module requires an existing flood study like a National Flood Insurance Program Flood Insurance Studies or new local study. It also requires preliminary design specifications at a minimum the basic design concept and the best available cost estimate. This module also requires a post mitigation profile to be determined to what level will the improvement minimize flooding and the software compares existing flood profiles to post-mitigation profiles to determine benefit.

The Damage Frequency Assessment (DFA) Module, which was formerly known as Limited Data Module (LDM), is the most appropriate module for local drainage improvement projects. The DFA module typically requires the most assumptions and engineering judgment, provides the most accurate analysis if no hazard data or specific building data are available. However, historical damage information is required including: date, extent and magnitude of impacts of previous floods; photos of historic flooding; overall cost of damages; and estimated frequency of each event. The DFA performs an analysis based on historical hazard frequency data, damage observations, and engineering judgment. The DFA calculates project benefits based on two or more historical damage events and the frequencies of the events. The advantage of DFA module is its flexibility; it can be used for a wide range of hazards and project types including local drainage improvement projects.

However, with this flexibility also comes a requirement for detailed DFA input data. The DFA must have documented historical damages/losses from two or more hazard events of known frequencies based on FEMA Project Worksheets/Damage Survey Reports, Insurance or repair records, or Newspaper articles citing other credible sources. It must have documented frequencies associated with each hazard event based on comparison of observed flood elevations or discharges to FIS, stream gauge or tide gauge data, documented data from a credible source to estimate frequencies, or the unknown frequency calculator with supporting documentation when the requirements are met.

**DR-1604-MS HMGP Drainage Applications**

MEMA set a high priority on DR-1604-MS HMGP Drainage Applications and set aside $70M Federal of HMGP funding for drainage improvement projects. Over 120 projects with an estimated value of over $100M Federal were considered. Only 12 drainage improvement applications have been submitted with an estimated project cost for all submitted of $21.4M. To date only 2 of these projects have been approved and obligated with an estimated value of over $2.6M Federal.

**Damage History Documentation**

Why aren't more projects being funded? Inability to prove that the projects are cost effective, lack of funds to meet cost share, 75% maximum Federal Share, and lack of funds for initial project development (architectural and engineering).

What can be done to improve this damage history documentation? Perhaps a major step is through better education of the state and subgrantees. Some of the problems leading to inadequate documentation could include: HMGP involves all communities in state and some may have little experience with previous disasters and disaster documentation requirements such as for PA or HMGP; no plan to collect data on a year round basis; lack of education, reading and writing ability; lack of computer and electronic data skills; and the belief that large cost events (usually low frequency) are more important than low cost events (usually higher frequency). When probability is included and annualized, the benefits generated by the higher frequency, lower cost events generally are greater.

How should damage history data be managed? A designated person should coordinate accumulation of records. This person could be housed in any number of community agencies including: Grant Coordinating Office Official; Flood Plain Management Official; Building Official; Emergency Management Official; Publics Works Official; Road Department; or other responsible official, perhaps even a community volunteer. Next, events and expenses during disaster response/recovery should be collected accurately and continuously. An effective data collection system should be established in most communities. This should involve simple file systems; data bases systems: permitting data; public works data; road department data; local EMA data; utilities data; etc. One simple investment that could help with those employees, with limited reading and writing skills, would be the issuance and training on with digital voice recorders and digital cameras.

**Conclusion**

Detailed data collection that is needed is much like the detailed data collection individuals use to file travel vouchers or income tax reports. Many communities already have data collection systems used for payroll, equipment usage, etc. There is no best solution; it depends on the needs, abilities and economics of each community. It should be obvious from the many unsuccessful local damage improvement projects mentioned in MS related to the Katrina Disaster DR-1640-MS, if detailed damage data is not collected, the opportunity of substantial HMGP Federal disaster assistance will not be seized. FEMA does not dictate how communities collect the damage history documentation, but will make suggestions and assist as requested. The time to act is now to establish a sound data collection system for local damage improvement projects in order to be prepared for the next disaster funding opportunity, which unfortunately will likely reoccur. This effort will help citizens collect the necessary documentation to mitigate through local drainage improvement projects.

# Protecting Water Quality in Your Community

Casey DeMoss Roberts, Gulf Restoration Network

Most of us would prefer to ignore sewage. Rarely do we discuss what happens to water after it exits our homes through toilets, sinks, and showers. Yet, it has important ramifications for the rivers and streams that we love. Fresh, clean water is a human right and serves as the lifeline of the earth's ecosystems. Not only do we drink water, we use it for cooking, cleaning, recreation, fishing, transportation, and commerce. All those uses are jeopardized when surface water is polluted by sewage.

In order to help Gulf residents recognize and address sewage pollution problems in their streams, bayous, and lakes, the Gulf Restoration Network produced *Our Water Our Health, A Citizen's Guide to Sewage Pollution* manual and training seminar. The basics of the training include sewage 101, documenting a problem, commenting on permits, how to run a public campaign for clean water, messaging techniques, how to set up a press conference, and many other skills and knowledge based modules. The manual reviews topics such as: how sewage treatment works, law and policy of wastewater, what types of pollution come from sewage treatment plants, how to identify problems in your local water supply, and the basics of how states grant permits to sewage treatment plants. After attending this training, participants will be able to successfully advocate for better wastewater treatment, utilizing tools such as coalition building, media, and the Clean Water Act!

Key words: Treatment, water quality, wastewater, surface water

Managment/Sustainability

**Management/Sustainability**

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# Support for a Northeast Mississippi Regional Water Management Plan

Mary Love M. Tagert, Mississippi State University

Water and wastewater infrastructure are national priority issues for economic development, pubic health and environmental concerns. Currently, in predominantly rural states such as Mississippi, water supply infrastructure is operated and maintained largely by many independent small public water systems. Similarly, rural wastewater infrastructure is essentially nonexistent. As new development projects have recently been announced in Northeast Mississippi, regional water and wastewater organizations are critical for Northeast Mississippi Counties to plan, build, operate and maintain the necessary infrastructure to ensure an adequate water supply for the future and adopt a viable rate schedule to be self-sufficient. Recognizing this situation, the Tombigbee River Valley Water Management District (TRVWMD) is formally creating two new multi-county water and sewer organizations within their twelve member Counties. The 'Tri-County District' covers Itawamba, Prentiss, and Tishomingo Counties, while the 'Five-County District' covers Chickasaw, Clay, Kemper, Lowndes, and Noxubee Counties. All participating Counties have passed resolutions to establish a new Water and Sewer District, and the TRVWMD sought Mississippi State University's assistance in completing a Water Management Plan for the Tri-County District, which is a requirement of the formal permitting process to establish a new District. This presentation will address the planning process and elements of the Tri-County Water Management Plan, which has a primary emphasis on water supply and contains contributions from various Northeast Mississippi stakeholders such as local, state, federal, and regional agencies and organizations.

Key words: water quantity, water use, management and planning

# The Oklahoma Water Bank Project

Kelly Hurt, Chickasaw Nation Division of Commerce

The Arbuckle Simpson aquifer is located in south central Oklahoma. Although it is a highly productive karst aquifer that provides a crystal clear supply of groundwater to a multitude of springs and streams in the area, it has relatively limited storage. As such, frequent recharge events are necessary to maintain spring flows, base flows in area streams and water levels in area wells. Development of the local area and reliance on groundwater and spring water for municipal supplies has resulted in increased depletion rates during drought periods such as the extreme 2005 – 2006 period. However, during 2007, the area experienced multiple flood events that caused millions of dollars of damage to homes, property and businesses.

This back to back occurrence of damaging droughts and floods set the stage for local leaders, scientists and regulators to write legislation supporting the Arbuckle Simpson Water Bank project. The project is designed to divert surface water captured by upstream flood control structures (i.e., NRCS watershed lakes) to the subsurface during flood events. This management approach allows the refilling of aquifers with damaging floodwater that downstream users do not desire. In a sense it turns flood lemons into drought lemonade. The partners on the project include the City of Ada, OK, the Chickasaw Nation, the Oklahoma State Climatologist, the Oklahoma Water Resources Board, the Oklahoma State Legislature, the National Weather Center, the National Severe Storms Lab, the Oklahoma Department of Environmental Quality, the Oklahoma Conservation Commission, the Bureau of Reclamation, University of Oklahoma and Oklahoma State University. The project was recently selected as the winner of the 2009 Secretary of the Interior's "Partners in Conservation" award.

This presentation will include information on cutting edge technology used to predict, measure, manage and recharge water, including:

- Advanced radar systems,
- Mesonet meteorological stations,
- Passive filtration systems,
- Engineered recharge zones,
- Computer modeling of predicted water supply inventories,
- Web based information sharing.

Key words: Drought, floods, water supply

# Collective Action Regimes in Inland Marine Port Clusters: The Case of the Tenn-Tomm Waterway System

Chad Miller, University of Southern Mississippi
Bethany Stich, Mississippi State University

This paper examines the innovativeness and competitiveness of the Tennessee-Tombigbee (Tenn-Tom) waterway using a cluster analysis approach. The focus of the case study is on the collective action regimes and local governance within which the cluster operates. In particular, inland marine innovations and collective action problems are examined. These include but are not limited to: system reliability, container-on-barge, funding, governance, hinterland access, knowledge networks and leader firms.

Key words: Economics, Institutes and Policy, Management and Planning

## Introduction

The movement of freight on the inland waterway system is crucial for the U.S. economy, but the system faces serious problems and needs to innovate. The importance of the nation's rivers, canals, and lakes in carrying cargo is often overlooked. According to the Federal Highway Administration (2002), 19.3 billion tons of freight were moved by all modes. The inland waterways maintained by the U.S. Army Corps of Engineers (Corps) annually handles over 600 million tons of freight valued at over $70 billion (U.S. Army Corps of Engineers, 2000, 2007; Waterways Council Inc., 2009a). Barges directly serve 87% of all the nation's major cities, accounting for 14% of intercity freight ton-miles. Sixty percent of U.S. grain and 20% of the nation's coal, enough to produce 10% of all electricity used each year in the U.S., moves on the marine highway system (American Waterways Operators, 2009). The amount of freight being carried on the system has leveled off since the 1990s (see Figure 1), but there are several drivers that are likely to cause the system to see greater demand.

### *Drivers of Increased Inland Waterways Usage*

Waterways are the only mode of transportation that have the capacity to handle large increases of freight movement. Furthermore, the system has enough excess capacity that it can handle the increase in domestic and international freight as well as ease increasing highway and railway congestion by carrying cargo that would otherwise travel via those modes. America's inland waterway system currently carries the equivalent of 58 million truck trips each year. Without this system, truck traffic on the Interstates would double or rail tonnage would increase by 25% (Kruse et. al., 2007). International freight movement is expected to double by 2020 to 6 million tons per day and domestic freight movement is expected to increase to 62 million tons per day (American Association of State Highway and Transportation Officials, 2007). With highways and railroads at or near full capacity, the waterways will be in more demand.

In addition to congestion leading to increased demand, rising fuel prices are likely to increase the interest in moving more freight by water due to its energy-efficiency and affordability. Its energy consumption per ton-mile of transported goods corresponds to one-sixth of the consumption by truck and to half that of rail transport (Inland Rivers Ports & Terminals Inc., 2009). One 15-barge river tow has the same capacity as 1,050 trucks and 216 rail cars pulled by six locomotives. As a result, barges can move one ton of freight 576 miles per gallon of fuel while a modern locomotive would move that same ton of freight 413 miles per gallon of fuel, and a truck would move it 155 miles (Kruse et al., 2007). That means barges have energy efficiency 3½ times that of trucks and provide a $10.67 per ton cost advantage (Waterborne Commerce Statistics Center, 2009). Waterborne transportation saves shippers and consumers more than $7 billion annually compared to alternate transportation modes (American Society of Civil Engineers, 2009). Related to the efficiency factors are the environmental and carbon foot print implications of moving freight by water instead of road or rail.

Inland waterway transport generates fewer emissions than rail or truck per ton-mile. The total external costs of inland navigation, in terms of accidents, congestion, noise emissions, air pollution and other environmental impacts, are significantly lower than those of road transport (Flemish Institution for Technological Research, 2004; Sudar, 2005). Inland waterway transport generates fewer emissions of particulate matter, hydrocarbons, carbon monoxide and nitrous oxide than rail or truck on a per ton mile moved basis. With environmental and global warming concerns increasing, there is more incentive than ever to move freight by water.

Congestion, fuel prices, and environmental concerns are expected to lead to increased usage, but funding rehabilitation and maintenance of the waterways is a serious challenge (Grier, 2004). The aging infrastructure and the lack of adequate public funding for the waterways are major difficulties. Over half of the 240 locks in the system are over fifty years old. The replacement value of the nation's lock and dam facilities has been estimated at more than $125 billion (U.S. Army Corps of Engineers, 2000). Assuming that no new locks are built by 2020, another 93 existing locks will be obsolete, rendering more than 8 out of every 10 locks now in service outdated (American Society of Civil Engineers, 2009). Many locks currently in use are too small for today's larger tows (Waterways Council Inc., 2008). They are susceptible to closures and long delays for repairs and are unable to deal effectively with lines and wait times that result from their obsolescence. In 2003 and 2004, several high-profile lock closures brought the problem to the public's attention (McKay, 2004).

***Structural Problems with the US Inland Waterways System***

With an expected average rehabilitation cost of $50 million per lock, the current U.S. Army Corps of Engineers budget of $200 million per year for lock repairs is woefully insufficient (Water Resources Coalition, 2009). Further exasperating the problem is that recent lock modernization projects have far exceeded their respective budgets and have taken much longer than projected to complete. Operation and maintenance (O&M) expenses for the inland waterway system average around $500 million annually and have remained flat for more than two decades allowing minimal funds for routine maintenance.

Prior to 1986, inland waterway infrastructure was almost entirely a federal general revenue expense. The Water Resources Development Act (WRDA) of 1986 fundamentally transformed the financing of the Corp's water projects, including its commercial navigation projects. The act created 20 cents per gallon tax on diesel fuel to underwrite the cost of modernizing locks and dams. As a result, the barge and towing industry annually pay $80 to $100 million per year into a trust fund (Wilken, 2008). A cost-sharing formula was established under which one-half of a lock reconstruction would be paid from the trust fund and the other half from general revenues. A surplus had been gathering in the Inland Waterways Trust Fund, from $200 million to $400 million from 1992 to 2002, but this has been spent (Mecklenborg, 2007). Other funding sources (e.g., a lockage tax) have been considered but failed to be enacted. The $403 million for modernizing inland waterway locks and dams in the American Recovery and Reinvestment Act (ARRA) should help, but it falls far short of the $1.5 billion that the Waterways

Council, Inc. (WCI) is seeking for lock-and-dam modernization projects (Waterways Council Inc., 2009b). At the current funding level, the inland waterway system moves 1.4 tons of freight per dollar (Vachal, Hough, & Griffin, 2005). This compared to 0.52 tons per dollar by truck. The Highway Trust Fund averages $35.8 billion a year. Of that, 62% is spent on public roads that carry the 11.5 billion tons of trucked freight (Siggerud, 2006). Clearly, more public funding is justifiable and necessary to keep the waterways running efficiently as the current funding system is antiquated and problematic.

***Problems with the System Requiring Regional Innovation***

Even if the funding issues can be addressed and the infrastructure modernized, the inland waterway system needs to innovate to meet the demands of today's global supply chain. The inland waterways have traditionally been used to carry bulk commodities including coal, grain, chemicals, petroleum products, iron, steel, and aggregates. It has also been a good option for moving cargo that is too large to transport over the nation's highways or rails. This "project cargo" includes freight such as NASA rocket boosters or parts for electric generating stations. However, global logistics demand the containerization of freight. Therefore, the greatest growth in freight tonnage and value is in containerized freight. The U.S. waterway system is ill equipped to handle containerized freight, and thus, cannot take full advantage of the global supply chain.

The intermodal movement of containerized cargo is the biggest trend in freight transportation. Global international trade is expected to double by 2020, but containerized freight is expected to nearly triple in the same time frame (American Association of State Highway and Transportation Officials (AASHTO), 2007). The international trade of twenty-foot equivalent units (TEUs), the standard size of a container, tripled in volume from 137 million TEUs to 387 million TEUs between 1995 and 2008, growing at an average annual rate of about 8 percent (U.S. Department of Transportation Research and Innovative Technology Administration Bureau of Transportation Statistics, 2009). Domestic cargo volumes are also expected to increase by 70% by 2020 with a similar increase in the usage of the standardized shipping container (U.S. Department of Transportation, 2002). If the U.S. inland waterway system expects to increase their role in the modern supply chain, they need to innovative and adopt container-on-barge (COB).

Container-on-barge is already a standard practice in Europe's modernized inland marine highway system. Inland navigation carries 12% of the freight in the European Union and grew 17% in the last 10 years (European Commission's Directorate-General for Energy and Transport Development, 2003). In some European regions, the 'modal share' in terms of ton-miles of inland waterway transport reaches over 40%. Europe began moving containerized freight on their extensive river system in the 1970s in conjunction with the transport of ocean freight in standardized boxes. Limited highway and freight rail infrastructure and supportive public policies (e.g., Europe provides environmental credits to the waterways for taking trucks off the road, which provides additional funding for maintenance and modernization), encouraged the development of COB, but perhaps even more important was the innovative nature of the participants in the European inland waterways system.

Besides COB, another area requiring innovation is the adoption of lean supply chain principals. The U.S. inland waterway system suffers from queues and congestion due to aging infrastructure, but also a lack of business commitment to reliability (Hanson Professional Services Inc, 2007, 2009). It will take innovations in operations to achieve timely and reliable delivery. Many industries (e.g., automotive assembly) have gone to just-in-time (JIT) operations and require freight to be delivered exactly when it is needed in the production process. Any delay in delivery will shut down production as the inventory is in transit. Inland navigation vessels operate at a relatively slow commercial speed, 5-10 miles per hour (mph) versus 10-20 mph for rail, and 20-30 mph for trucks, so barge transport is not practical for urgent goods e.g., perishables (ECMT, 2006). However, most freight used in JIT conditions is not urgent but it must arrive exactly when planned; reliability not speed is the crucial factor. With modern tow operations, using improved and well-maintained infrastructure, freight can be delivered reliably by inland waterways systems if the institutions involved are committed to process.

In order to meet the needs of today's global transportation system, the U.S. inland waterway system needs to adopt new practices and operate differently than it has in the past. The growth of freight tonnage, congestion on alternative modes, environmental concerns, and fuel costs all portend increased utilization of the nation's rivers, lakes, and canals for the movement of freight. There are national barriers (e.g., funding for modernization) that the entire system must address, but regional innovation can be achieved. Container-on-barge and highly reliable delivery are two innovations that require coordination at the regional level and are attainable goals.

### *Clusters and Innovation*

The cluster concept is the most popular way to discuss regional innovation. According to cluster theory, business clusters form because co-located firms enjoy a wide range of economic advantages relative to firms that are geographically isolated from other firms in the same line of economic activity (Blair & Carroll, 2009). Despite some debate on nuanced terminology and how to operationalize clusters, researchers and practitioners alike generally accept Porter's (2000) description of clusters as "geographic concentrations of interconnected companies, specialized suppliers and service providers, firms in related industries, and associated institutions (e.g., universities, standard agencies, and trade associations) in particular fields that compete but also cooperate" (p. 15). The cluster concept is based on the recognition that firms and industries are interrelated in both direct and indirect ways. They each contribute to a region's "collective efficiency"— a combination of external economies and joint actions that explain the higher returns that accrue to firms that are spatially clustered (Krugman, 1991). The promotion of business clusters, with their attributes of dynamic local firms, productivity-enhancing spillovers, concentrations of allied and supporting firms, efficient labor markets, and business culture connectivity, is viewed as a means to stimulate local economic growth, increase employment, and raise income levels, but mostly importantly for this study, innovation.

Silicon Valley is the classical example where tech savvy people can switch jobs without changing parking spaces and networking socially allows cross fertilization of new ideas. Clustering facilitates the spread of specialized knowledge that is improved and developed by dissemination amongst experts. The co-location of a specific industry and it ancillary institutions and suppliers allows horizontal and vertical knowledge to flow among sage individuals and institutions. To put it briefly, having a group of smart people (and organizations) in a setting where they can share ideas and learn from each other on a particular topic leads to new and better ideas. However, not all clusters of firms are innovative. A prerequisite is to have quality physical infrastructure and good governance. The critical drivers of innovation vary from sector to sector, but availability of a well-qualified and specialized talent pool is essential.

### *Applying the Cluster Concept to Marine Highway Systems*

The cluster concept has been applied to many industries, but there has been limited use of the concept as an approach to understanding freight movement systems. De Langen (2004) appears to be the exception. He used the approach to study the port clusters of Rotterdam and the Lower Mississippi. No research was found that specifically examined clusters of inland ports, but de Langen's findings on mixed ocean and river port networks should be instructive for the U.S. inland waterways system.

The first step in cluster analysis is to identify the organizations, public and private, involved with the economic activities of the ports. De Langen and Visser (2005) broke the component clusters into the activities of cargo handling, transport, logistics, manufacturing, and trade. The geographically concentrated interconnected organizations of the U.S. waterways system include the ports, towboats and barges, and shippers. The specialized suppliers and service providers include shipyards, tugs, freight forwarders, and consultants. Firms in related industries include railroads, truckers, and economic development organizations. Associations would include the U.S. Army Corps of Engineers, state waterways associations, and regional waterway development authorities. Taken together these organizations form the collective action regime that governs the inland waterways cluster.

De Langen and Visser (2005) identified five variables that influence the quality of the governance emanating from the collective action regime.

1. The presence of leader firms that desire to develop the cluster.
2. There needs to be collaborative involvement of public organizations.
3. An organizational structure that enables cooperation must exist.
4. There must be cluster consensus and a shared value system.
5. There needs to be openness or "voice" that allows input from all the components of the cluster.

These characteristics should allow the collective action regime to provide good governance which, along with the modernized physical infrastructure and specialized talent pool, is necessary for an innovative cluster.

## Methodology

In order to apply cluster theory to the U.S. inland waterways system and to shed light on the local governance and collective action regimes necessary for innovativeness and ultimately competitiveness, a spatial proximate and linked part of the system was selected. The U.S. inland waterway system is comprised of connected navigation systems such as the McClellan-Kerr Arkansas, Black Warrior-Tombigbee (BWT), Columbia-Snake, Red River, Apalachicola-Chattahoochee-Flint (ACF), Arkansas, and the Tennessee-Tombigbee waterway. Each of these could be viewed as a cluster of spatially connected and interlinked companies and related organizations.

The Tennessee-Tombigbee (Tenn-Tom) waterway was selected due to data availability and its similarities to the other navigation systems that comprise the inland water network. The Tenn-Tom is a $2 billion two hundred thirty four mile navigable waterway that connects Tennessee and Tombigbee rivers. It was opened for commercial traffic in 1985 after a long political struggle. The manmade waterway connects 18 states and 14 river systems totaling some 4,500 miles of navigable waterways serving a large swath of southern and middle America. The Tombigbee River empties into the Gulf of Mexico at Mobile so the canal allowed water traffic to avoid travelling hundreds of miles north before turning south and reaching the Gulf of Mexico on the Mississippi river at New Orleans. It also allows the Port of Mobile, which recently added a $300 million dollar container port, greater access to the hinterland.

Commercial traffic has steadily grown each year since the waterway opened in 1985. The Tennessee-Tombigbee moves approximately 10 million tons of commerce each year at an annual savings of nearly $100 million in transportation costs (Tennessee-Tombigbee Waterway Development Authority, 2007). Principal commodities include forest products (44%), coal (27%), construction material (14%), chemicals (8%), and steel (5%). There is basically no COB on the Tenn-Tom (Hanson Professional Services Inc., 2007). Seventeen public ports and terminals are open to commercial traffic and more than 40 waterfront industrial sites offer river access. Major companies have located along the waterway include Boeing, Weyerhaeuser, and steel companies such as SeverStal, ThyssenKrupp, U.S. Steel, Dynasteel, and G&G Steel. A recent economic analysis study found that since 1996 the nation has realized a direct, indirect, and induced economic impact of nearly $43 billion due to the existence and usage of the Tenn-Tom (Edwards, Mixon, & Burton, 2009).

The Tennessee-Tombigbee Waterway Development Authority is the public agency that oversees the waterway. The authority's membership is limited to the governors of Alabama, Kentucky, Mississippi and Tennessee along with five gubernatorial appointees from each state. The authority created the Tennessee-Tombigbee Waterway Development

Council to provide a forum for the multitude of public and private interests in the cluster. The over 200 members of the non-profit organization represent commercial users in the operation and maintenance of the project and addresses research needs and technical matters that may impact its potential benefits. The council is the organizational structure that enables collaboration and the authority involves public organizations. Thus, the Tenn-Tom cluster has two of the five criteria quality governance: the involvement of public organizations and an organizational infrastructure.

***Survey***

De Langen (2004) created a survey that would, "identify which factors influence the performance of the Lower Mississippi Port Cluster and how" (p. 231). The survey allows the researchers to analyze the influence of both the structure and the governance on the performance of the cluster. The survey consisted of four sets of questions:

1. Questions to assess the embeddedness and linkages of the respondent's organization in the cluster.
2. Questions to find out the opinion of the respondents with regard to a number of propositions, derived from the theoretical framework. The experts are asked to indicate whether or not they agree with the propositions.
3. Questions to access the relative importance of the various variables of cluster performance. Apart from the validity of a variable, the survey questions address the issue of the importance of a variable, compared to the other variables.
4. Questions to compare the strengths and weaknesses of the case study port cluster with competing clusters. These results can be compared with reports and studies to cross check for consistency and to assess the quality of governance, compared to competing ports. This provides a basis for analyzing which governance arrangements are effective (p. 76-77).

The examination Lower Mississippi port cluster identified five important collective action problems including education infrastructure, marketing, innovation, internationalization, and hinterland access. The lack of leader firms, financing, organizational infrastructure, and co-operation were identified as factors limiting the ability of the cluster's collective action regime to address these problems particularly when compared to the port cluster in Rotterdam.

The survey used to examine the Lower Mississippi port cluster by de Langen (2004) was revised for this research in order to examine the Tennessee-Tombigbee port cluster (TTPC). The questions were inserted into an online survey tool, Survey Monkey, and distributed to 21 port directors and 70 tenants, shippers, operators, and affiliated businesses; of these, thirty-three responded to the survey instrument. After initially sending out the electronic survey, follow-up phone calls were made to encourage participation.

***Findings***

Most of the respondents agreed that internal competition adds to the performance of the port cluster (63.6%) and leads to vitality and vibrant competition (54.2%) but were relatively split on whether increased internal competition would lower costs. However, they did not believe that internal competition was stronger than external competition (17.4%). Indeed, no internal competition was reported most frequently regardless of market segment. All the sectors appear to lack extensive competition with container handling and pilotage being identified as sectors having the least internal competition (See Figure 2). The development of a more internal environment through the entrance of new organizations could improve the performance of the entire TTPC.

The essential ingredients for a cluster (e.g., specialized labor force, interrelated companies) appear to be in place, but some areas need improvement. When asked why firms would want to locate on the Tenn-Tom, all respondents agreed cluster related labor force (69.6%), customers and suppliers (91.7%), and knowledge (87%) were success factors for the TTPC. Congestion, wage levels and power of labor organizations were not concerns. Barriers to starting a new business in the Tenn-Tom cluster were thought to reduce the cluster's performance (75%). These barriers are caused by inaccessibility of knowledge and networks, and the unavailability of local capital. Interestingly, this lack of capital translates directly into a concern for the quality of the local governance (75%). The TTPC seems to have many successful cluster attributes such as efficient labor markets, concentrations of allied and supporting firms, and productivity-enhancing spillovers, but needs improvement in promoting dynamic local firms and business culture connectivity.

Opportunities for cooperation and innovation are thought to be higher the more diverse the cluster population. There was less certainty that the diversity of the cluster population would reduce the vulnerability of a cluster, whereas the diversity of the resource base would. Cooperation between firms in the TTPC was seen to be of more importance compared to cooperation with firms outside the cluster. When asked specifically about the respondents organization, most thought they were moderately diverse in their economic activities and firm size, but not in their international scope.

This lack of diversity is in part the perceived reason for the lack of development of the cluster (50.9%), but the lack of a culture of trust was seen as the biggest reason (90%). Trust was seen as important because it lowers transaction costs and enables cooperation. Leader firms were seen as important for increasing the quality of the governance of the cluster, as were intermediaries. However, there was no clear intermediary that was of the most importance. Ship's agents, forwarders, ship brokers, associations, commodity traders, and non asset-owning logistic service providers were all seen as relatively important but none as extremely important. However, "knowledge intermediaries" were seen as a source of influence on the port cluster.

These "knowledge intermediaries" are particularly important because practically all the respondents (95%) believe that accessibility of knowledge and information sources influence the performance of the port cluster. Most firms in the port cluster access knowledge and information through contacts with "knowledge intermediaries" located in the cluster. However, increased trust and improved networking is needed so the knowledge spreads throughout the cluster.

A number of important collective action problems were identified in the survey (See Figure 3). Problems are present with hinterland access being the greatest issue.

Hinterland access was considered important or very important by 95.5% of the respondents. Marketing and promotion (90%), and training and education (95.2%) were also considered important or very important. International opportunities and innovation were not consistently perceived as being very important.

### Discussions of the Findings

The same collective action problems found with the Lower Mississippi port cluster including education and training, marketing and promotion, innovation, internationalization, and hinterland access were also identified in the Tenn-Tom cluster. The lack of leader firms, financing, organizational infrastructure, and co-operation were identified as factors limiting the ability of the cluster's collective action regime to address these problems, but the issues did not seem as severe as De Langen and Visser (2005) found facing the Lower Mississippi port cluster. Further, there are several indications that the TTPC is addressing in the process of addressing its collective action problems.

Five of the ports have come together to form a partnership, GrowPorts, to promote "green energy driven economic development and transportation through the development of a comprehensive, energy-efficient intermodal transportation network connecting the inland waterways of the Tennessee River with the international waterways through Mobile, Alabama" (Growports, 2009). COB and timely delivery are major goals of this new partnership. This organizational infrastructure has already improved cooperation including jointly seeking ARRA stimulus funding, but more competition and leader firms are still needed.

Internal competition contributes to the performance of port clusters since monopoly pricing is prevented, and it fosters specialization and innovation (de Langen, 2004, p. 136). The lack of internal competition, diversity and trust is hurting the Tenn-Tom cluster. Collective action problems that exist and need to be addressed include the lack of innovation (e.g., COB), marketing and promotion, and hinterland access. An example of how the hinterland access can be improved is through revitalization of the shortline railroads that service the Tenn-Tom including the Columbus and Greenville railroad line (Stich, Martin, Waide, & Eksioglu, 2007). Nevertheless, the availability of labor, customers and suppliers and the knowledge base of the cluster are strengths that the collective action regime can build upon.

Leader firms are "firms with both the ability and the incentives to make investments with positive external effects for other firms in the cluster" (de Langen, 2004, p. 194). The Tenn-Tom cluster will need to attract or develop leader firms that can contribute to the understanding of governance in the cluster. The analysis of the collective action problems show the difficulties that arise when leader firms and strong local governance is absent.

There are implications from the findings on the Tenn-Tom's collective action regime for the innovations of container-on-barge and system reliability needed to be part of lean production supply chains. There is extensive transportation knowledge in the cluster along with a skilled workforce, but the level of trust and knowledge information flow needs to be improved. Governance needs to be enhanced to allow for better coordination and the development of the shared vision required for COB and tightly scheduled deliveries. The need for this is evident considering the mixed perceived importance of the international opportunities created by containerization and innovation needed to make it happen. Addressing the shortcomings of the present collective action regime will enable the Tenn-Tom to become more innovative and competitive.

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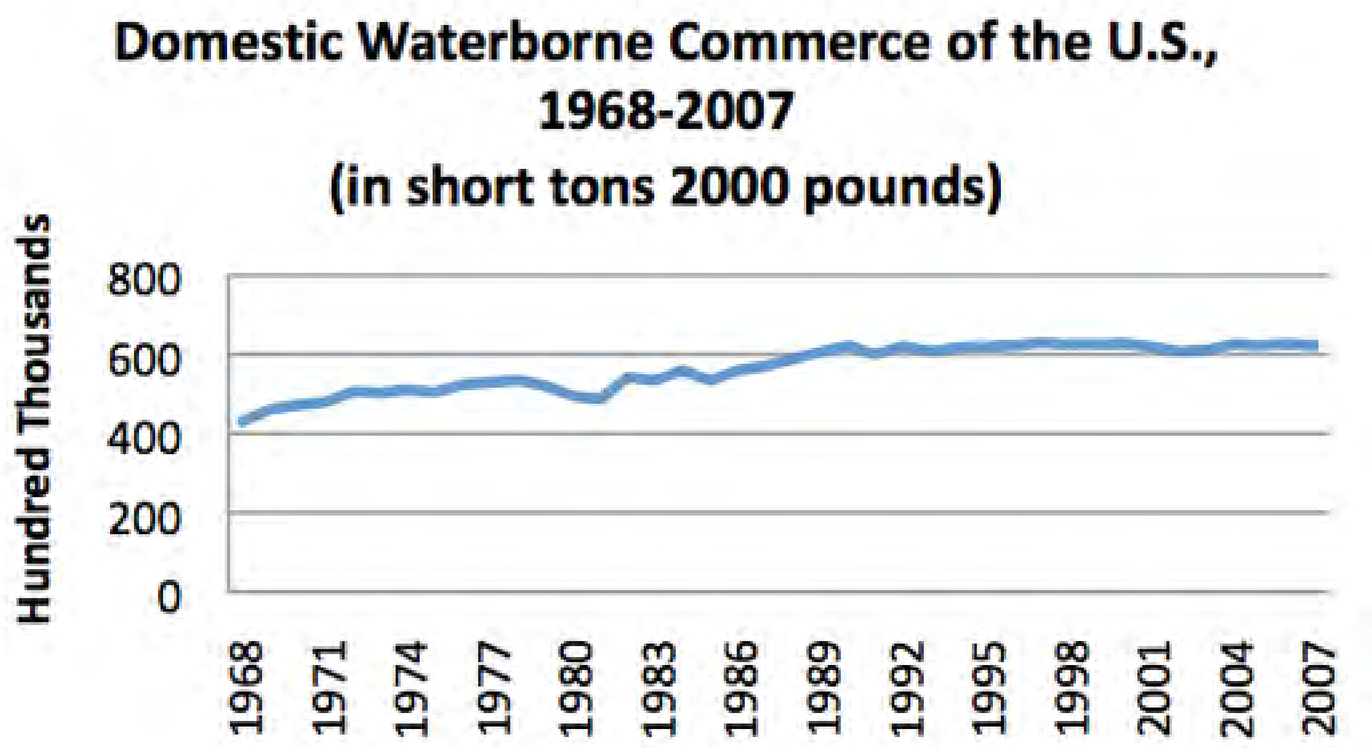


Figure 1 Freight Movement on the Inland Waterways System (Waterborne Commerce Statistics Center, 2009).

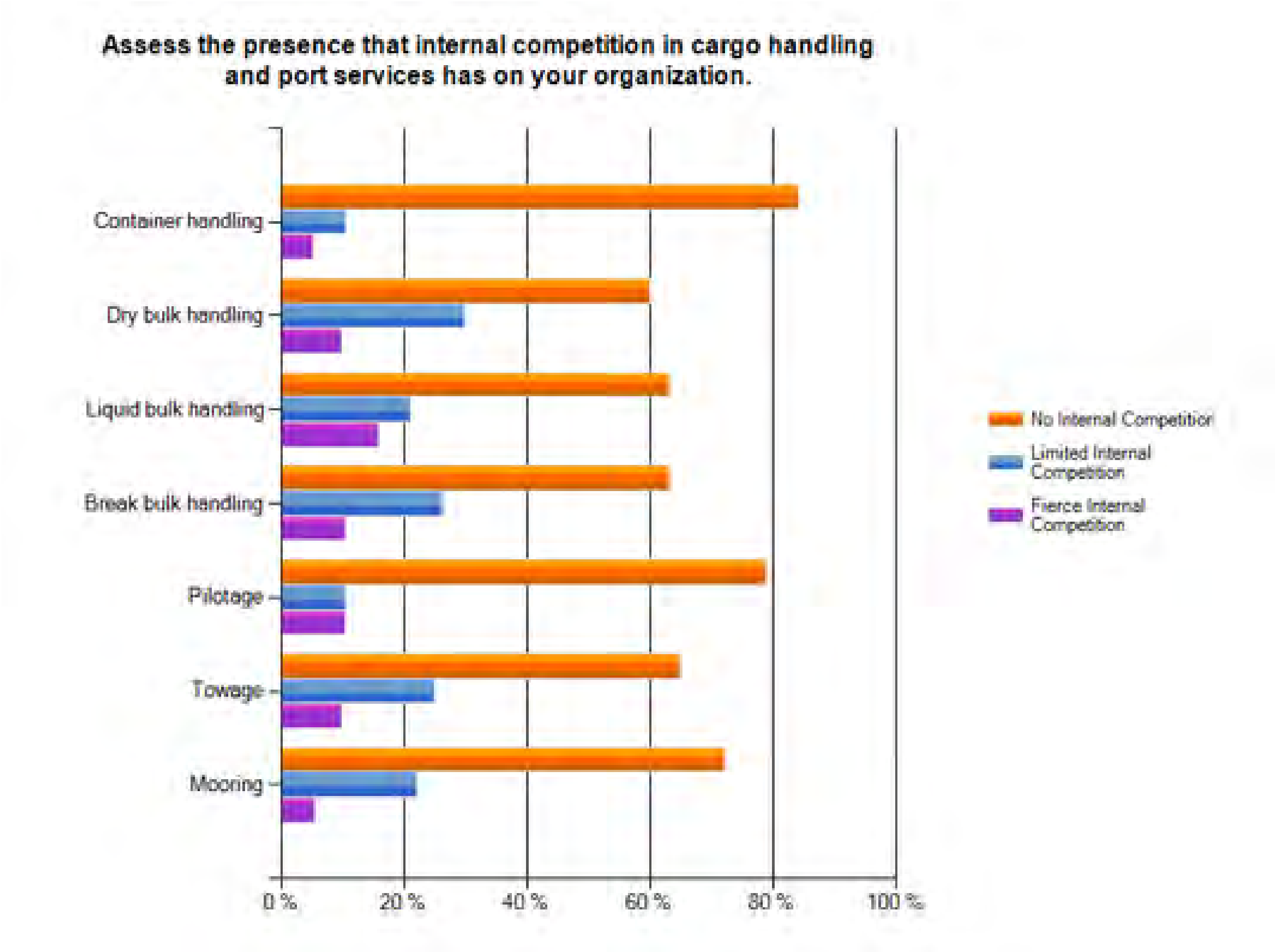


Figure 2. Presence of Internal Competition in the TTPC

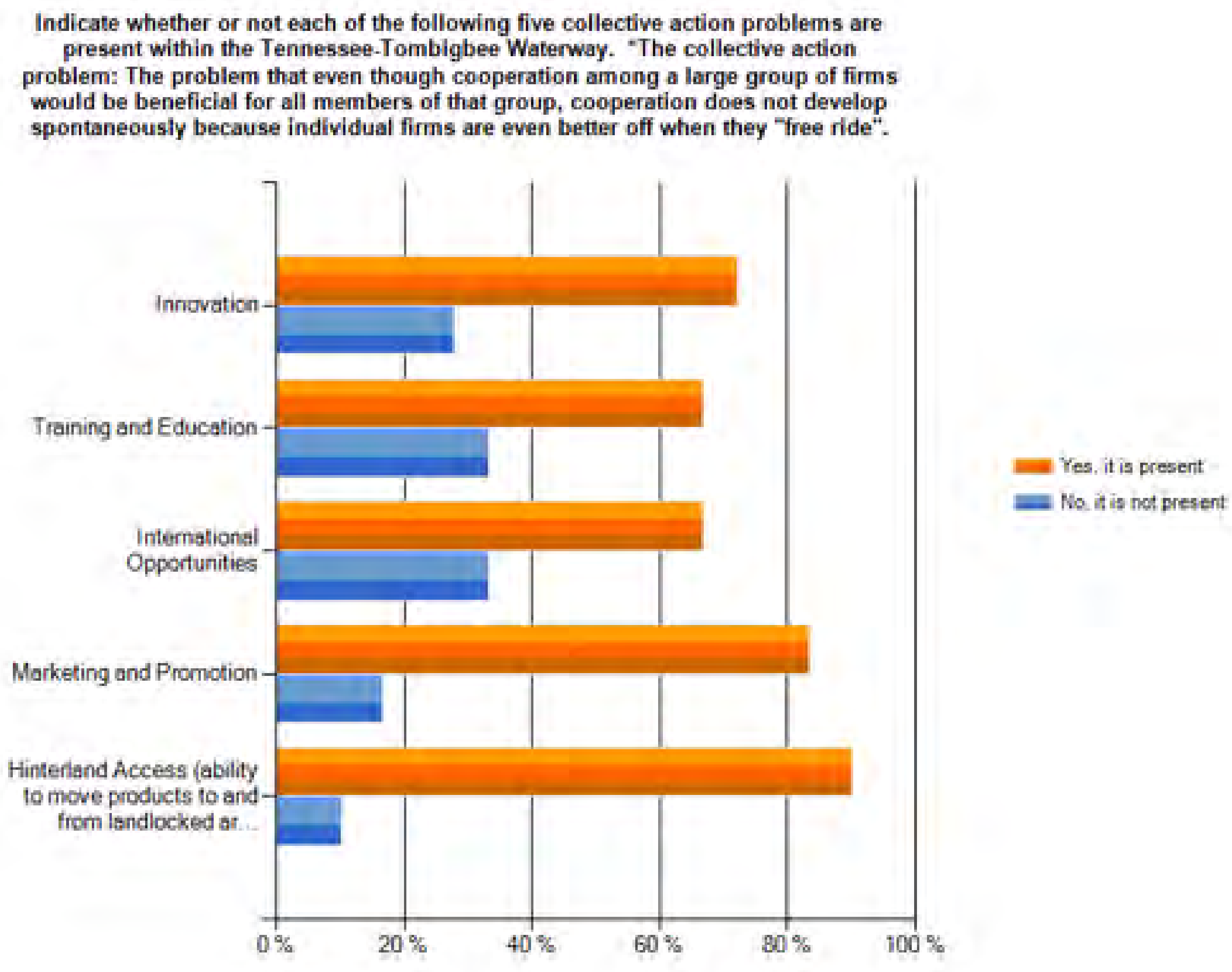


Figure 3. Collective Action Problems of the TTPC

# Sequence Stratigraphy, Depositional Systems, and Ground-Water Supply

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Ground-water supplies in the state's Tertiary, Late Cretaceous, and even Paleozoic aquifers are not all evenly distributed. Many (and some of the most prolific) are concentrated in valley-fill deposits created during times of low sea level and in the channels of fluvial and deltaic systems that formed during sea-level lowstands and sea-level highstand-regressive intervals. Examples of such linear and lenticular water-supply sands include: (1) valley-fill sands in the Tuscaloosa Formation, (2) valley-fill sands in the basal Clayton Formation, (3) valley-fill sands in the Coal Bluff Member of the Naheola Formation (lower Wilcox aquifer), (4) valley fill sands in the Gravel Creek Sand Member of the Nanafalia Formation (lower Wilcox aquifer), (5) valley-fill sands in the basal Tuscahoma Formation (middle Wilcox aquifer), (6) highstand-regressive channel sands in the lower Hatchetigbee Formation (upper Wilcox aquifer), (7) valley-fill sands in the Meridian Sand (upper Wilcox aquifer), (8) highstand-regressive channel sands in the Kosciusko Formation (Sparta Aquifer), (9) highstand-regressive channel sands in the Cockfield Formation, (10) valley-fill sands in the Forest Hill Formation, (10) valley-fill sands in the Waynesboro Sand, (11) valley fill sands in the basal Catahoula Formation, (12) valley-fill sands in the Citronelle Formation and other high-level terrace deposits, and (13) valley-fill sands in the Mississippi River Alluvium (Alluvial aquifer).

There are two major drainage systems responsible for most of the valley-fill and fluvial/deltaic-channel deposits, which serve as aquifers for ground-water supplies in Mississippi. The first is an ancient drainage basin with an Appalachian source, which is often referred to as the ancestral Tennessee River. This ancient river system is responsible for valley-fill gravels and sands of the Tuscaloosa Formation in northeastern Mississippi and for the vein-quartz and heavy minerals in the state's Tertiary and Quaternary gravels and sands. The second drainage basin drained a portion of the North American mid-continent and is referred to as the ancestral Mississippi River. This river system has been credited for fluvial sands as old as the Late Jurassic sandstones in the Smackover Formation in west-central Mississippi. It is certainly responsible for those Late Cretaceous and Tertiary formations that thicken along the axis of the Mississippi Embayment as well as the Pliocene gravels of the Citronelle Formation in west-central Mississippi and the perched Early Pleistocene pre-loess gravel deposits below the loess along the eastern Mississippi River valley wall, extending from Tennessee to Louisiana.

Key words: Ground Water, Hydrology, Water Quantity, Water Supply

**Ground-Water Supplies in Lowstand Valley-Fill Sands**

The following are selected examples of low-stand-valley-fill-sand aquifers in Mississippi. In each case, the greatest quantity of ground water can be obtained along the axis of the ancient stream channel.

***Tuscaloosa Formation.***

When the U. S. Army Corps of Engineers made borings in preparation for the divide cut on the Tennessee-Tombigbee Waterway they encountered east-to-west-trending paleovalleys in the eroded Paleozoic basement containing more that 300 feet of Tuscaloosa sand and gravel. At other sites, the Tuscaloosa was absent over Paleozoic highs. Thick occurrences of the Tuscaloosa Formation should provide an excellent ground-water source for central Tishomingo County, Mississippi. Merrill (1988, p. 76, figure 74) gave an isopach map for thickness of the Tuscaloosa Formation in Tishomingo County and a cross section across paleovalleys (Figure 1).

***Coal Bluff Member of the Naheola Formation.***

Beach and nearshore sands of the Coal Bluff Member of the Naheola Formation stretch along an ancient shoreline from the type locality in Wilcox County, Alabama, where the member contains marine fossils and overlies lignite-bearing clays of the Oak Hill Member of the Naheola Formation, through Kemper (Figures 2) and Noxubee (Figure 3-5) counties northward to Union County (Figure 6) and the Tennessee state line. These sands rest on the weathered and eroded upper surface of the Oak Hill Member, which in places has weathered to a regolith of bauxite and kaolinitic clay. The sands of the Coal Bluff Member and those of the overlying Gravel Creek Member of the Nanafalia Formation (Figure 7), which channel into lignitic, kaolinitic, and bauxitic strata of the upper Coal Bluff Member, comprise the lower Wilcox aquifer.

***Tuscahoma Formation.***

The lower Tuscahoma Formation contains a fluvial sand interval above the lignite-bearing clays and sands of the Grampian Hills Member of the Nanafalia Formation. The lower Tuscahoma sand interval is called the Middle Wilcox aquifer. There is an east-to-west-trending channel at the base of the lower Tuscahoma sand that was exposed in the Red Hills Lignite Mine in Choctaw County, Mississippi. Water seepage from this channel sand has been a problem at the mine, but such channels could be an important ground-water resource (figures 8-9). Figure 10 shows a lignite-filled oxbow-lake channel in the upper Tuscahoma Formation in a roadcut on Interstate 20 east of Meridian.

***Lower Hatchetigbee Sand and Meridian Sand.***

The lower sand of the Hatchetigbee Formation of the upper Wilcox Group and the Meridian Sand of the lower Claiborne Group are placed together within the Upper Wilcox aquifer. Though the fluvial lower Hatchetigbee sand is part of a regressive highstand sequence at the top of the Wilcox Group and the Meridian Sand is the lowstand beach sand of the transgressive lower Claiborne Group, these sands are separated at times by only a thin, clay-rich, floodplain section of the upper Hatchetigbee Formation (Figure 11) and both may be strongly cross bedded. Figures 11-13 show the cross bedded lower Hatchetigbee sand at the excavation site of the Super Wal-Mart in Meridian. Excavations in the old Colvert sand pit in Meridian, to the west of the Super Wal-Mart site, exposed massive channel sands of the lower Hatchetigbee Formation, containing large clasts of bedded silt and clay eroded into the channel from levee deposits (figures 14 and 15). Figures 16-19 show the cross bedded Meridian Sand in a sand pit on Mt. Barton in Meridian. Figure 20 shows Ophiomorph burrows, the borrows of nearshore callianassid shrimp, in a road cut in the Meridian Sand on Highway 16 near Philadelphia, Mississippi.

***Waynesboro Sand.***

Hendy (1948, p. 29) named the Waynesboro Sand as a cross-bedded fluvial channel sand of early Bucatunna age. He stated that: “A fairly large stream in the general vicinity of the present Chickasawhay River eroded a surface well down into the Marianna in an area centering approximately two miles west of the common corner of Twps. 9 and 10 N., Rgs. 6 and 7 W [Wayne County, Mississippi]." Hendy (1948) gave a measured section of the Waynesboro Sand in Stop 10 of the Mississippi Geological Society Sixth Field Trip Guide Book. Johnson (1982) recognized the Waynesboro Sand as a lentil of the Bucatunna Formation and illustrated the laminated and cross bedded strata of this lentil at Hendy's Stop 10 locality. He also included three cross sections, a net sand isopach for the Waynesboro Sand in Wayne County, and a isopach map of the interval between the base of the Glendon Formation and the top of the Bucatunna clay. The greater thicknesses of the latter map tracked the depth of the erosional surface above the Glendon and Marianna limestone sections. Johnson noted the thickest Waynesboro Sand section, approximately 100 feet of sand resting on the lower ledges of the Glendon Limestone, to occur beneath the Town of Waynesboro where it served as a good source of water for small-capacity wells.

Though both Hendy and Johnson placed the deposition of the Waynesboro Sand as contemporaneous with the typical marine/lagoonal Bucatunna Clay, it is more likely a valley-fill lowstand deposit associated with the drastic 29 Ma sea level fall on the "Cenozoic Cycle Chart" of Vail and Mitchum (1979) discussed below. Dockery in MacNeil and Dockery (1984, p. 22-23) stated that: "Fresh water flowing through the Waynesboro fluvial system flushed through the underlying Glendon bedrock to produce vuggy limestones, collapsed rubble zones, and other karst features." Figure 21 illustrates a Waynesboro channel sand cutting into leached Glendon Limestone at a quarry of the Wayne County Lime Company north of Waynesboro, where the Glendon contains large masses of sparry calcite, a rarity in the state.

**Ground-Water Supplies in Highstand Regressive Fluvial and Deltaic Sands**

Both the Kosciusko and Cockfield formations of central and northwestern Mississippi contain highstand regressive fluvial and deltaic sands, which are important aquifers in the Delta region and across central Mississippi. In northwest Hinds County both formations contain upper and lower aquifer sands, and in both cases the lower sand has the better water supply. The Kosciusko sands in the subsurface are referred to as the Sparta aquifer.

A study of confining beds (aquitards) bounding the Cockfield Formation and the net sand thicknesses within the formation showed the presence of channel systems associated with ancient rivers and delta distributaries (Dockery 1976). Such channel sands produce the greatest ground-water supply within the formation. A sea-level rise in the late Middle Eocene Cook Mountain Formation established a limestone bank and shelf across southern Mississippi and a clay-rich shelf across west-central Mississippi, which now function as an aquitard between aquifer sands in the Kosciusko and Cockfield formations. Deltas, followed by river systems, prograded southward above the underlying Cook Mountain marine shelf, as the shelf filled with sediments and the ocean retreated. A second sea-level rise flooded the deltas and produced a second limestone shelf across areas of southern Mississippi. The final progradation of Cockfield deltas covered the second limestone shelf with a thick clay and sand sequence and covered the offshore Cook Mountain carbonate bank with a layer of clastic marine mud. The stratigraphic sequence produced by prograding deltas, in ascending order, include: (1) prodelta clays, (2) delta-front sands, (3) distributary-mouth-bar sands, and (4) delta plain clays and lignites. While delta-front sands may produce a tabular, wide-spread sand unit, distributary-mouth-bar sands are lenticular, linear, thicker, and thus have the potential to produce a greater water supply.

Figure 22 shows facies of the Cook Mountain and Cockfield formations across their outcrop belts in central Mississippi. Figures 23-25 show the Archusa Marl Member of the Cook Mountain Formation at Dobys Bluff on the Chickasawhay River near Quitman, Mississippi. This is the best exposure of the Cook Mountain limestone shelf, which underlies much of southern Mississippi as shown in Figure 26. North-to-south and northwest-to-southeast cross sections across the limestone shelf and bank (figures 27-28) show the updip and downdip deltaic and marine facies of the overlying Cockfield Formation.

Figure 29 shows the formation of a second Cook Mountain limestone shelf and marine reworking of delta sands in the Cockfield Formation. In one area, the second marine shelf and reworked delta sands merge together.

Figure 30 shows an exposure in Clarke County of the Cockfield delta-front sands overlain by delta plain deposits, including a lignitic-clay-filled channel. These sediments are part of a second deltaic progradation in the Cockfield Formation, which is illustrated in the net-sands map of Figure 31. Updip fluvial facies, as seen in the west-to-east cross section of Figure 32, are characterized by thick linear channel sand trends, containing an abundant groundwater supply. Figure 33 contains a north-south cross section down a fluvial and delta-distributary sand trend and a northeast-to-southwest cross section across delta-sand trends. Figure 34 follows a delta sand trend from northwestern Madison County till the trend ends in southeastern Jasper County. A recent (September 21, 2009) water-well geophysical log made along this trend in Rankin County at an elevation of 600 feet above sea level in the ACL Water Association #3 Firetower well in Section 36, T. 5 N., R. 4 E. showed 75 feet of clay-rich delta-plain deposits in the upper Cockfield Formation followed by a continuous 195-foot-thick channel sand at the base of the formation. Below this was 85 feet of the Cook Mountain marine clay and sand. The Kosciusko Formation below contained the following, in ascending order: (1) 130 feet of clay-rich delta-plain deposits, (2) continuous channel sand that was 190 feet thick, (3) 40 feet of clay-rich sediments, and (4) 130-foot-thick basal sand. At this site, the driller had a choice of three aquifer sands to screen for a water well; it is usually the lower sand of the Kosciusko Formation that provides the most abundant water supply of the three sands.

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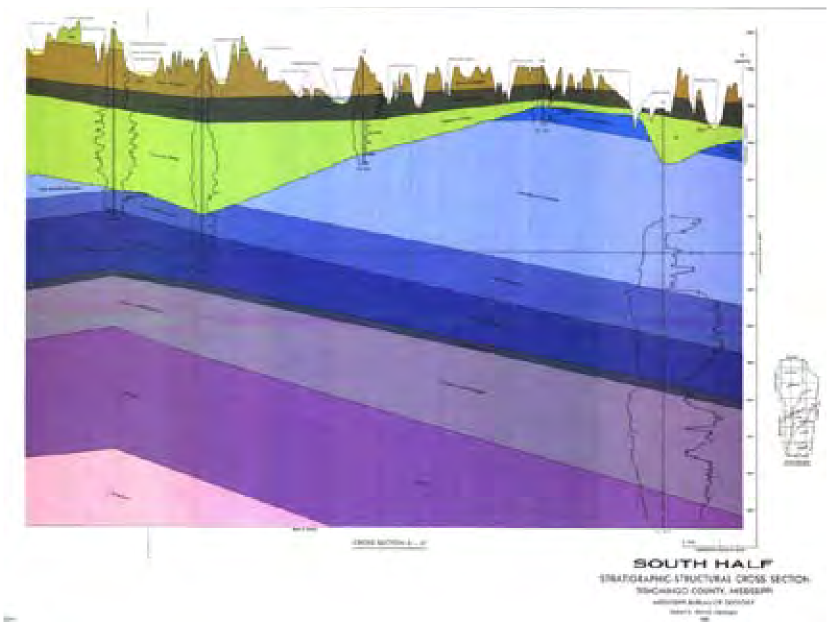


Figure 1. South half of a north-south cross section through Tishomingo County, Mississippi, by Bob Merrill (1988), showing the thickening of the Tuscaloosa Formation (green) within a valley cut into the Paleozoic bedrock.

Figure 2. Ernest Russell (left) and Tom Gibson (right) at USGS sample site 16.1 in the Oak Hill Member just below sands of the Coal Bluff Member in the SW/4, SW/4, Section 23, T. 11 N., R. 16 E., Kemper County. Picture (Kodachrome slide 404-2) taken on May 9, 1990.

Figure 3. Contact of clay and lignite (just below contact) of the Oak Hill Member with sands of the overlying Coal Bluff Member at the Delta Brick clay pit in the SE/4, NW/4, Section 7, T. 13 N., R. 155 E., Noxubee County. Picture (Kodachrome slide 223-7) taken on May 10, 1990.

Figure 4. Tom Gibson taking a clay sample below the lignite seam at the top of the Oak Hill Member and below the sands of the overlying Coal Bluff Member. Picture (Kodachrome slide 223-6) taken on May 10, 1990.

Figure 5. George Puckett (left) and David Thompson at sand pit in the Coal Bluff Member with cross-bedded, white, very loose sands, containing quartzite pebbles in Section 15, T. 13 N., R. 15 E., Noxubee County. Picture (Kodachrome slide 231-11) taken on October 7, 1992.

Figure 6. David Dockery standing on a quartzite ledge protruding from the sands of the Coal Bluff Member in a sand pit on the south side of Highway 30 in the NW/4, SW/4, Section 9, T. 7 S., R. 1 E., Union County. Picture (Kodachrome slide 399-11) taken in June of 1973.

Figure 7. Lignite seam (site of USGS sample 21) and brick clay in the Coal Bluff Member (Naheola Formation) below channel sand in the Gravel Creek Sand Member (Nanafalia Formation) in the Delta Brick pit in the NE/4, SE/4, Section 28, T. 12 N., R. 15 E., Kemper County. Picture (Kodachrome slide 404-18) taken on May 10, 2990.

Figure 8. A channel sand in the lower Tuscahoma Formation at the Red Hills Lignite Mine underlies the J seam and, at right, cuts out the I and H2 seams. The G and F seams can be seen bending beneath the channel sand where they intersect the ramp ascending from the quarry floor. Picture (slide 393-38) taken on November 10, 2004.

Figure 9. Lignite seams bend beneath a fluvial channel sand (upper right) in the middle Tuscahoma Formation, which cuts out the I and H2 lignite seams. The red cable carries 60,000 volts to power the dragline. Picture (color negative 531-16) taken on November 11, 2004.

Figure 10. Channel lignite in the Tuscahoma Formation on south side of Interstate 20 in the SW/4, SE/4, Section 23, T. 7 N., R. 17 E., Lauderdale County. Picture (slide 131-14) taken in September of 1976.

Figure 11. Ken Davis holding survey rod on a channel sand in the lower Hatchetigbe Formation at the construction side of a Super Wal-Mart in Meridian, Mississippi. Here the channel sand is about 30 feet thick and comprises the excavation floor and two benches in the high wall. Picture (slide 341-14) taken on October 13, 2000.

Figure 12. Ken Davis holding survey rod on a bench cut into the cross-bedded channel sands of the lower Hatchetigbee Formation at the construction site of the Super Wal-Mart (power pole site) in Meridian (view is to the west). Picture (slide 341-5) taken on October 13, 2000.

Figure 13. Ken Davis holding survey rod beside cross-bedded channel sand in the lower Hatchetigbee Formation at the Super Wal-Mart construction (at power pole site) in Meridian, Mississippi (view is to the west). Cross-bed laminae indicate that stream flow was from north to south. Picture (slide 340-15) taken on October 13, 2000.

Figure 14. From left to right, Ernest Mancini, Jan Handronbol, and Bill Berggren at the Covert pit in Meridian. Mancini is looking at boulder-size clay clasts in the channel sands of the lower Hatchetigbee Formation. Picture (Kodachrome slide 225-8) was taken on October 27, 1991.

Figure 15. Tom Gibson examining large clay clasts embedded in the channel sands of the lower Hatchetigbee Formation at the Covert sand pit west of 31st Street and south of I-20 in Meridian, Mississippi. Picture (Kodachrome slide 222-10) taken on May 8, 1990.

Figure 16. Contact of the cross-bedded Meridian Sand and the overlying, more-massive Tallahatta Formation at Mt. Barton south of Interstate 20 in Meridian, Mississippi. Picture (slide 136-20) taken on March 21, 1981, during a GSA field trip.

Figure 17. Crossbed sets in the upper Meridian sand at Mt. Barton in Meridian, Mississippi. Picture (Kodachrome slide 237-14) taken on June 5, 1993, during a GSA field trip.

Figure 18. Bill Berggren (far left) looking at the Meridian-Tallahatta contact as pointed to by Nick Tew (second from left) at Mt. Barton in Meridian, Mississippi. Picture (Kodachrome slide 224-20) taken on October 27, 1991.

Figure 19. Bill Berggren just above the Meridian-Tallahatta contact on the slope of Mt. Barton, an outlier of the Tallahatta cuesta with a view of Meridian to the north. Picture (slide 203-2) taken on August 16, 1988.

Figure 20. *Ophiomorpha*, trace fossils of callianassid shrimp burrows, in the Meridian Sand in a road cut on Highway 16 west of Philadelphia, Mississippi. Picture (slide 368-12) taken on September 4, 2003.

Figure 21. Hammer marks the base of a channel in the Waynesboro Sand cut into the leached zone of the Glendon Limestone in a test pit at the agricultural lime quarry in Wayne County. Picture (Kodachrome slide 140-15) taken on February 11, 1984.

Figure 23. The contact of the Dobys Bluff Tongue of the Kosciusko Formation (gray at bottom) and the Archusa Marl (white limestone on top) at Dobys Bluff on the Chickasawhay River below Quitman in Clarke County (MGS locality 26). Picture (slide 314-11) taken by Linda Ivany.

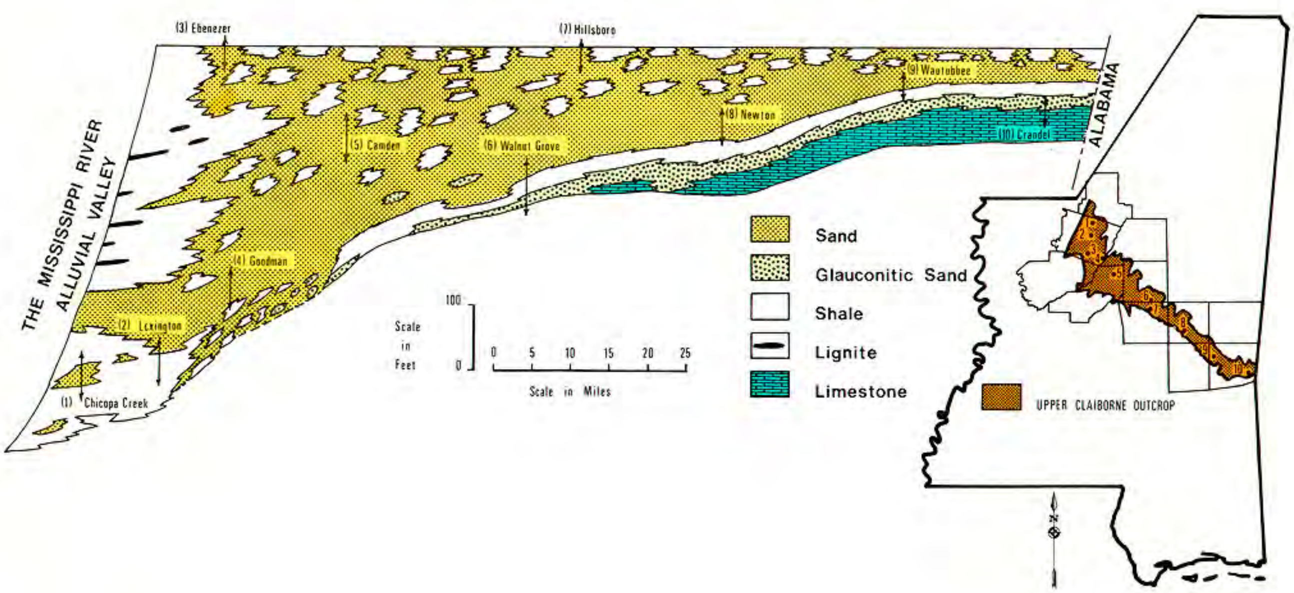


Figure 22. Facies of the Cook Mountain and Cockfield formation along their outcrop belt. Marine carbonates and clastics of the Cook Mountain Formation grade north and west into the laminated shales of the Gordon Creek Shale Member (after Thomas, 1946).

Figure 24. David Williamson standing on the bank of the Chickasawhay River at Dobys Bluff (MGS locality 26), where the Archusa Marl forms a vertical wall. Picture (slide 132-28) on August 26, 1976.

Figure 25. David Williamson points at contact of the Dobys Bluff Tongue of the Kosciusko Formation (below) and the Archusa Marl Member of the Cook Mountain Formation (above) at Dobys Bluff on the Chickasawhay River (MGS 26). Picture (slide 119-2) taken in June of 1974.

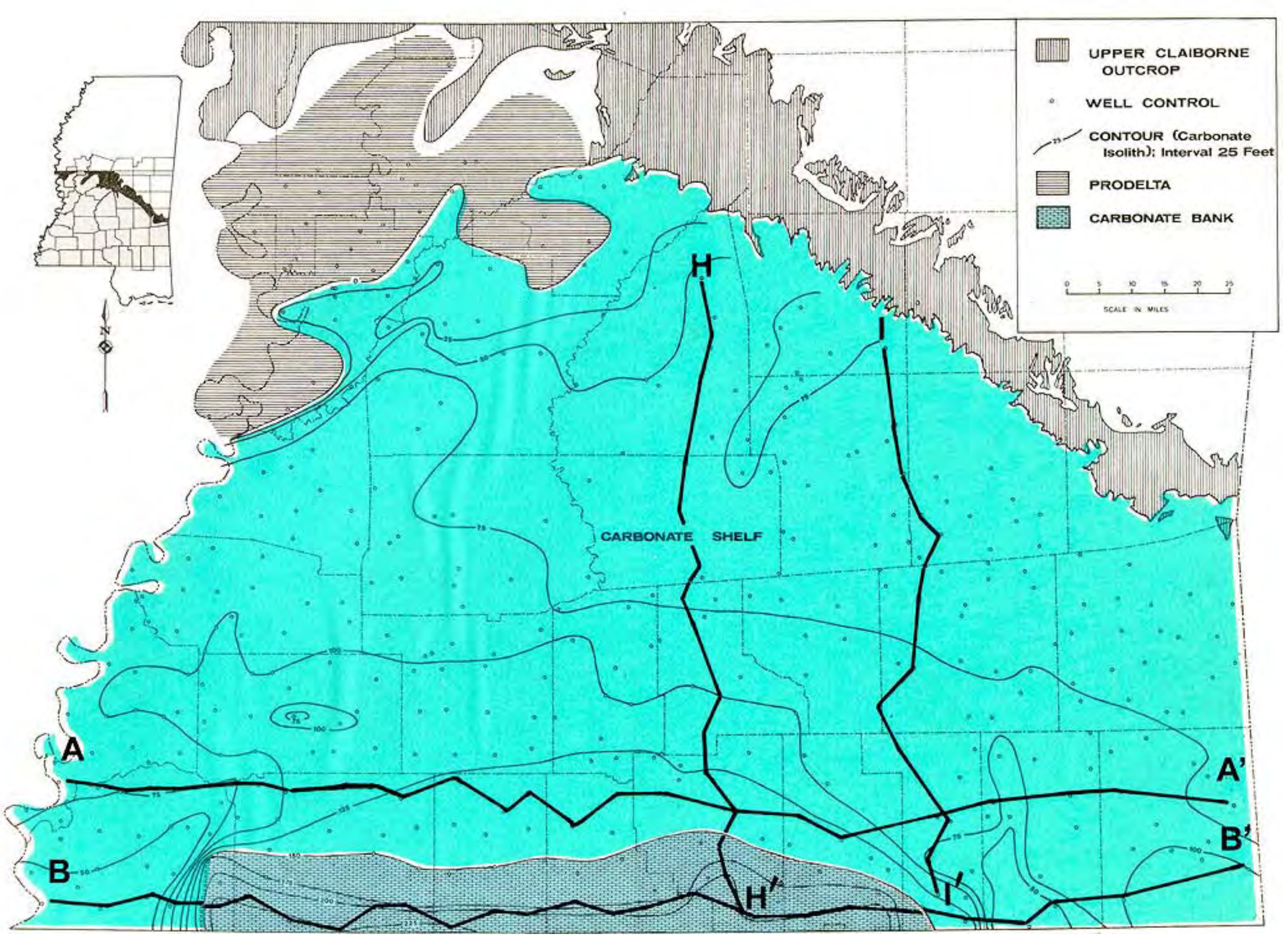


Figure 26. Carbonate isolith map of the Cook Mountains limestone in south-central Mississippi and location map for east-west cross sections A-A' and B-B' and north-south cross sections H-H' and I-I'. B-B' follows depositional strike across a carbonated bank, while H-H' is a dip section extending across the carbonate shelf to the carbonate bank (from Dockery, 1976).

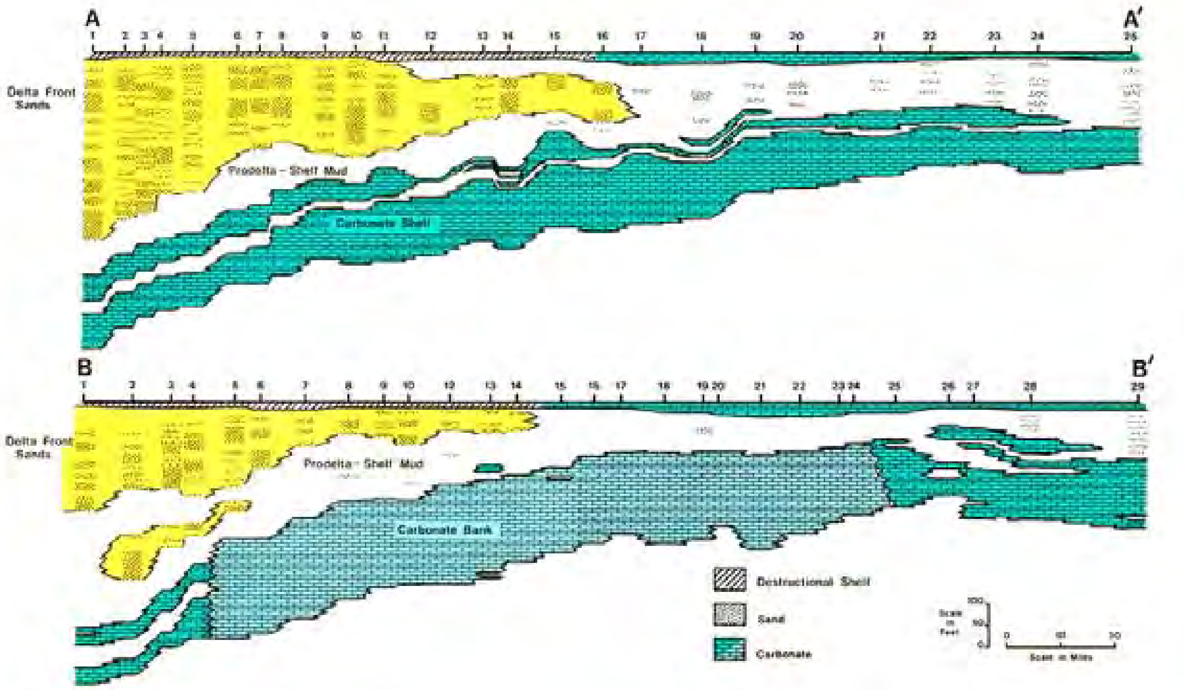


Figure 27. East-west cross sections A-A' and B-B'; A-A' shows the lower and upper carbonate shelf units of the Cook Mountain Limestone, while B-B' extends across a carbonate bank south of the carbonate shelf (from Dockery, 1976).

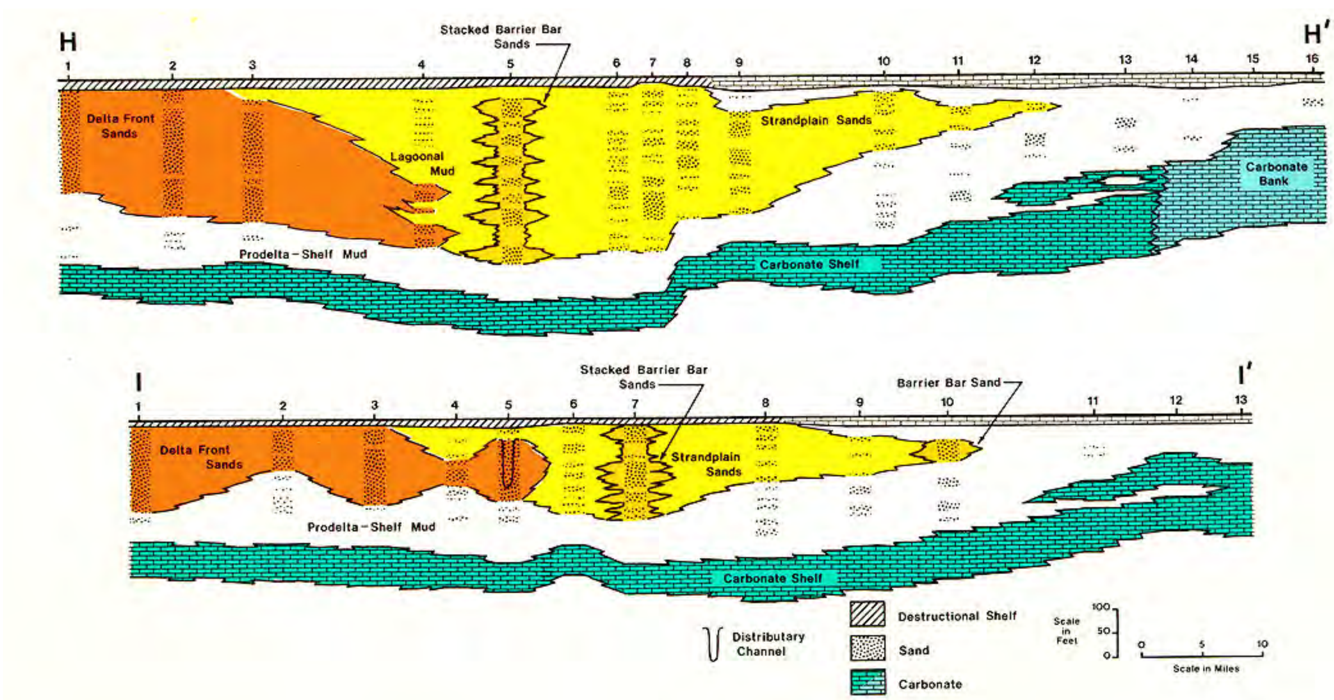


Figure 28. North-south cross section H-H' and I-I', showing updip delta-front sand facies and downdip barrier-bar facies of the Cockfield Formation (from Dockery, 1976).

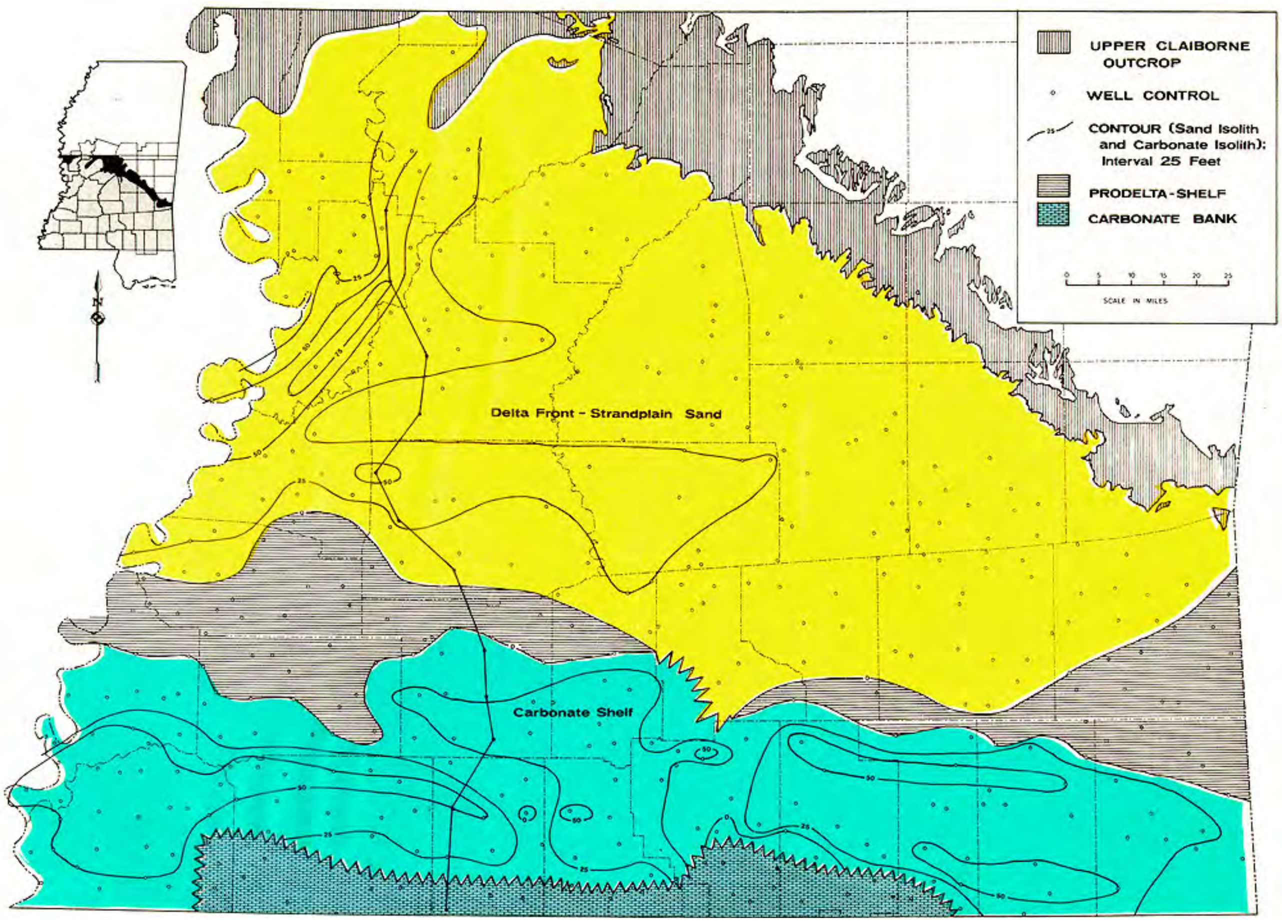


Figure 29. Net sand isolith map for the lower sand sequence of the cockfield Formation and carbonate isolith map for the upper shelf carbonate unit of the Cook Mountain Formation. The lower sand sequence and the upper carbonate unit are separated by marine shales except in Jefferson Davis county where they merge.

Figure 30. Michael Bograd walking toward exposure of the lower delta-front sands and overlying delta-plain sands and lignitic clays of Cockfield Formation at MGS locality 56 in Clarke County. Picture (slide 119-7) taken in June of 1974.

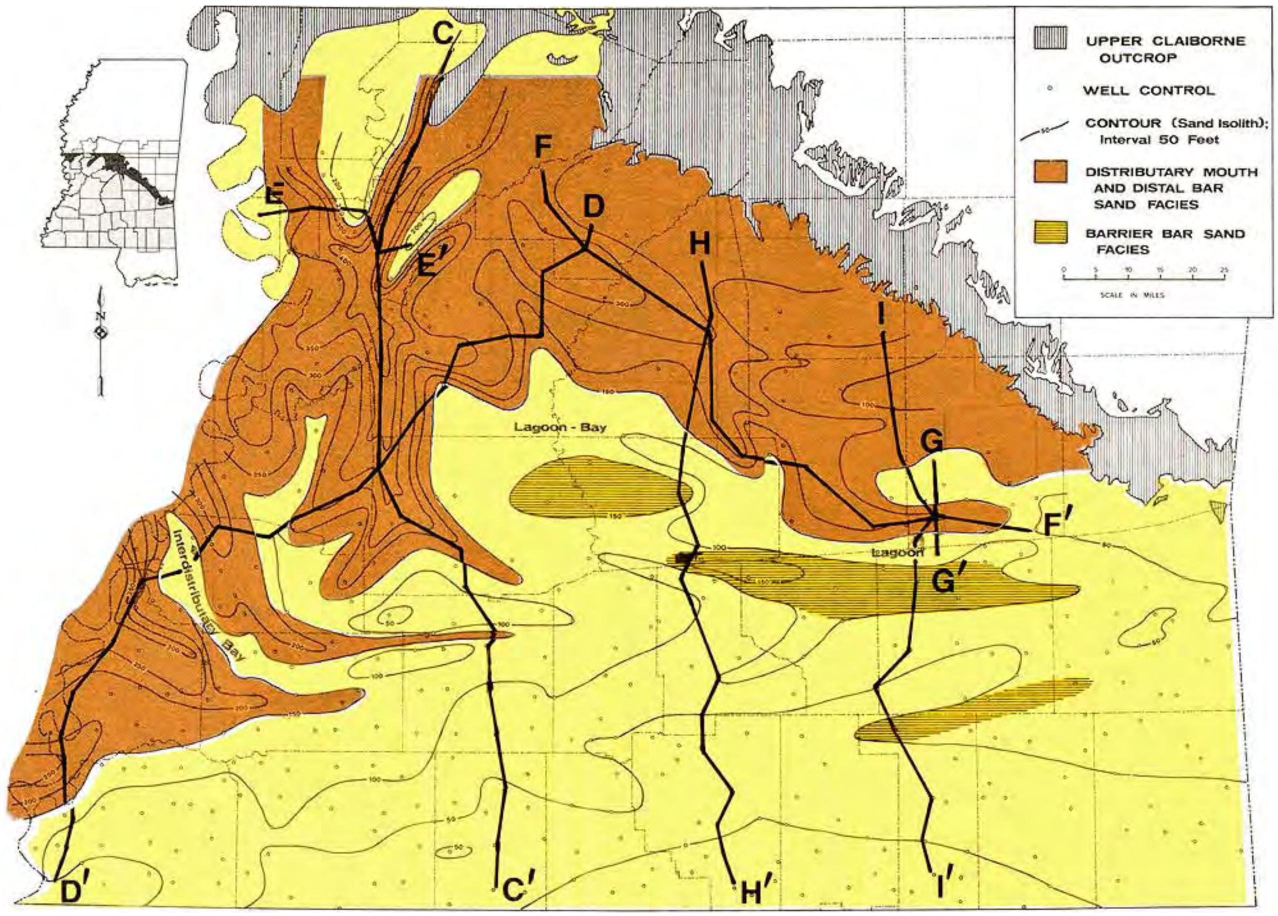


Figure 31. Net sand isolith map, showing delta distributary-mouth-bar-sand trends in the Cockfield Formation of south-central Mississippi and location map from cross section C-C' through I-I'. Delta-front sands occur in the north and west, while barrier-bar sands are present in the southeast (from Dockery, 1976).

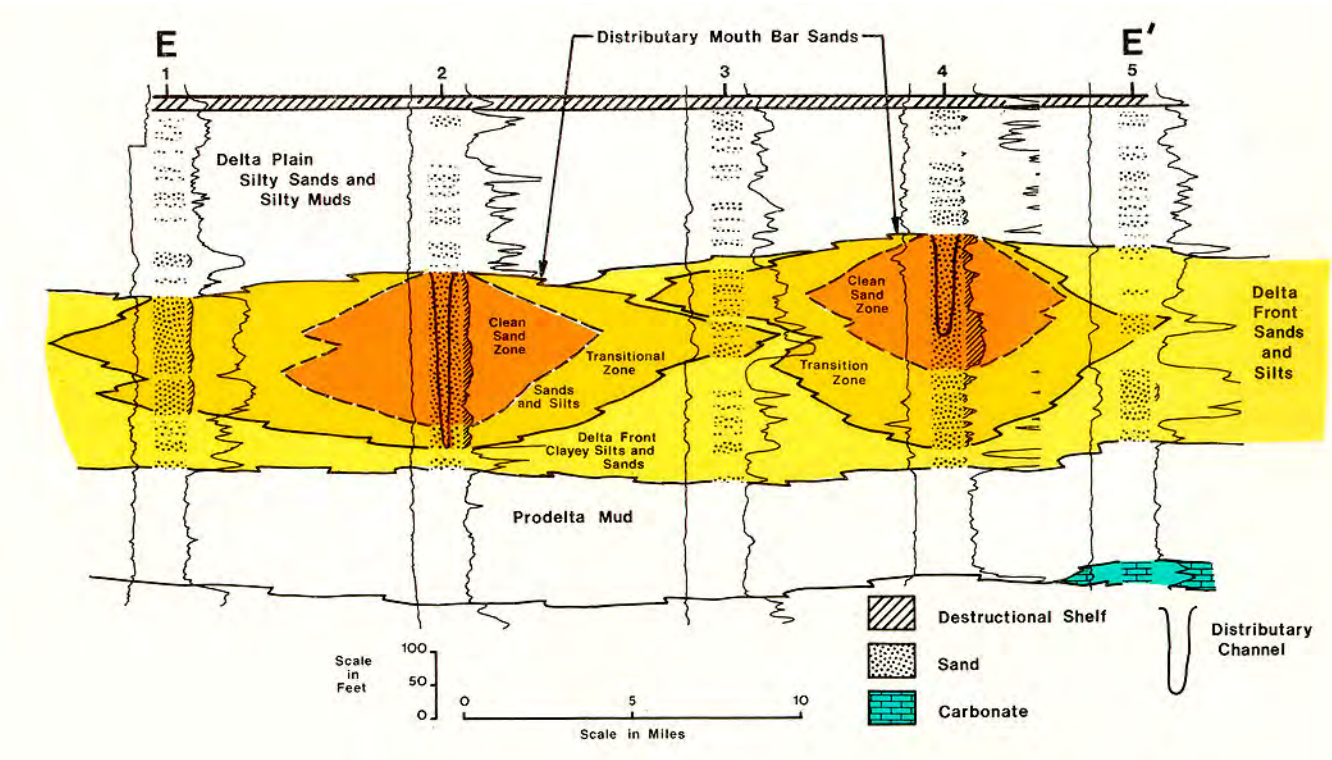


Figure 32. East-west cross section E-E' along depositional strike and across lenticular distributary-mouth-bar sands of the Cockfield Formation in Warren and Yazoo counties, Mississippi (from Dockery, 1976).

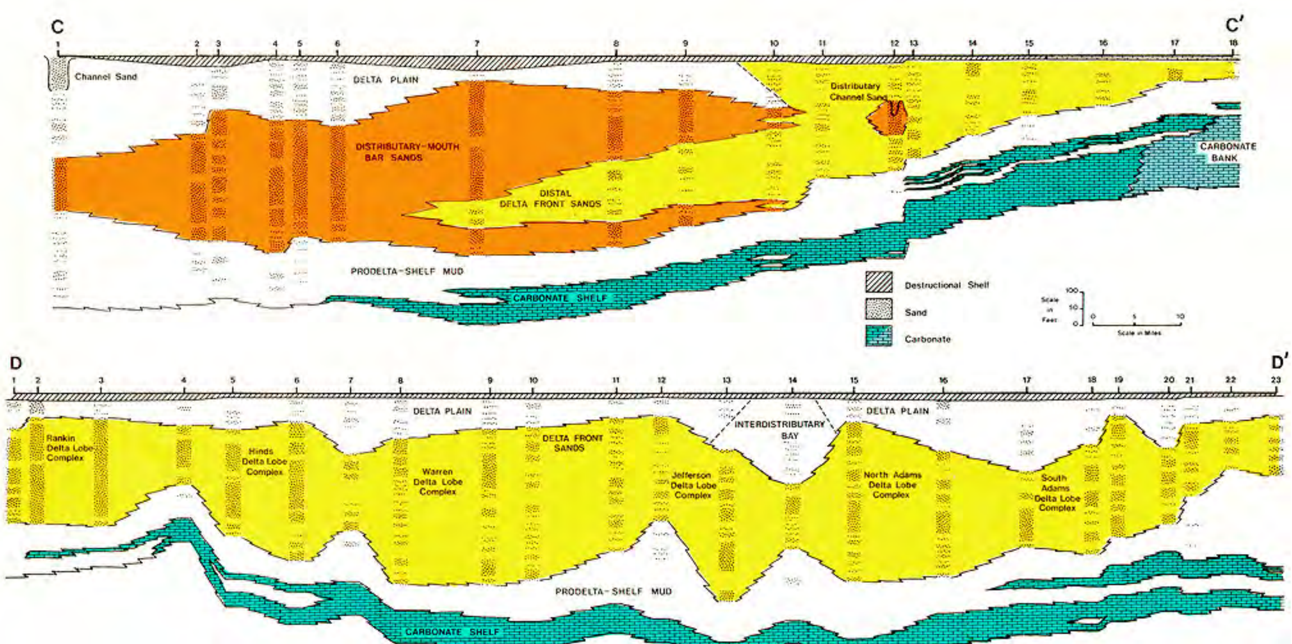


Figure 33. North-south cross section C-C' along the deposition slope of a major delta distributary-mouth-bar-sand trend, extending from Yazoo to Wilkinson County and cross section D-D' along deposition strike and across major delta-sand lobes in the Cockfield Formation (from Dockery, 1976).

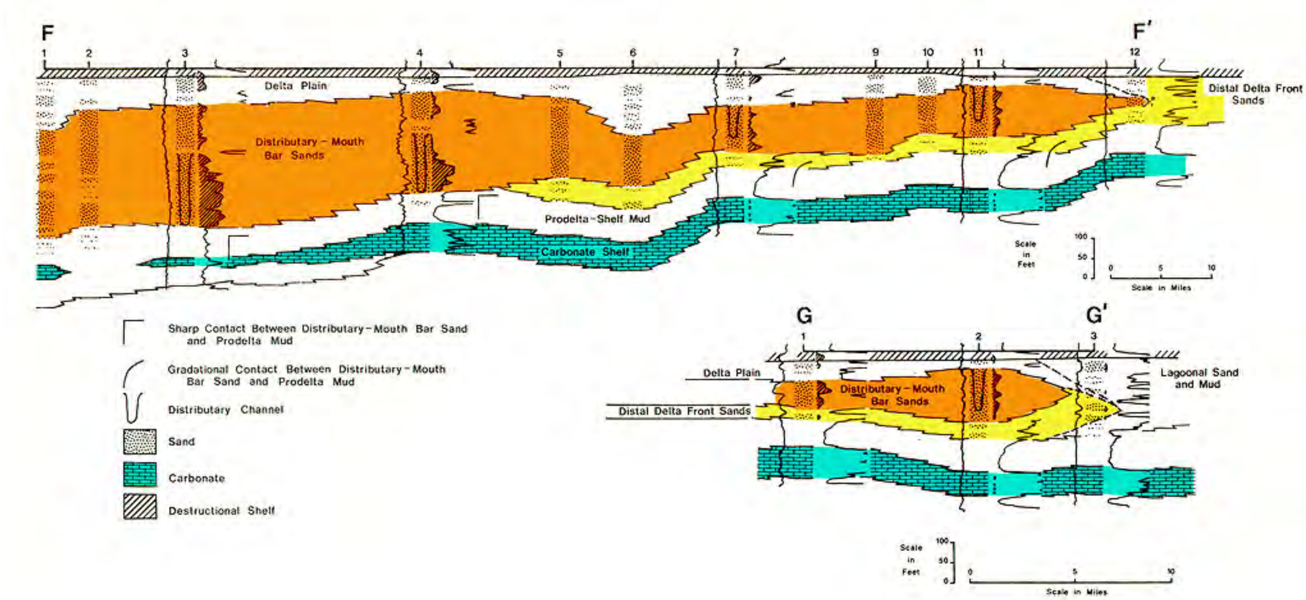


Figure 34. Cross section F-F' follow a distributary-mouth-bar-sand trend in the Cockfield Formation along the depositional slope, while G-G' cuts across the trend in a view that shows the sand to be lenticular (from Dockery, 1976).

# Anthropogenic Chemicals in the Source and Finished Water from Three Mississippi Communities that Use Surface Water as Their Drinking-Water Supply

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The U.S. Geological Survey, in cooperation with the Mississippi Department of Environmental Quality, began a sampling program in the fall of 2007 to analyze water samples for a suite of wastewater indicator compounds and pesticides for the three drinking-water facilities in Mississippi that use surface water from the Pearl, Tombigbee, and Tennessee Rivers as their source water. Three samples, from both source water and finished water, were collected from each facility in October 2007, and January and May 2008. Few wastewater indicator chemicals were detected in source water; however, low concentrations of some commonly used herbicides were detected in the source and finished water from all three facilities. None of these compounds were detected in finished water at or above established drinking-water standards. Modern society depends upon chemicals to prevent and combat disease, cleanse and soften skin, smell better, reduce wrinkles, influence moods, and control weeds and insects for safety and aesthetic reasons. These compounds, which can be found in any drug or hardware store, enter the environment through runoff from agricultural fields, urban lawns, highway rights of way, parks and recreational areas, domestic sewage, and other sources. Some of these compounds have been shown to be stable in the environment, and also have been shown to survive the conventional drinking-water treatment process and be detected in the finished drinking-water supply. Little is known about the abundance and persistence of these compounds in surface waters of Mississippi; hence, there is little information on what effect further development in basins upstream of source-water intakes will have on downstream communities that rely on surface water as their source for drinking water.

Key words: Nonpoint Source Pollution; Source Water; Surface Water; Water Quality; Water Supply

## Introduction

Human impact upon a watershed is inevitable and unavoidable, and the results of these impacts are reflected in the quality of the water that drains the watershed. Modern society depends upon chemicals to prevent and combat disease, cleanse and soften skin, create perfumes, reduce wrinkles, influence moods, and control weeds and insects for safety and aesthetic reasons. These compounds, which can be found in any drug or hardware store, enter the environment through runoff from agricultural fields, urban lawns, highway rights-of-way, parks and recreational areas, domestic sewage, and other sources. Some of these compounds have been shown to be stable in the environment, and also have been shown to survive the conventional drinking-water treatment process and be detected in the finished drinking-water supply. Little is known about the abundance or persistence of these compounds in surface waters of Mississippi; hence, there is little information on what effect further development in basins upstream of source-water intakes will have on downstream communities which rely on surface water as their source for drinking water.

Pesticides are used extensively throughout the United States to improve crop yields, protect the health and safety of citizens, and increase the aesthetic value of parks, golf courses, ponds, and other recreational areas. However, the extensive use of these pesticides has led to the degradation of surface- and ground-water quality in many areas, and in some cases, poses a direct threat to human or aquatic health (Barbash and Resek, 1996; Larson et al., 1997). Pharmaceuticals and endocrine disrupting compounds are subclasses of organic contaminants that have been detected in waste and surface waters throughout the world (Kolpin et al., 2002; Glassmeyer et al., 2005; Boyd et al., 2003; and Ternes et al., 1999). Their occurrence in surface water is most often a result of municipal wastewater discharge, as many of these compounds are not completely removed during treatment (Ternes et al., 1999).

More than 130 million people in the United States receive their drinking water from surface-water sources (Hutson et al., 2004). Surface waters are vulnerable to pesticide contamination because they receive runoff directly from agricultural fields, urban areas, golf courses, rights-of-way, reforested areas, and other areas that typically receive pesticide applications. Pesticides have also been shown to be carried in the atmosphere and to be deposited by wet or dry deposition far from their point of application (Majewski and Capel, 1995). Wastewater treatment plants often discharge into receiving streams that are upstream from intakes for public-water sources.  Some pesticides and other compounds found in wastewater effluent have been shown to survive the treatment process (Coupe and Blomquist, 2004). Scientists and water managers are concerned about the level of risk that may be associated with the presence of these compounds in drinking water (Fono and McDonald., 2008; Donald et al., 2007; Winchester et al., 2009; and Schreinemachers, 2003), as many drinking-water treatment plants use source water impacted by wastewater and/or agricultural runoff.

This paper presents the results of a study to determine the occurrence of pesticides and wastewater indicator compounds in the source and finished water of three public water systems in Mississippi that use surface water as their source of drinking water. This study began in October 2007 and was conducted by the U.S. Geological Survey (USGS) in cooperation with the Mississippi Department of Environmental Quality (MDEQ).  Samples were collected in October 2007, January 2008, and May 2008.

**Background**

The State of Mississippi is rich in water resources, and currently (2009) only three public water systems (PWS) (table 1) use surface water as their source for drinking water. Each of the PWS uses one or more of several basic treatment types: disinfection, coagulation and clarification, filtration, and adsorption (table 2). The method of disinfection varies among PWS, as well as where disinfection occurs in the treatment process. The method of filtration, as well as the type of adsorption, also varies among PWS in this study, and some of these processes vary seasonally dependent upon the quality of the source water.

The quality of the source water used for drinking water is dependent upon basin activities. The Short-Coleman PWS takes its source water from Pickwick Lake, which is a part of the Tennessee River (figure 1). Although the Tennessee River basin is quite rural, and land use is mostly forested (pasture is second to forested), there are major cities in the drainage basin of the Tennessee River which potentially contribute wastewater to the Tennessee River.

The source of water for the City of Jackson is the Ross Barnett Reservoir, which is a water supply and recreational reservoir on the Pearl River in central Mississippi. The drainage area of the Ross Barnett Reservoir is approximately 3,000 square miles, and land use is mostly forest (silvilculture) and some agriculture. There are a number of small communities within the drainage area that potentially contribute wastewater to the Pearl River.

The Northeast Mississippi Water Association (NEMWA) uses the Tombigbee River as its source water. The Tombigbee River basin is rural, and the primary land use is forest. However, when the Tombigbee River falls below a certain stage, the U.S. Army Corps of Engineers diverts water from the Tennessee-Tomibgee Waterway, allowing some water from the Tennessee River into the Tombigbee River. Subsequently, the source water for NEMWA can be quite varied, due to the lockage, as can Short-Coleman PWS' source, due to the varied land use within the basin. Because of this interbasin transfer, the true drainage basins are indeterminate for the purposes of this paper.

**Methods**

The U.S. Geological Survey, in cooperation with the Mississippi Department of Environmental Quality, began a sampling program in fall 2007 to analyze water samples for a suite of wastewater indicator compounds and pesticides for the three drinking-water facilities in Mississippi that use surface water from the Tennessee, Pearl, and Tombigbee Rivers as their source water. Three samples, from both source and finished water, were collected at each facility in October 2007, and January and May 2008.

***Sample collection***

Water samples were collected from a tap on the intake line or, if the tap was not available, from the reservoir or river near the intake line; consecutively, samples were collected from a tap after the treatment process and before entering the distribution system. Because samples were collected consecutively, the intake sample may not represent the sample collected after the treatment process due to the time of travel through the treatment plant. However, due to the relatively short flow-through period at the plants, and the size of rivers and/or reservoirs which would tend to prevent rapid changes in source-water quality under normal conditions, it is expected that any difference would be slight. For the purpose of this paper, it is assumed that the samples are paired samples, and therefore, the difference in concentration represents the effect of the treatment processes.

***Water analysis***

Water samples for the analysis of wastewater indicator compounds were collected in baked amber glass bottles. For finished water samples, a preservative (ascorbic acid and tris-(hydroxymethyl) aminomethane)) was used to quench the free chlorine in the sample and prevent further degradation. The water samples for pesticide analysis were filtered on-site by using an aluminum filter plate with a combusted (baked at 400°C for at least 2 hours) 0.7-micrometer nominal pore size glass fiber filter (Advantec GFF) into 1-L combusted amber bottles. The samples were packed in ice and shipped to the USGS National Water Quality Laboratory in Denver, Colorado, for extraction and analysis. Liquid-liquid extraction was used to isolate the wastewater compounds from the whole water samples, followed by gas chromatography/mass spectrometry (GC/MS). Solid phase extraction (SPE) was used to extract the pesticides from the filtered water samples followed by analysis of the samples by GC/MS. As a quality-assurance measure, additional samples were spiked with surrogate compounds before extraction to measure the extraction efficiency. Pesticides and other related compounds were analyzed by GC/MS as described by Zaugg et al. (1995). Wastewater compounds were analyzed as described by Zaugg et al. (2006). A total of 139 compounds were analyzed using the two methods in this study.

**Results and Discussion**

Of the 139 compounds analyzed for, 120 compounds were not detected in both the source and the finished paired water samples; of the 120 compounds, few were detected in either source or finished water (table 3). Most of the 120 compounds were not detected in any sample. Nineteen compounds were detected in both the source and finished water for at least one sample at one of the PWS's during the study (table 4). None of these concentrations exceeded USEPA Maximum Contaminate Levels. Most of the detected compounds were pesticides or pesticide degradates.

The compounds fall into four broad categories: A.) Compounds detected at all sites and in most sampling events; B.) Compounds routinely detected at just one site; C.) Compounds detected, but not systemically across sampling events or sites; and D.) Compounds that were not detected in any samples. Each category is explained in more detail below:

A. The five compounds that were detected at all sites and in almost all samples were; atrazine, 2-chloro-4-isopropylamino-6-amino-s-triazine (CIAT, a degradate of atrazine), metolachlor, simazine and tebuthiuron. These are all herbicides that are ubiquitous in the environment and frequently used in agricultural and/or urban settings.
B. Fluridone and hexazinone were detected in every sample from the Ross Barnett Reservoir and in the finished water from the City of Jackson. An invasive aquatic plant, hydrilla, has been found in the Ross Barnett Reservoir and fluridone has been used annually for several years as part of the control process (Wersal et al., 2009). Fluridone is applied directly into the reservoir, generally in the spring; hence, the much higher concentrations in May as opposed to October or January. Hexazinone is an herbicide used in forestry, and much of the Ross Barnett Reservoir drainage basin is used for silvilculture.
C. The other 12 detected compounds have no discernable pattern of occurrence and are only observed occasionally and usually at only one site.
D. No information other than these compounds were not detected above the reporting limits can be gleaned from these data.

**Conclusions**

The U.S. Geological Survey, in cooperation with the Mississippi Department of Environmental Quality, began a sampling program in fall 2007 to analyze water samples for a suite of wastewater indicator compounds and pesticides for the three drinking-water facilities in Mississippi that use surface water from the Pearl, Tombigbee, and Tennessee Rivers as their source water. Three samples, from both source and finished water, were collected in October 2007, and January and May 2008. Few wastewater indicator chemicals were detected in source water; however, low concentrations of some commonly used herbicides were detected in the source and finished water from all three facilities. None of these compounds were detected in finished water at or above established drinking-water standards.

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Table 1. Community water systems in Mississippi that use surface water as their source water, sampled 2007-2008.

| Water Treatment Plant | Predominant Land Use | Areas Served | Population Served | Source Water |
|---|---|---|---|---|
| Short-Coleman Water Association | Agriculture/ silvilculture | A small area of rural northeastern Mississippi | 1,483 | Pickwick Lake/ Tennessee River |
| O.B. Curtis Water Treatment Plant | Agriculture/ silvilculture | City of Jackson | 230,125 | Ross Barnett Reservoir/Pearl River |
| Northeast Mississippi Regional Water Supply | Agriculture/ silvilculture | City of Tupelo/ Itawamba/Lee County | 58,000 | Tombigbee River/ Tenn- Tom Waterway/ Tennessee River |

Table 2. Order of water treatment stages and chemicals used during treatment at the community water systems in this study.

| Water Treatment Plant | Order of Water Treatment Stages and Chemicals Used |
|---|---|
| Short-Coleman Water Association | 1. raw water intake,<br>2. dual pump,<br>3. storage,<br>4. dual influent mixing,<br>5. dual filter (soda ash, aluminum, polymer, chlorine),<br>6. effluent pumping (chlorine),<br>7. ground storage,<br>8. high service pump station,<br>9. distribution |
| O.B. Curtis Water Treatment Plant Conventional Process (October 2007 and January 2008 samples) | 1. raw water intake,<br>2. potassium permanganate,<br>3. dual 1 mm raw screens,<br>4. 4 raw water pumps (potassium permanganate, ammonia feed, lime feed),<br>5. dual pre-oxidation basins (chlorine feed),<br>6. dual rapid mix (aluminum chloral hydrate, anionic polymer feed, lime feed, powdered activated carbon),<br>7. three tri-stage flocculators,<br>8. three sedimentation basins (residuals handling facility, chlorine dioxide),<br>9. Six dual media filters (filter backwash, ultraviolet light),<br>10. 5 million gallon clearwell (fluoride feed, lime feed, chlorine, ammonia feed),<br>11. high service pump station,<br>12. distribution |
| O.B. Curtis Water Treatment Plant Ultrafiltration (May 2008 samples only, due to new filtration system in operation) | Ultrafiltration followed by chlorine disinfection. |
| Northeast Mississippi Regional Water Supply | 1. raw water intake: add potassium permanganate if necessary,<br>2. meter pit: add aluminum before flash mixer,<br>3. flash mix: add lime when necessary and cationic polymer,<br>4. clarification: chlorine feed after clarification but before filtration,<br>5. filtration<br>6. common weir: post chlorination, fluorination, phosphate and pH adjustment,<br>7. 1.5 million gallon clearwell,<br>8. 3.0 million gallon clearwell: pH adjustment with caustic,<br>9. pump house: ammonia feed |

Table 3. Compounds analyzed for but not detected in both the raw and finished water from three public water supply facilities in Mississippi.

| Compound | Possible Compound Use or Source | Reporting Limit ug/L |
|---|---|---|
| 1,4-Dichlorobenzene | moth repellent, fumigant, deodorant | 0.2 |
| 1-Methylnaphthalene | 2-5% of gasoline, diesel fuel, or crude oil | 0.2 |
| 1-Naphthol | insecticide and insecticide degradate | 0.04 |
| 2,6-Diethylaniline | herbicide and herbicide degradate | 0.006 |
| 2,6-Dimethylnaphthalene | present in diesel/kerosene (trace in gasoline) | 0.2 |
| 2-Chloro-2,6-diethylacetanilide | herbicide and herbicide degradate | 0.01 |
| 2-Ethyl-6-methylaniline | herbicide and herbicide degradate | 0.01 |
| 2-Methylnaphthalene | 2-5% of gasoline, diesel fuel, or crude oil | 0.2 |
| 3,5-Dichloroaniline | herbicide and herbicide degradate | 0.008 |
| 3-beta-Coprostanol | carnivore fecal indicator | 2, 0.8 |
| 3-Methyl-1(H)-indole | fragrance, stench in feces and coal tar | 0.2 |
| 3-tert-Butyl-4-hydroxy anisole (BHA) | antioxidant, general preservative | 0.2 |
| 4-Chloro-2-methylphenol | herbicide and herbicide degradate | 0.005 |
| 4-Cumylphenol | nonionic detergent or metabolite | 0.2 |
| 4-n-Octylphenol | nonionic detergent or metabolite | 0.2 |
| 4-Nonylphenol diethoxylate (NP2EO) | nonionic detergent or metabolite | 3 |
| 4-Nonylphenol monoethoxylate (NP1EO) | nonionic detergent or metabolite | 2 |
| 4-tert-Octylphenol diethoxylate (OP2EO) | nonionic detergent or metabolite | 0.32 |
| 4-tert-Octylphenol monoethoxylate (OP1EO) | nonionic detergent or metabolite | 1 |
| 4-tert-Octylphenol | nonionic detergent or metabolite | 0.2 |
| 5-Methyl-1H-benzotriazole | antioxidant in antifreeze and deicers | 2, 3 |
| Acetochlor | herbicide | 0.006 |
| Acetophenone | fragrance in detergents and tobacco, flavor in beverages | 0.2, 0.3 |
| Acetyl hexamethyl tetrahydronaphthalene (AHTN) | musk fragrance, persistent; widespread in ground water, concern for bioaccumulation and toxicity | 0.2 |
| Alachlor | herbicide | 0.006 |
| alpha-Endosulfan | insecticide | 0.006 |
| Anthracene | component of tar, diesel, or crude oil | 0.2 |
| Anthraquinone | manufacture of dye/textiles, seed treatment, bird repellent | 0.2 |
| Azinphos-methyl-oxon | degradate | 0.04 |
| Azinphos-methyl | insecticide | 0.12 |
| 2,2`,4,4`-Tetrabromodiphenyl ether (BDE 47) | widely used brominated flame retardant | 0.2 |
| Benfluralin | herbicide | 0.004, 0.006, 0.010 |

Table 3. Compounds analyzed for but not detected in both the raw and finished water from three public water supply facilities in Mississippi (continued)

| Compound | Possible Compound Use or Source | Reporting Limit ug/L |
|---|---|---|
| Benzo[a]pyrene | regulated PAH, used in cancer research | 0.2 |
| Benzophenone | fixative for perfumes and soaps | 0.2 |
| beta-Stigmastanol | herbivore fecal indicator (digestion of sitosterol) | 0.2, 0.8 |
| | | |
| Bisphenol A | manufacture of polycarbonate resins, antioxi-dant | 0.4 |
| Bromacil | herbicide | 0.2, 0.3 |
| Caffeine | beverages, diuretic, very mobile/biodegradable | 0.2 |
| Camphor | flavor, odorant, ointments | 0.2 |
| Carbazole | insecticide, manufacture of dyes, explosives, and lubricants | 0.2 |
| Tris(2-chloroethyl)phosphate | plasticizer, flame retardant | 0.2 |
| Chlorpyrifos oxon | insecticide and insecticide degradates | 0.06 |
| Chlorpyrifos | insecticide | 0.005, 0.007 |
| cis-Permethrin | insecticide and insecticide degradates | 0.01 |
| Cotinine | metabolite of nicotine | 0.8 |
| Cyanazine | herbicide | 0.02 |
| Cyfluthrin | used in pesticide products | 0.016 |
| lambda-Cyhalothrin | insecticide | 0.004, 0.007 |
| Cypermethrin | insecticide | 0.014 |
| Dacthal (DCPA) | herbicide | 0.003 |
| Diazinon | insecticide, > 40% nonagricultural usage, ants, flies | 0.2 |
| Dichlorvos | insecticide, pet collars, naled or trichlofon deg-radates | 0.01 |
| Dicrotophos | insecticide | 0.08 |
| Dieldrin | insecticide | 0.009 |
| Diethyl phthalate | plasticizer for polymers and resins | 0.2 |
| Dimethoate | insecticide | 0.006 |
| Disulfoton sulfone | degradate | 0.01 |
| Disulfoton | insecticide | 0.04 |
| d-Limonene | fungicide, antimicrobial, antiviral, fragrance in aerosols | 0.2 |
| Endosulfan sulfate | degradate | 0.022 |
| EPTC (Eptam) | herbicide | 0.002 |
| Ethion monoxon | degradate | 0.02 |
| Ethion | pesticide | 0.006 |
| Ethoprophos | insecticide | 0.012 |

Table 3. Compounds analyzed for but not detected in both the raw and finished water from three public water supply facilities in Mississippi (continued)

| Compound | Possible Compound Use or Source | Reporting Limit ug/L |
|---|---|---|
| Fenamiphos sulfone | degradate | 0.053 |
| Fenamiphos sulfoxide | degradate | 0.04, 0.20 |
| Fenamiphos | insecticide | 0.03 |
| Fipronil | insecticide | 0.02 |
| Fipronil sulfide | degradate | 0.013 |
| Fipronil sulfone | degradate | 0.024 |
| Fluoranthene | component of coal tar and asphalt (only traces in gasoline or diesel fuel), | 0.2 |
| Fonofos | insecticide | 0.01 |
| Hexahydrohexamethylcyclopentabenzopyran (HHCB) | musk fragrance, persistent, | 0.2 |
| Indole | pesticide inert ingredient; fragrance in coffee | 0.2 |
| Iprodione | fungicide | 0.01 |
| Isoborneol | fragrance in perfumery, in disinfectants | 0.2 |
| Isofenphos | insecticide | 0.006 |
| Isophorone | solvent for lacquer, plastic, oil, | 0.2 |
| Isopropylbenzene | manufactures phenol/acetone, fuels and paint thinner | 0.2 |
| Isoquinoline | flavors and fragrances | 0.2, 0.4 |
| Malaoxon | degradate | 0.020, 0.040 |
| Malathion | insecticide | 0.016 |
| Menthol | cigarettes, cough drops, liniment, mouthwash | 0.2 |
| Metalaxyl | fungicide | 0.007 |
| Methidathion | insecticide | 0.004 |
| Methyl salicylate | liniment, food, beverage, UV-absorbing lotion | 0.2 |
| Metribuzin | herbicide | 0.012 |
| Molinate | herbicide | 0.003, 0.019, 0.021, 0.024, 0.026, 0.028 |
| Myclobutanil | fungicide | 0.01 |
| Naphthalene | manufactures of moth repellents, toilet deodorants, dyes, resins, tanning leather agents, carbaryl | 0.2 |
| Oxyfluorfen | herbicide | 0.006 |
| para-Nonylphenol | personal care and domestic product use | 2 |
| Paraoxon-methyl | degradate | 0.01 |

Table 3. Compounds analyzed for but not detected in both the raw and finished water from three public water supply facilities in Mississippi (continued)

| Compound | Possible Compound Use or Source | Reporting Limit ug/L |
|---|---|---|
| Parathion-methyl | insecticide | 0.008 |
| Pendimethalin | herbicide | 0.012 |
| Pentachlorophenol | wood preservative, termite control | 0.8, 2 |
| Phenanthrene | manufacture of explosives, component of tar, diesel fuel, or crude oil | 0.2 |
| Phenol | disinfectant, manufacture of several products, leachate | 0.2 |
| Phorate oxon | degradate | 0.03 |
| Phorate | insecticide | 0.04 |
| Phosmet oxon | degradate | 0.05 |
| Phosmet | insecticide | 0.008 |
| Prometryn | herbicide | 0.006 |
| Propyzamide | herbicide | 0.004, 0.005 |
| Propanil | herbicide | 0.006 |
| Propargite | insecticide | 0.04 |
| Pyrene | component of coal tar and asphalt | 0.2 |
| Tefluthrin | pesticide | 0.003 |
| Terbufos oxon sulfone | degradate | 0.04 |
| Terbufos | insecticide | 0.02 |
| Terbuthylazine | herbicide | 0.01 |
| Tetrachloroethylene | solvent, degreaser, veterinary anthelmintic | 0.4 |
| Thiobencarb | herbicide | 0.01 |
| Tribufos | used in pesticide products | 0.035 |
| Tributyl phosphate | used as a solvent in inks, synthetic resins, gums, adhesives | 0.2 |
| Triclosan | found in soaps, deodorants, toothpastes, shaving creams, mouth washes, and cleaning supplies | 0.2 |
| Triethyl citrate | used as a food additive, found in medicines, as a plasticizer, and in cosmetics. | 0.2 |
| Triphenyl phosphate | manufacturing additives | 0.2 |
| Tris(2-butoxyethyl)phosphate | flame retardant | 0.2 |
| Tris(dichlorisopropyl)phosphate | manufacturing additives | 0.2 |

Table 4. Compounds analyzed for and detected at least once at or above the reporting limit in both the source and finished water from three public supply facilities in Mississippi; October 2007, January and May 2008.
*[<, less than; --, no data; E, estimated; M, presence verified but not quantified. Detections are in italics.]*

| | | Tombigbee River/ Northeast Mississippi Regional Water Supply | | Ross Barnett Reservoir/ City of Jackson | | Pickwick Lake/ Short-Coleman Water Association | |
|---|---|---|---|---|---|---|---|
| **Compound** | **Month of Sample** | **raw ug/L** | **finished ug/L** | **raw ug/L** | **finished ug/L** | **raw ug/L** | **finished ug/L** |
| 3,4-Dichloroaniline (degradate) | Oct-07 | <0.006 | <0.006 | <0.006 | <0.006 | <0.006 | <0.006 |
| | Jan-08 | <0.006 | <0.006 | <0.006 | <0.006 | -- | -- |
| | May-08 | <0.006 | <0.006 | *E 0.004* | *E 0.006* | <0.006 | <0.006 |
| 3, 4-Dichlorophenyl isocyanate (Degradate of diuron, a noncrop herbicide) | October | <2.0 | <2.0 | <2.0 | <2.0 | <2.0 | <2.0 |
| | January | <2.0 | <2.0 | <2.0 | <2.0 | -- | -- |
| | May | *E 0.41* | *E 0.17* | *E 0.66* | *E 0.60* | *E 0.24* | <2.0 |
| Atrazine (selective triazine herbicide) | October | *0.027* | *0.027* | *0.069* | *0.066* | *0.015* | *0.016* |
| | January | *0.014* | *0.013* | *0.044* | *0.041* | -- | -- |
| | May | *0.303* | *0.295* | *0.119* | *0.114* | *0.11* | *0.085* |
| Carbaryl (insecticide) | October | <0.060 | <0.060 | <0.060 | <0.060 | <0.060 | <0.060 |
| | January | <0.060 | <0.060 | <0.060 | <0.060 | -- | -- |
| | May | *E 0.012* | *E 0.013* | <0.060 | <0.060 | <0.060 | <0.060 |
| Carbofuran (insecticide) | October | <0.020 | <0.020 | <0.020 | <0.020 | *E 0.009* | *E 0.016* |
| | January | <0.020 | <0.020 | <0.020 | <0.020 | -- | -- |
| | May | <0.020 | <0.020 | <0.020 | <0.020 | <0.020 | <0.020 |
| 2-Chloro-4-isopropylamino-6-amino-s-triazine (CIAT) (degradate of atrazine) | October | *E 0.008* | *E 0.009* | *E 0.012* | *E 0.011* | *E 0.006* | *E 0.005* |
| | January | *E 0.007* | *E 0.009* | *E 0.010* | *E 0.012* | -- | -- |
| | May | *E 0.020* | *E 0.025* | *E 0.012* | *E 0.013* | *E 0.019* | *E 0.015* |
| cis-Propiconazole (fungicide) | October | <0.006 | <0.006 | <0.006 | <0.006 | <0.006 | <0.006 |
| | January | <0.006 | <0.006 | <0.006 | <0.006 | -- | -- |
| | May | *E 0.004* | *E 0.043* | <0.006 | <0.006 | <0.006 | <0.006 |
| Desulfinylfipronil (degradate) | October | <.012 | <.012 | <.012 | <.012 | <.012 | <.012 |
| | January | <.012 | <.012 | E .004 | <.012 | -- | -- |
| | May | <.012 | *E.007* | *E .003* | *E .003* | *E.007* | <.012 |
| N,N-diethyl-meta-toluamide (DEET) (mosquito repellent) | October | <0.2 | *M* | *M* | *M* | M | M |
| | January | <0.2 | <0.2 | *M* | <0.2 | -- | -- |
| | May | <0.2 | <0.2 | *0.2* | <0.2 | <0.2 | <0.2 |

Table 4. Compounds analyzed for and detected at least once at or above the reporting limit in both the source and finished water from three public supply facilities in Mississippi; October 2007, January and May 2008.
*[<, less than; --, no data; E, estimated; M, presence verified but not quantified. Detections are in italics.] (continued).*

| | | **Tombigbee River/ Northeast Mississippi Regional Water Supply** | | **Ross Barnett Reservoir/ City of Jackson** | | **Pickwick Lake/ Short-Coleman Water Association** | |
|---|---|---|---|---|---|---|---|
| **Compound** | **Month of Sample** | **raw ug/L** | **finished ug/L** | **raw ug/L** | **finished ug/L** | **raw ug/L** | **finished ug/L** |
| Fluridone (aquatic herbicide) | October | <0.026 | <0.026 | *0.034* | *0.037* | <0.026 | <0.026 |
| | January | <0.026 | <0.026 | *E 0.024* | *0.029* | -- | -- |
| | May | <0.026 | <0.026 | *0.26* | *0.226* | <0.026 | E 0.003 |
| Hexazinone (herbicide) | October | <0.008 | <0.008 | *E 0.011* | *E 0.011* | <0.008 | <0.008 |
| | January | <0.008 | <0.008 | *0.011* | *E 0.012* | -- | -- |
| | May | <0.008 | <0.008 | *0.051* | *0.052* | <0.008 | <0.008 |
| Metolachlor (herbicide) | October | <0.010 | <0.010 | *0.01* | *0.01* | <0.010 | <0.010 |
| | January | *E 0.010* | < 0.010 | *E 0.009* | *0.01* | -- | -- |
| | May | *0.046* | *0.053* | *0.079* | *0.073* | *0.013* | *0.013* |
| *p*-Cresol (wood preservative) | October | <0.2 | <0.2 | <0.2 | <0.2 | <0.2 | <0.2 |
| | January | <0.2 | <0.2 | <0.2 | <0.2 | -- | -- |
| | May | <0.2 | *M* | *M* | *M* | <0.2 | <0.2 |
| Prometon (herbicide) | October | <.04 | <.01 | <.01 | <.01 | <.01 | <.01 |
| | January | <.01 | <.01 | <.01 | <.01 | -- | -- |
| | May | <.01 | *E .01* | <.01 | <.01 | *E .01* | *E .01* |
| Simazine (herbicide) | October | *0.014* | *0.013* | *0.009* | *0.009* | *0.011* | *0.012* |
| | January | *0.01* | *0.009* | *0.018* | *0.015* | -- | -- |
| | May | *0.015* | *0.017* | *0.013* | *0.014* | *0.024* | *0.022* |
| Tebuthiuron (herbicide) | October | *0.02* | <0.02 | <0.02 | <0.02 | *E 0.01* | *0.02* |
| | January | *0.02* | *0.03* | *E 0.01* | *0.02* | -- | -- |
| | May | *0.04* | *0.05* | *E 0.01* | *E 0.01* | *0.04* | *0.04* |
| trans-Propiconazole (fungicide) | | <0.02 | <0.02 | <0.02 | <0.02 | <0.02 | <0.02 |
| | | <0.02 | <0.02 | <0.02 | <0.02 | <0.02 | <0.02 |
| | | *E .01* | *E .01* | <0.02 | <0.02 | <0.02 | <0.02 |
| Trifluralin (herbicide) | October | <0.006 | <0.006 | *0.017* | *0.027* | <0.006 | <0.006 |
| | January | <0.007 | <0.006 | <0.006 | <0.006 | -- | -- |
| | May | <0.009 | <0.009 | *E 0.003* | <0.009 | <0.009 | <0.009 |

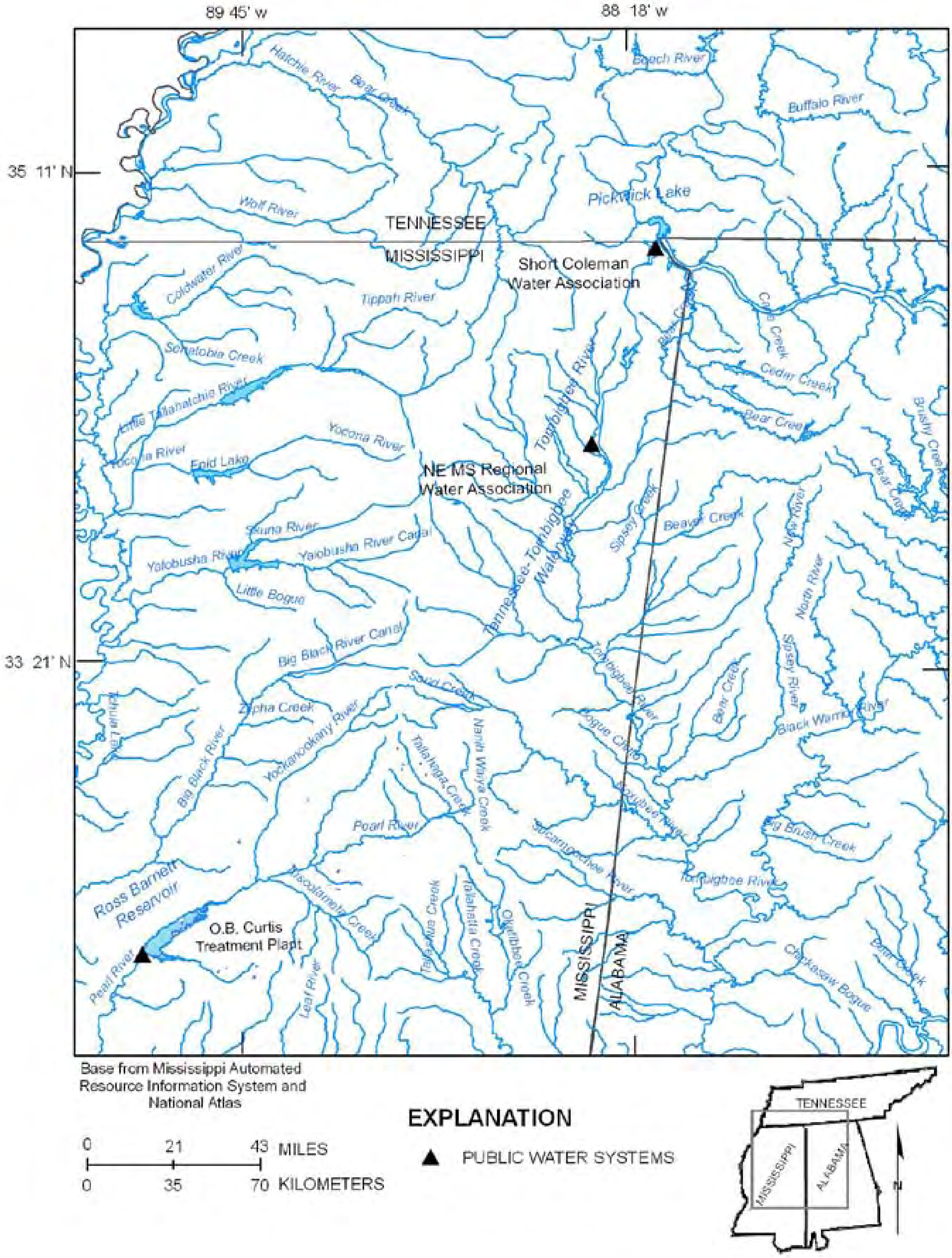


Figure 1. Location of three public water systems in northeastern Mississippi.

# Drinking Water Systems in Mississippi: Public Owned or Government Owned?

Jason Barrett, Mississippi State University

Mississippi (MS) contains approximately 1300 water systems (system). Currently, there has been no issue raised in an effort to make systems more efficient or more economical for the customers. Also, there has been no effort to determine if a system is efficient or economical. The Mississippi State Department of Health (MSDH) completes a capacity development assessment annually for every system and the scores encompass technical, managerial, and financial, ranging in value from 0 (zero/worst) to 5 (five/best). Approximately forty percent of systems with a population below 501 consistently score below 3.0 on the capacity assessment. There are contradictory mindsets in MS as to the future direction of systems: (1) all systems should take whatever actions possible to provide safe drinking water to their customers at an affordable price and (2) this water system has been in my family for generations or this water system holds this community together. I will use the MSDH assessment scores to view the viability of specific systems by population ranges. This will set a basis to current status and possible future action in relation to systems by asking: does the system remain apathetic and ask for assistance once the system is in disrepair, does the state of MS take over, or will water related agencies promote continuing education in an effort for the systems to increase viability themselves. With each of these three options, I will look at the agencies and individuals involved and delineate how they will be affected and why it matters to them. The results should show how economies of scale affect systems in the matter that smaller systems tend not to be as economical or efficient for its customers.

Key words: Water systems, viability, capacity development

Wood Treatment

## Wood Treatment

| | |
|---|---|
| **Lauren Mangum**<br>*Mississippi State University* | Treatment of Timtek Process Water by Co-Composting |
| **Amy M. Parker**<br>*Mississippi State University* | Environmental Impact and Disposal of CCA-Treated Wood Waste |
| **Heather Thomas**<br>*Mississippi State University* | Life Cycle Assessment of Wood Pyrolysis for Bio-Oil Production |
| **Melissa Cook**<br>*Mississippi State University* | Recycling CCA-Treated Wood Waste: Design and Operation of a Laboratory Scale Pyrolysis System |
| **Mark Bricka**<br>*Mississippi State University* | Laboratory Scale Treatment of CCA Contaminated Wood Waste |

# Treatment of Timtek Process Water by Co-Composting

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A six month study was conducted to evaluate the effectiveness of co-composting of the TimTek process water with wood waste and chicken manure as a method of remediation. Wood waste from the pilot facility in Shuqualak, MS was ground into sawdust. This sawdust was composted using four treatments with deionized water or process water to adjust moisture content. Two treatments were amended with manure to provide a nitrogen source; two received only deionized water or process water. The compost end-products for all treatments were then evaluated for relative toxicity, and weight loss. Additional testing was conducted to determine the toxicity of compost leachate and to evaluate the effects on germination rates of sensitive plant species. Co-composting successfully reduced the bulk and toxicity for all treatments. Treatments containing manure and process water showed over 90% emergence rate of radish seeds by day 90.

Key words: Treatment, Wastewater and Water Use

## Introduction

According to U.S. Census data, as of 1997, there were over 890 wood product manufacturing facilities in Mississippi. These facilities produce several million tons of waste every year, and less than 75 percent of this waste is utilized for energy or other economical purposes (Borazjani et al., 2004). The demand for high quality, construction sized wooden beams has outpaced reforestation, and fast-grown timbers do not provide the quality beams necessary for construction purposes. In the near future, it is anticipated that a new facility creating steam-pressed scrim lumber from small diameter trees will open in Lauderdale County, MS and begin production of structural quality timbers. This process involves an initial crushing process, which yields long fibers of wood called scrim, some of which is unusable, and must be disposed. The initial crushing and the steam press process also yield a water effluent that contains a high concentration of organic material, wood extractives, and fibers. This effluent water is the main concern for disposal as it has a high biological oxygen demand (BOD), making disposal as a hazardous waste very costly. BOD is a measurement of the rate at which the available oxygen in an aqueous environment is depleted by microorganisms. Current methods of treating waste water with a high BOD are aerated ponds, bioreactors, and coagulation and flocculation followed by filtration (Ali and Skreerishnan, 2001; Huang et al., 2004; Pokhrel and Viraraghavan, 2004). These processes are costly and disposal of spent filtrate or filter cakes produced by flocculation and coagulation remains an issue. A new method of treatment that would allow for the timely discharge of treated water into the environment is necessary.

A viable alternative to separate treatment of wastes is co-composting. Composting is the aerobic biodegradation of organic material into stable, humus material by microorganisms at elevated temperatures. Composting reduces the overall volume and toxicity of waste products, yielding a valuable, nutrient rich product that can be used as a soil amendment (Borazjani, 2000). Co-composting process of forest products wastes, such as waste wood waste from the furniture manufacturing industry, preservative treated wood waste, as well as the composting of wastewater sludge from the paper and pulp industry has been previously conducted (Borazjani et al. 2004; Marche et al., 2003; Wiltcher et al., 2000). Additionally, the positive effects of co-composted paper and pulp industry sludge and different residuals on soil properties and cereal yields has documented (Sippola et al., 2003). Co-composting of wastewater and wood waste generated on site, combined with poultry manure from nearby broiler houses provides a simple and cost effective solution to problems posed by these three waste materials. Poultry manure was chosen as a nitrogen source because it is in abundant supply in Mississippi as a waste product. In 2007, Mississippi alone produced 824 million broiler chickens (http://www.nass.usda.gov/Charts_and_Maps/Poultry/brlmap.asp, 2008). According to estimates of 1.5 kg of manure per bird per year (Moore et al., 1998) this yields more than 1.26 million metric tons of broiler manure for the 2007 production year. As these three wastes contain only natural material and chemicals, biological decomposition through composting leads to an end product that is stable and can be sold as a soil additive or container media.

## Methods

Characterization of Process Water An initial sample of process water was collected from the facility in Lauderdale County, MS. This initial sample was diluted to an approximately 1 to 4 ratio using distilled water. Two identical samples of this initial dilution were collected and sent to an off-campus environmental testing facility to determine the BOD (EPA method 405.1), COD (EPA method 8000), total suspended solids (EPA method 160.2), and total K and N content (EPA method 351.4). Metal content was determined at this time. In order to further characterize the process water, additional testing was conducted to determine the glucose content of undiluted water. HPLC analysis for glucose content was conducted at the Mississippi State Chemistry Laboratory on the MSU campus.(Table 1).

### *Compost Setup*

Chicken manure was used as an N source in the composting process. The manure was collected from the Poultry Science Department on the MSU campus. The manure was obtained from caged chickens and contained little sawdust or bedding material. The manure was spread in a dry, covered area to allow for some moisture evaporation (the manure was saturated) over the course of 48 hours. After the 48 hour drying period, samples were taken from the manure in order to determine the overall moisture content, which was determined to be 50% by weight.

Scrim material was collected from the pilot plant. This scrim was ground into sawdust using a mill to approximately 5mm size particles. The moisture content of the wood waste was determined to be approximately 10% by weight. These measurements were needed to ensure accurate calculation of weight loss on a dry weight basis. Before the experiment began, additional process water was collected from the pilot plant. When the process water was added to the composting replicates, it was diluted 1:1 with DI water.

Compost experimental design was a modified version of that used by Hatten et al (2009). Twelve 30L cans were prepared for experiment. Five 3cm holes were drilled into the bottom of each can and a layer of gardener's fabric was placed on the bottom of each can to prevent compost from falling through the holes. On day zero of the composting experiment, each can was weighed individually and the weight was recorded. Five Kg of sawdust was weighed out and then added to each can, and .45Kg of chicken manure was added to six of the treatments The compost in these cans was thoroughly mixed and 3 L of water, either distilled or a 1:1 dilution of distilled water and process water was added to each can. The cans were weighed again and set in a permanent location. The treatments were as follows:

1. Sawdust using rain water to provide moisture

(control)

2. Sawdust using only process water to provide moisture
3. Sawdust using rain water and 10% poultry litter (dry weight basis)
4. Sawdust using process water and 10% poultry litter (dry weight basis)

A complete randomized design with three replications for each treatment was used in this study. The compost treatments were placed outside and were aerated by hand once per week to ensure an aerobic environment. Moisture content was assessed weekly and was adjusted accordingly to keep the moisture levels at 50-65% range using either distilled water or a 1:1 dilution of process water and distilled water. Samples were taken at forty-five day intervals. At each sampling interval, samples were tested for pH, toxicity, compost maturity, and moisture content.

***Aeration***

Aeration of all treatments and replications was performed weekly by physically turning the compost by hand to ensure thorough mixing. Aeration of the compost ensured that the moisture content remained around 50%-70% within each container to prevent anaerobic conditions. Moisture content was adjusted through rain fall or by adding either distilled water or a 1:1 mixture of distilled water and process water. Compost cans were aerated once or twice per week depending on precipitation conditions or how much water was added.

Pile temperatures above that of the ambient air temperature served as an indicator of the composting process. In the thermophilic stage of composting, approximately 160°F, the pile should be significantly warmer than the surrounding air. To ensure that the treatments were composting properly, temperatures were monitored on and in-between sampling days.

***Sampling***

At each sampling period, each container was thoroughly mixed before sampling was conducted to ensure a homogenous sample was obtained. Before collecting samples, each compost container was weighed to determine the overall weight of the compost. Samples weighing 150g were collected from each container. Small sub-samples were taken for moisture content and toxicity. Percent moisture content was determined for each sample and then extrapolated to determine the overall moisture content of the pile.

***Toxicity***

Toxicity was determined using the Microtox® technique which has been shown to be effective in measuring toxicity of compost leachates (Kapanen and Itavaara, 2001). 18 ml aliquots of distilled water were added to twelve clean, 50 ml culture tubes and these tubes were labeled with the appropriate corresponding sample number. To each tube, 2 grams of compost sample was added. These samples were vortexed, followed by sonication in a water bath for 10 minutes. The samples were then placed in the refrigerator overnight. After refrigeration, each sample was centrifuged at 50,000 rpm for 20 minutes. The pH of each sample was measured following the Microtox and accordingly adjusted to a range of 6.0-8.0. Cuvettes were prepared with 0.05 g NaCl. 2.5 ml of each sample was mixed and properly distributed among prepared cuvettes. Toxicity readings were taken for each sample and toxicity was determined as more than a 5% difference between the control and leachate readings.

***Emergence Test***

Compost maturity was determined using a modified radish seed emergence test, based on the maturity tests described by Florida's Online Composting Center (compostinfo.com). The radish test is an indication of how the compost performs as a soil additive and if it is harmful to the plants. Radishes are very sensitive and need specific growth parameters so if the compost affects those parameters in a negative way the test allows for the visualization of these negative effects.

***Analysis of Composting Data***

Weight loss and toxicity results from the co-composting study were statistically analyzed to determine significant differences among treatments. Mean comparisons were made using a least significant difference at the $\alpha$=0.05 probability level by the Statistical Analysis System (SAS) using Duncan's multiple range analysis. Co-composting treatments are listed below in table 2.

## Results

### *Weight Loss Results*

Dry weight for each sampling period as well as weight loss results are summarized in figures 1 and 2, respectively. Within treatments, day 0 and day 180 dry weights were significantly different. In terms of percent weight loss there was no statistical difference when rain water was added versus TimTek process water. However, the addition of manure did statistically increase the amount of weight loss.

### *Toxicity Screening*

Composting resulted in a decrease in the overall toxicity of all treatments. In all treatments, compost was significantly less toxic by day 45, showing at least a 50% drop in toxicity levels. Statistical analysis of treatments showed that there was a significant difference in toxicity between day 0 and all other sampling periods. There was not a significant difference in toxicity within treatments between day 90 and day 180. Figure 3 illustrates the toxicity levels for all treatments on all sampling days.

### *Plant Germination Rates*

It can be said that compost was fully matured, as evidenced by radish seed germination tests. By day 180, all amendments showed seed germination rates of 100%, indicating a mature product. Seed germination rates for all sampling periods are listed in table 3.

## Conclusions

This study found that this process water has a high BOD, COD, and TSS. Further characterization of the process water determined that metal content was not a major concern as most metals, aside from Zn, were present in low concentrations. Co-composting offer a potential solution to the problems that may be presented by the Timtek manufacturing process. This study has shown it is possible to co-compost two wastes from the same facility, sawdust and process water, with chicken manure to produce a mature product. Lowered toxicity and higher germination rates can be achieved without the addition of poultry manure; however, it will occur at a much slower rate. Radish seed germination tests have indicated that the mature compost is a non-toxic media that can offers nutrients to plants. However, the composted material did not attain a humus-like texture. It can be said that the compost did partially compost as it did reach sustained temperatures of approximately 120-130oF. As such, the composted material might be more suited as a soil additive that could be effectively mixed with top soil, to produce a suitable potting media. The composted material could potentially be popular with nurseries and sold to farmers as a bulking agent and nutrient source, adding revenue to the future facility.

More studies are needed to determine optimal ratios of process water, wood waste, and chicken manure to accelerate the composting process.

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Table 1. Background analytical results of TimTek process water in terms of mg/L.

| Chemicals | Results in mg/L | Detection limit (mg/L) | Method Used |
|---|---|---|---|
| Arsenic | <0.002 | 0.002 | 200.7 |
| Beryllium | <0.001 | 0.001 | 200.7 |
| Cadmium | 0.0044 | 0.001 | 200.7 |
| Chromium | 0.034 | 0.01 | 200.7 |
| Copper | 0.21 | 0.001 | 200.7 |
| Lead | 0.0092 | 0.005 | 200.7 |
| Nickel | 0.032 | 0.007 | 200.7 |
| Selenium | <0.002 | 0.002 | 200.7 |
| Silver | <0.002 | 0.002 | 200.7 |
| Antimony | <0.006 | 0.006 | 200.7 |
| Thallium | <0.01 | 0.01 | 200.7 |
| Mercury | <.0002 | 0.0002 | 245.1 |
| Glucose | Non Detect | 10 | 977.20 |
| BOD | >5190 | 100 | 405.1 |
| COD | >6135 | 100 | 8000 |
| TKN | >10 | 0.10 | 351.4 |
| TSS | >235 | 10 | 160.2 |

Table 2. Description of each treatment of co-composting study.

| Treatment descriptions | Percent manure | Treatment number | Replicates |
|---|---|---|---|
| Sawdust + DI Water | 0 | Treatment 1 | 3 |
| Sawdust + Timtek | 0 | Treatment 2 | 3 |
| Sawdust + DI Water + Manure | 10 | Treatment 3 | 3 |
| Sawdust + Timtek + Manure | 10 | Treatment 4 | 3 |

Table 3. Percent seed germination rates

| Treatment | Day 0 | Day 45 | Day 90 | Day 135 | Day 180 |
|---|---|---|---|---|---|
| Sawdust+DI water | 96 | 92 | 100 | 100 | 100 |
| Sawdust+DI water | 92 | 79 | 83 | 100 | 96 |
| Sawdust+DI water | 79 | 79 | 92 | 83 | 100 |
| Sawdust+Timtek Water | 96 | 71 | 100 | 75 | 100 |
| Sawdust+Timtek Water | 71 | 88 | 96 | 92 | 100 |
| Sawdust+Timtek Water | 58 | 79 | 100 | 96 | 100 |
| Sawdust+DI water+Manure | 83 | 79 | 100 | 100 | 100 |
| Sawdust+DI water+Manure | 92 | 92 | 88 | 100 | 100 |
| Sawdust+DI water+Manure | 67 | 96 | 100 | 96 | 100 |
| Sawdust+Timtek water+Manure | 75 | 92 | 100 | 100 | 100 |
| Sawdust+Timtek water+Manure | 83 | 75 | 88 | 100 | 100 |
| Sawdust+Timtek water+Manure | 100 | 100 | 100 | 100 | 100 |
| Control Potting Mix | 100 | 100 | 100 | 100 | 100 |

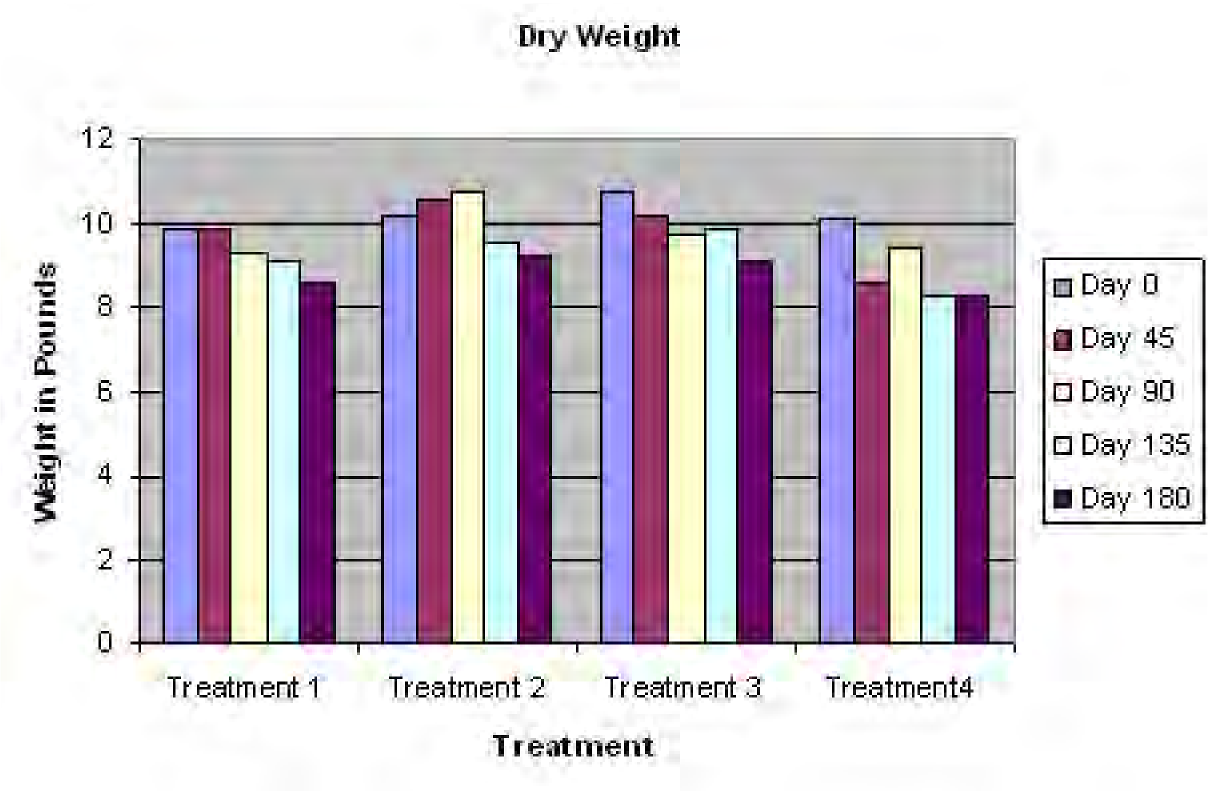


Figure 1: Reduction in dry weight at each sampling period for all treatments.


Figure 2. Percent weight loss at day 180. Columns with different letters indicate a significant difference between weight loss at the $\alpha$=.05 level of significance.

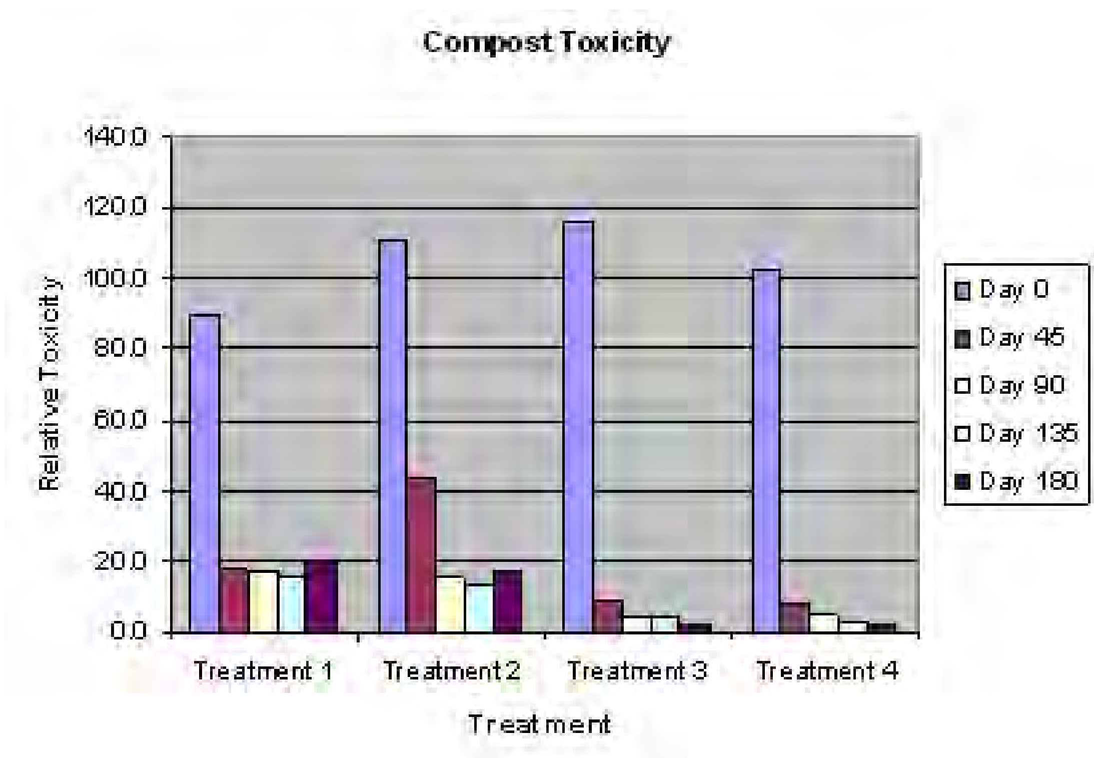


Figure 3. Relative percent toxicity of compost leachate as compared to distilled water. Columns with different letters above them indicate a significant difference between toxicity measurements at the $\alpha$=.05 level of significance. "A" statistical grouping refers only to Day 0. All other sampling periods fall under "B" statistical group, indicating no significant difference between all other sampling periods.

# Environmental Impact and Disposal of CCA-Treated Wood Waste

Amy M. Parker, Mississippi State University
Mark Bricka, Mississippi State University

Wood products are treated with preservatives to prohibit degradation by a multitude of organisms and to prolong the products' life in adverse environments. The most widely used wood preservative since the early 1970's has been chromated copper arsenate (CCA), resulting in nearly 80% of all treated wood products in North America being treated with CCA. In 2002 the wood preservative industry voluntarily adopted a restricted consumer use policy, and by late 2003 CCA-treated wood was limited to industrial applications due to concerns over possible exposure to toxic substances. Due to the restricted use policy, it is estimated that as much as 24 million tons of CCA may be available for disposal by 2020. Until recently, landfilling the out of service CCA-treated material was the accepted method of disposal. However, problems associated with soil and groundwater contamination, directly linked to the leaching of CCA-metals from landfills, have generated the need for a more effective and efficient disposal method for CCA-treated wood waste. Alternative approaches to CCA-treated wood disposal include utilizing advanced sorting techniques to place the treated wood waste in hazardous waste landfills, using chemical extraction to remove the CCA-metals, and employing thermochemical conversion processes to isolate the CCA-metals and reduce waste volume. This paper will provide detailed information on the environmental impact and disposal of CCA-treated wood waste, including environmental standards, test methods, and discussion of on-going research.

Key words: groundwater, toxic substances, policy, methods

# Life Cycle Assessment of Wood Pyrolysis for Bio-Oil Production

Heather Thomas, Mississippi State University
Mark Bricka, Mississippi State University

The Department of Chemical Engineering is evaluating a pyrolysis process for the conversion of wood into bio-oil or pyrolysis oil for use in wood treatment. Historically, wood has been treated with a mixture of copper, chromium, and arsenic. Due to the toxic substances and potential leaching into the ground water supply, CCA has been banned from use in the U.S. As older wood is being taken out of service, new methods of preservation are being explored for the wood being put into service. The resulting bio-oil from this pyrolysis process has shown promise as a wood preservative.

Before full scale production can begin a Life Cycle Assessment (LCA) will be performed on the process. LCA is a cradle-to-grave analysis involving the feedstock and materials of construction as well as storage, transportation, and disposal issues. It helps quantify emissions into the air and ground water. The results of the LCA model will be used to determine the economic viability of the process, the energy "break-even point," and the carbon footprint of the process. LCA can also be used to aid in future management and planning for the process.

Key words: toxic substances, ground water, economics, model

# Recycling CCA-Treated Wood Waste: Design and Operation of a Laboratory Scale Pyrolysis System

Melissa Cook, Mississippi State University
Amy Parker, Mississippi State University
Mark Bricka, Mississippi State University

Since the early 1970's, the most widely used wood preservative has been chromated copper arsenate (CCA), resulting in nearly 80% of all treated wood products in North America being treated with CCA. By the end of 2003 CCA-treated wood was restricted to industrial applications, resulting in a considerable increase in the volume of CCA-treated wood slated for disposal. Landfilling was considered an acceptable means of discarding CCA-treated wood products until recently, as there have been instances of the toxic metals leaching from the landfills and contaminating the surrounding soil and groundwater. It is clear that traditional disposal methods are not adequate and that a safe and efficient disposal method for CCA-treated wood must be developed.

Fast pyrolysis, the heating of biomass at temperatures between 400°C and 650°C in the absence of oxygen, is a promising technology that can be applied to CCA-impregnated wood waste. Pyrolysis of lignocellulosic material produces char, liquid condensate (bio-oil), and non-condensing gases. The focus of this research is on removing the CCA-metals from the treated wood waste while recovering the energy value of the wood. This is accomplished by concentrating the CCA-metals in the bio-oil, for possible re-use in wood preservatives, during pyrolysis. A laboratory scale pyrolysis system, capable of operating in the desired temperature range under atmospheric and vacuum conditions, has been designed. The system is also designed to enable the collection of each pyrolysis product so that complete mass balances on the metals can be performed, tracking the fate of the CCA components. This paper discusses the process of designing and operating the laboratory scale pyrolysis system, as well as preliminary experimental results.

Key words: groundwater, toxic substances, methods

# Laboratory Scale Treatment of CCA Contaminated Wood Waste

Mark Bricka, Mississippi State University
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Since the early 1970's, the most widely used preservative in the wood preservation industry has been chromated copper arsenate (CCA) treatment. Current estimations suggest that there may be as much as 240 million tons of CCA wood waste available for Disposal by the year 2020.

Until recently, landfilling the out of service materials was a generally accepted method of disposal. Recently, problems with soil and groundwater contamination have arisen, and the role of CCA impregnated wood waste in the matter has been confirmed. As a result, the need for an efficient and effective method of heavy metal separation form wood waste has become eminent.

In this research, electrokinetic treatment of CCA impregnated wood fines was examined. Out of service CCA wood waste was subjected to electrokinetic treatment in a batch reactor under pH controlled conditions. The ionic nature of the metal oxides contained in the CCA impregnated wood will allow for the metals to be mobilized and metal concentrations are expected to decrease in the waste wood while increasing the proximity of the electrodes. In addition to this base case study, chemical extractions with electrode amendments were examined under controlled conditions before they were subjected to electrokinetic treatment, and final overall metal removal. Mass balances were performed using ICP-AES equipment. In the extended research plan, the more effective reactions sequences will be subjected to further testing where the roles of independent variables such as reactor solution pH, particle size, current density, Oxidation/Reduction potential, and treatment time will be examined. The ultimate goal of this research will be to evaluate the feasibly of Electrokinetic pretreatment for CCA impregnated wood.

Key words: Copper, chrome, arsenic, treated wood, recycling

Modeling

## Modeling

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| **Jim Steil**<br>*Institutions of Higher Learning* | A New Hydro-Enforced, 1:24,000 Digital Elevation Model for Mississippi |
| **John B. Czarnecki**<br>*U.S. Geological Survey* | Conjunctive-Use Optimization Modeling of the Mississippi River Valley Alluvial Aquifer: Evaluation of Groundwater Sustainable Yield |
| **Terrance W. Holland**<br>*U.S. Geological Survey* | Arkansas' Expanded Relational Water-Use Program |
| **Claire E. Rose**<br>*U.S. Geological Survey* | Simulated Solute Transport and Shallow Subsurface Flow in Northwestern Mississippi |
| **Brian R. Clark**<br>*U.S. Geological Survey* | The Mississippi Embayment Regional Aquifer Study (MERAS) - Model Construction, Simulation of Groundwater Flow, and Potential Uses of a Regional Flow Model |

# A New Hydro-Enforced, 1:24,000 Digital Elevation Model for Mississippi

Jim Steil, Mississippi Institutions of Higher Learning
Steve Walker, Mississippi Institutions of Higher Learning

A new, 10 meter, statewide, hydro-enforced, digital elevation model [DEM] was recently developed by the Mississippi Automated Resource Information System [MARIS] in cooperation with the USGS to better support modeling efforts than the previous 30 meter DEM. The utility of the old 30m DEM was limited by scale, artifacts of processing, and substantial data exclusions such as the Tenn-Tom Waterway and significant migration of the Mississippi River. The new model was developed over a number of years beginning with Mylar separates of 7.5 minute quadrangles. Mylar separates were scanned, vectorized, and resulting lines tagged with elevation values and other attributes. As contour lines are not contiguous across individual quad maps, each contour was connected to the contour of the adjacent quad to create a continuous line for a seamless coverage. Carrying contours were added throughout the state to ensure proper hydrologic modeling. Digital Rater Graphics [DRG's] were also available to provide clarification for incorrectly tagged elevation values especially at quad boundaries. The 2007 National Aerial Imagery Program [NAIP] 1 meter imagery was used to perform the inclusion and proper placement of the Tenn-Tom Waterway as it was not included in many of the original quadrangles. NAIP imagery was also the basis for correcting the placement of the Mississippi River which had migrated up to 5 miles from the position on the original 7.5 minute maps. Some corrective hydrologic changes were made to the 1:24,000 National Hydrologic Dataset [NHD] to provide more accurate modeling. Partially as a result of this project, MARIS has become the steward of the NHD for Mississippi. Preliminary geometric changes were made to the NHD to reflect changes in the landscape since the publication of the quad maps. These changes were most common in the Delta region and will be incorporated into the official NHD. Due to software limitations, each county was processed separately with a 400 meter buffer. The ESRI Topo-to-Raster command was used to generate each county DEM. Each County was checked by USGS at Rolla, MO. The final DEM's are included as part of the official National Elevation Dataset [NED] and are available for download from USGS or MARIS http://www.maris.state.ms.us/HTM/DownloadData/DEM.html . http://seamless.usgs.gov

Key words: Geomorphological Processes, Education, Hydrology, Models, Surface Water

# Conjunctive-Use Optimization Modeling of the Mississippi River Valley Alluvial Aquifer: Evaluation of Groundwater Sustainable Yield

John B. Czarnecki, U.S. Geological Survey

The Mississippi River Valley alluvial aquifer (the alluvial aquifer) is a water-bearing assemblage of gravels and sands that underlies about 32,000 square miles of Missouri, Kentucky, Tennessee, Mississippi, Louisiana, and Arkansas. The alluvial aquifer ranks third among the most productive aquifers in the United States. In 2000, more than 9 billion gallons per day of water were pumped from the alluvial aquifer by more than 45,000 wells, primarily for irrigation and for fish farming. Since the widespread agricultural use of the aquifer began, several large cones of depression have formed in the potentiometric surface, resulting in lower well yields and degraded water quality in some areas.

Conjunctive-use optimization modeling was done to assist water managers and planners by estimating the maximum amount of groundwater that hypothetically could be withdrawn from alluvial wells and from hydraulically connected streams without violating hydraulic-head or streamflow constraints. Optimization models showed that continued pumping at 1997 rates are unsustainable without violating head constraints imposed as a part of Arkansas's Critical Groundwater Area criteria. Streamflow constraints specified within the model were based partly on minimum flow requirements for maintaining either navigation requirements, water quality, or fish habitat. Continuously pumping at 1997 rates resulted in water levels dropping below the hydraulic-head constraints (either half the aquifer thickness or 30 feet of saturated thickness), making those rates unsustainable. Optimized sustainable pumping was obtained such that water levels were maintained at or above the hydraulic-head constraints, and streamflow was maintained at or above minimum flow requirements. No single value of groundwater sustainable yield exists, as it depends on the specification of water-level and streamflow constraints, and the specification of potential groundwater and stream-withdrawal locations and their maximum allowable withdrawal rates.

Key words: Groundwater; Models; Water supply

# Arkansas' Expanded Relational Water-Use Program

Terrance W. Holland, U.S. Geological Survey

The Arkansas Water-Use Program is a cooperative effort between the Arkansas Natural Resources Commission (ANRC) and the U.S. Geological Survey (USGS). Site-specific data for several water-use categories are reported annually by water users and are electronically stored. Water users that withdraw 1 acre-foot or more of surface water per year or operate wells with the capability of pumping 50,000 gallons of ground water per day or more must report their withdrawals. Site-specific water-use data for irrigation, livestock, duck hunting clubs, public supply, commercial, industrial, mining, and power generation are stored in the Arkansas Water-Use database developed and maintained by the USGS Arkansas Water Science Center (AR WSC). Data for the irrigation, livestock, aquaculture, and duck hunting club categories are reported through the Conservation District offices in selected counties. Users report data for about 54,000 agricultural measurement points through the County Conservation District offices via a secure internet Web page that is the entry point into the Arkansas Water-Use Data System. Water-use data for the other categories are reported directly to the Arkansas Natural Resource Commission on paper registration forms generated by AR WSC staff as output from the data base management system. These forms are mailed out by ANRC staff to about 1,200 additional water users that do not report their water use via the Web. The completed registration forms are returned to U.S. Geological Survey for entry in to the Arkansas Water-Use Data Base System. The amounts of water withdrawn, sources of water, how the water was used, and how much water was returned are available to water-resources managers and policy makers through retrievals from the Arkansas Water-Use Data Base System.

Expansion of the Arkansas Water-Use System began 3 years ago for multiple reasons. ANRC needed a viable way to store and retrieve water-well construction information that Arkansas law requires be reported to the Arkansas Water-Well Commission (a component of ANRC) and, the understanding of ground-water use would be enhanced with a relational link to well construction information; and, a better understanding of hydrogeologic structure would further compliment ground-water use understanding and provide enhanced information concerning water-bearing zones contributing to wells. Consequently, tables have been added to the system as a repository for water-well construction data and a Well Log Archive. Staff at the ANRC enters data into the water-well construction tables. Construction data for approximately 57,000 wells reside in the database at this time. Well log archiving is a continuing effort, in the ANRC/USGS cooperative program, to archive and interpret borehole geophysical logs. As a part of our continuing cooperative program, well logs for a few Arkansas counties are scanned and geo-referenced each year - 12 counties have been completed to date. The tops of aquifers and confining units are interpreted from these logs for the purpose of creating a digital framework of the subsurface. This framework of hydrogeologic units is used in conjunction with a reported water-use location to determine/verify contributing aquifers. This is a "visual" process, using an interactive mapping application.

Key words: Ground Water, Management and Planning, Models, Water Quantity

# Simulated Solute Transport and Shallow Subsurface Flow in Northwestern Mississippi

Claire E. Rose, U.S. Geological Survey
John R. Nimmo, U.S. Geological Survey
Kim S. Perkins, U.S. Geological Survey
Richard H. Coupe, U.S. Geological Survey

Solute transport and subsurface flow through a Sharkey Clay soil typical of a soybean field in the alluvial plain of northwestern Mississippi were simulated using the two-dimensional, variably-saturated flow model of solute transport (VS2DTI) developed by the U.S. Geological Survey. The model was developed and validated using data collected from a 2-m ring infiltration test, which include: calcium bromide (CaBr) concentrations at depth, water flux, and soil moisture content. Local and State agencies are attempting to develop a plan for sustainable use of the Mississippi River Valley alluvial aquifer, which is heavily pumped for irrigation and has documented water-level declines of tens of feet in some areas over time. A critical component to determining the sustainable yield of the aquifer is recharge, both the amount and source. The most recent groundwater model simulation by the U.S. Geological Survey in 2001 estimated that about 5 percent of precipitation recharges the alluvial aquifer annually; more localized studies found that number is as high as 17 percent. Due to the complexity of recharge processes, a tool for local estimation of recharge is necessary. In this study, simulated results, using VS2DTI, were compared to observed infiltration rates along with flow direction and extent of the CaBr tracer. Observed tracer concentrations and flow were found to be more spatially variable than simulated solute transport and subsurface flow. This suggests flow in the vadose zone is not only dependent on the medium of soil and its physical properties, but also on anisotropic anomalies, such as capillary or layer barriers, or mudcracks and large organic particles, which can produce preferential flow pathways.

Key words: Agriculture, Solute Transport, Models

# The Mississippi Embayment Regional Aquifer Study (MERAS) – Model Construction, Simulation of Groundwater Flow, and Potential Uses of a Regional Flow Model

Brian R. Clark, U.S. Geological Survey
Rheannon M. Hart, U.S. Geological Survey

The U.S. Geological Survey (USGS) Groundwater Resources Program supports projects to determine groundwater availability in multiple areas across the United States. One project is the Mississippi Embayment Regional Aquifer Study (MERAS). The primary tool used to evaluate groundwater availability in the embayment is the MERAS groundwater flow model. The construction of the MERAS model, using the USGS MODFLOW-2005 modeling software, included 2,700 geophysical logs for hydrogeologic framework development; 137 years of groundwater withdrawal information; 70,000 groundwater withdrawal locations; 39 rivers comprising 6,900 river miles; and precipitation, land use, surficial geology, and aquifer properties covering 78,000 square miles. Model calibration data include 55,000 ground-water level observations and streamflows at 14 stream-gage locations.

The MERAS model simulates groundwater flow from 1870 to 2007 and has been used to project impacts of climate variability on groundwater flow to the year 2037. Values of root mean square error between simulated and observed hydraulic heads of all observations up to 2007 ranged from 12.23 ft in 1919 to 48.19 ft in 1951. The MERAS model has been used to simulate climatic effects on the groundwater flow system by changing precipitation and streamflow input values based on projections of historic climate data analysis. Preliminary results of the groundwater flow model indicate deepening cones of depression over the next 30 years in the Mississippi River Valley alluvial aquifer in the northern part of the embayment.

Local stakeholders may also benefit from the use of additional MODFLOW-2005 methods and processes in conjunction with the MERAS model; the Local Grid Refinement (LGR) method and the Groundwater Management (GWM) process can provide excellent information for the local water manager. Potential use of the LGR method allows for more finely discretized local-scale areas to be simulated within the embayment while using the MERAS model as a boundary which contributes or receives flow. The GWM process allows for the optimization of groundwater pumpage given constraints such as drawdown, water level, and streamflow. These types of analyses with LGR and GWM can be particularly useful in areas where intense pumping stresses the groundwater- surface water system by lowering groundwater levels, reducing base flow, and ultimately inducing leakage from surface water bodies to the groundwater system. In a broader sense, the GWM process might be used in a regional application to evaluate issues related to resource sustainability on an intrastate or interstate scale.

Key words: Ground Water, Management and Planning, Models, Water Quantity

Soil and Water Treatment

## Soil and Water Treatment

| | |
|---|---|
| **Richard Lusk**<br>*Mississippi State University* | Electrokinetic Treatment of Mercury Contaminated Soil at the Mercury Refining Company Superfund Site |
| **John Blakely**<br>*Mississippi State University* | Evaluation of Phosphate Treatment Methods to Reduce Lead Mobility at Military Small Arms Training Ranges |
| **Mark Bricka**<br>*Mississippi State University* | Sulfate Removal from Ground Water |
| **Rheannon M. Hart**<br>*U.S. Geological Survey* | Use of Borehole Geophysics to Determine Zones of Radium Production in Northern Arkansas |
| **Wayne Kellogg**<br>*Chickasaw Nation Division of Commerce* | Beneficial Use of Marginal Quality Water |

# Electrokinetic Treatment of Mercury Contaminated Soil at the Mercury Refining Company Superfund Site

Richard Lusk, Mississippi State University
R. Mark Bricka, Mississippi State University

Mercury contamination due to leakage from industrial processes can result in serious environmental, health, and safety concerns. Traditional methods for the remediation of elemental mercury from contaminated sites include a dig and haul approach (retorting) and/or an isolation approach. However, these methods can be very costly and ineffective with regards to removing the mercury from the contaminated soil. Therefore, a new Electrokinetic Remediation method is proposed in which mercury can be cost effectively removed from a contaminated site in order to be recycled or disposed of properly. This method includes the use of anodes and cathodes installed in the ground throughout the contaminated site to produce an electric field which forces the contaminant to migrate to a specific position in which it can be efficiently removed. The use of several amendments to increase the solubility (and electrokinetic potential) of the mercury in the soil is also researched to determine a most effective and efficient mercury removal scheme. It was determined in batch and continuous electrokinetic cells that a 0.1 M Potassium Iodide, .01 M EDTA was effective in solubilizing and removing mercury below the EPA's regulatory limit of 31mg/kg.

Key words: Toxic Substances, Treatment, Nonpoint Source Pollution

# Evaluation of Phosphate Treatment Methods to Reduce Lead Mobility at Military Small Arms Training Ranges

R. Mark Bricka, Mississippi State University
John Blakely, Mississippi State University

The primary goal of the United States Military is to train and equip troops to maintain military readiness to defend the United States and its interests. Small arms range (SAR) training represents a major element in keeping the military ready to accomplish this mission.

Projectiles utilized as part of SAR training have accumulated in the soil at the SARs as a result of many years of use. These projectiles are composed of toxic metals. The projectiles, with weathering, change form allowing the metals to migrate to surface and ground water sources. Due to the toxicity associated with the metals, the SAR may pose a threat to humans and the environment. Current lead remediation techniques are costly and inefficient thus new cost effective remediation techniques must be developed and implemented.

Studies show that the treatment of the soil with phosphate-based binders may react with the metals, which results in lowering the solubility of the lead and other metals. The phosphate based-binders react with the metal ions, such as lead, to form insoluble metal phosphate complexes called pyromorphites as shown in equation 1.

$$10M^{2+} + 6H_2PO_4- + 2OH- \quad > \quad M_{10}(PO_4)_6(OH_2) + 12H+ \quad \text{Eq (1).}$$

Several types of phosphate binders can be used to form the desired pyromorphites, however, the kinetics of the reaction depend on the phosphate complex. This may be due to the ability of the specific binder to mix efficiently in the contaminated soil or due to the reactive nature of the specific form of phosphate applied to the site.

This paper presents the results of a study to investigate the effect of phosphates on the lead contained in soils collected at military SAR training areas. Laboratory evaluations consisted of adding various phosphates at different dosages to SAR samples. After treatment the soils were subjected to a series of leaching tests. The result of laboratory effort as well as the planned field activities will be presented.

Key words: Small arms, munitions, lead, radiation, and phosphate precipitation

# Sulfate Removal from Ground Water

R. Mark Bricka, Mississippi State University
Ben Stokes, Mississippi State University

A process to remove sulfates from ground and surface water to meet required drinking water standards has been completed. Several options were researched, including ion exchange, electrodialysis, electrodeionization and other membrane technologies. In evaluating each process, economical, environmental, health and safety issues were considered. A primary concern during assessment was the feasibility of scaling up a bench scale process to a system that can produce hundreds to thousands of gallons. While many of these are innovative technologies, ion exchange is a more commonly accepted process and is suitable for large scale production because of the lower operation costs.

This paper describes the process by which ion exchange technology occurs as well as the recommended design for scale up. The prototype design includes two columns packed with anion exchange resin. For the chosen set-up, one column will purify water, and the other column can be regenerated without interrupting continuous production. Multiple equilibrium and dynamic tests were performed to calculate the sulfate absorption capacity of the resin and determine the optimum treatment rates for maximum efficiency. The Environmental Protection Agency has numerous regulations and standards providing recommended contaminant levels of sulfates in drinking water. These standards provide a basis for testing and design. The process was scaled to purify 120,000 gallons of water per day while minimizing the concentrations of sulfates and other dissolved solids. All equipment, product, and operational costs were calculated and evaluated. Several waste treatment options were also evaluated, and a recommended design to employ evaporation ponds was chosen based on geographic location and arid climate. In the chosen waste treatment option, all regenerative waste is sent to an evaporation pond to recover and dispose of excess salt. The process of ion exchange successfully removed an adequate amount of sulfates and was proven to be a feasible solution for water treatment in areas with high sulfate concentrations.

Key words: Ground water, sulfate, ion exchange

# Use of Borehole Geophysics to Determine Zones of Radium Production in Northern Arkansas

Rheannon M. Hart, U.S. Geological Survey
Timothy M. Kresse, U.S. Geological Survey

Borehole geophysics can be used to identify zones of radium production and can aide in design of new well construction so that radium levels in new wells are minimized. Elevated radium levels in water from deep wells (average depth of approximately 2,000 feet) drilled into the Roubidoux Formation or Gunter Sandstone in northern Arkansas are an ongoing issue. Some wells drilled for public supply use have been abandoned because radium levels exceed the maximum contaminant level set by the U.S. Environmental Protection Agency. The U.S. Environmental Protection Agency has established a maximum contaminant level for combined Ra-226 and Ra-228 in public water supplies of 5 picocuries per liter. Radium levels (of about 6-7 picocuries per liter) in water samples from a public supply well near Hasty, Arkansas, exceed the maximum contaminant level.

Borehole geophysical methods are useful in determining physical and chemical properties of formations and groundwater in and around the well, in addition to aquifer hydraulic characteristics. A suite of geophysical logs that included flowmeter and natural gamma were recently completed by the U.S. Geological Survey Arkansas Water Science Center for a well near Hasty, Arkansas. These data were used to determine zones of flow into and out of the well, as well as the lithology near the flow zones. This information, combined with water-quality data, could provide insight needed to correlate specific lithology or fracture sets with radium levels.

Other wells in northern Arkansas contain elevated radium levels according to the Arkansas Department of Health. Zones of radium production will be evaluated in 3-5 of these identified wells to further correlate elevated radium with specific lithology or fracture sets. The identified lithology and fracture sets associated with the elevated radium can then be avoided or plugged in future well construction to minimize radium levels in those wells.

Key words: Groundwater, Water Quality, Water Supply

# Beneficial Use of Marginal Quality Water

Wayne Kellogg, Chickasaw Nation Division of Commerce

The Mississippi Alluvial Aquifer is the most heavily used aquifer in the state of Mississippi. Extensive use of the aquifer has overdrawn the aquifer in some areas and caused large cones-of-depression making continued pumping at the current rate unsustainable. The alluvial aquifer overlies deeper aquifers of the Mississippi Embayment Aquifer system. The alluvial aquifer can be as much as 250 feet thick and the Mississippi Embayment Aquifer system can be as much as 6,000 feet in thickness. Water usage is approximately 2 billion gal/day from the alluvial aquifer and 433 million gal/day from the deeper Mississippi Embayment Aquifers.

Many of the deeper aquifers contain fresh water (<500 mg/l TDS) in the northern part of the Mississippi Embayment, but TDS concentrations increase in the southern portion of the Embayment making the water unsuitable as a potable water supply without treatment. Many industries use fresh water supplies when they could be using brackish water (TDS 1,000 to 10,000 mg/l). In addition, desalination technology has improved a great deal in the past decade making desalination of brackish water a cost effective solution for obtaining additional sources of water supply.

Desalination of brackish water is becoming common in Florida, Texas, and California. Other states are now beginning to look at their brackish water aquifers as potential future supplies of potable water.

Key words: Ground water, sulfate, ion exchange

# Attendees

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