2004 Proceedings

Mississippi Water Resources Conference 2004

Conference Sponsors:

Mississippi Water Resources Research - GeoResources Institute

U.S. Geological Survey, Mississippi District Office

Mississippi Department of Environmental Quality's Offices of Land and Water Resources and Pollution Control

Mississippi Water Resources Association

GRI Mississippi State University

PREFACE

The 34th Annual Mississippi Water Resources Conference was held April 20-21, 2004 at the Eagle Ridge Conference Center in Raymond, Mississippi.

CONFERENCE SPONSORS:

Mississippi Water Resources Research - GeoResources Institute
U.S. Geological Survey, Mississippi District Office
Mississippi Department of Environmental Quality's Offices of Land and Water Resources and Pollution Control
Mississippi Water Resources Association

CONFERENCE MODERATORS:

Mickey Plunkett, District Chief, U.S. Geological Survey
Randy Reed, Mississippi Department of Environmental Quality
Dean Pennington, YMD Joint Water Management District
Chuck Hill, GeoResources Institute, Mississippi State University
Ken Griffin, Pearl River Water Supply District
Jonathan Pote, Mississippi State University office of Research
Fred Howell, Biological Sciences, University of Southern Mississippi
Mark Stiles, YMD Joint Water Management District
Jeff Ballweber, GeoResources Institute, Mississippi State University

CONFERENCE SPEAKERS:

P. Patrick Leahy, Associate Director for Geology, USGS
Kenneth Reinecke, USGS Biology Programs
Julia Giller, USGS Gulf Coast Liaison
Mickey Plunkett, USGS Mississippi District Chief
Senator Tommy Moffatt, Mississippi District 52
Bo Robinson, Northern District Public Service Commissioner
Dr. Bryant R. Boswell, Lewis and Clark Expedition
Representative Jamie Franks, Mississippi District 19
Representative Diane Peranich, Mississippi District 121

A SPECIAL THANKS

to Mrs. Patricia Wilson, Conference Coordinator, and her group of workers from the GRI and USGS for their hard work in making the 2004 Mississippi Water Resources Conference a great success.

List of Papers

Spatial Modeling of Soil Hydraulic Properties: Peter Ampim, Plant and Soil Sciences, Mississippi State University

Can Wetland Plants be Useful in Mitigating Nutrient Runoff from Agricultural Fields?: J. Beadle, Biology, University of Mississippi

Constructed Wetlands: An Edge-of-field Management Practice for Reduction of Coliforms: Charles M. Cooper, USDA-ARS, National Sedimentation Laboratory

Presence of Atrazine in Water in a Recharge Area of Guarany Aquifer in Brazil: Antonio Luiz Cerdeira, Embrapa, Research Division of the Brazilian Ministry of Agriculture, Brazil

Flux and Yields of Herbicides in the Yazoo River Basin, Mississippi, 1996-97: Angela Pell, USGS

Pesticide Concentrations in Surface Waters of Mississippi Lakes and Reservoirs: Charles M. Cooper, USDA-ARS, National Sedimentation Laboratory

The Demonstration Erosion Control Project: Aspects of Water Quality in Abiaca Creek, Mississippi: Richard E. Lizotte, Jr., USDA-ARS, National Sedimentation Laboratory

Optical Fiber Chemical Sensor for Water Quality Monitoring: Shiquan Tao, Diagnostic Instrumentation and Analysis Laboratory, Mississippi State University

Habitat Assessment of Selected Streams in the Mississippi River Alluvial Plain in Northwestern Mississippi and Eastern Arkansas: Winter and Summer 2002: Richard A. Rebich, USGS

Invasive Aquatic Plants: A Threat to Mississippi Water Resources: John D. Madsen, GeoResources Institute, Mississippi State University

Port Sedimentation Solutions: William H. McAnally, Civil Engineering, Mississippi State University

THE 34th ANNUAL MISSISSIPPI WATER RESOURCES CONFERENCE
Eagle Ridge Conference Center - Raymond, Mississippi

TUESDAY, APRIL 20, 2004

7:30AM **Registration and Continental Breakfast (The Gallery Area)**

OPENING PLENARY SESSION (Auditorium)
Moderator: Mickey Plunkett, USGS

8:30AM **Opening Remarks**

8:45AM **125 Years of USGS: P. Patrick Leahy, Associate Director for Geology, USGS**

9:30AM **USGS Biology Programs: Kenneth Reinecke, USGS Biology Programs**

10:00AM **USGS Mapping Programs: Julia Giller, USGS Gulf Coast Liaison**

10:30AM **USGS Water Programs, Mickey Plunkett, USGS Mississippi District Chief**

11:15AM POSTER SESSION (The Gallery Area)

Spatial Modeling of Soil Hydraulic Properties: Peter Ampim, Plant and Soil Sciences, Mississippi State University

Can Wetland Plants be Useful in Mitigating Nutrient Runoff from Agricultural Fields?: J. Beadle, Biology, University of Mississippi

Constructed Wetlands: An Edge-of-field Management Practice for Reduction of Coliforms: Charles M. Cooper, USDA-ARS, National Sedimentation Laboratory

Use of Mississippi River Alluvial Aquifer Decline Rates for Allocation of EQIP Funds: F. Elizabeth LaMastus-Stanford, YMD Joint Water Management District

Assessment of Bio-Contaminants in the Porter Creek Basin of the Homochitto National Forest: Stanley Mason, Agronomy, Alcorn State University

Improved Estimation of Nutrient and Pesticide Runoff Losses from Golf Courses and Residential Lawns in the South Atlantic-Gulf Region: Joe Massey, Plant and Soil Sciences, Mississippi State University

Water Quality Analysis of an Intensively Used Agricultural Reservoir: Matthew T. Moore, USDA-ARS, National Sedimentation Laboratory

Planform Changes in the Pascagoula River and Tributaries, Mississippi: Joann Mossa, Geography Department, University of Florida, and Chris Bowen, Pat Harrison Water District

Coastal Development and Water Quality: Assessing the Health of Mississippi's Estuarine Waters: Christine Trigg and Harriet Perry, Gulf Coast Research Laboratory, University of Southern Mississippi

Water Saving Irrigation: A Vital Step in Improving the Sustainability of Rice (*Oryza sativa*) Production in the Mississippi Delta: M. Cade Smith, Mississippi State University

Understanding the Link Between an Aquatic Shoreline and an Urban Development: A Mission of Planning and Management: Jonathan Sobley, Landscape Architecture, Mississippi State University

Geospatial Applications for Water Management Agencies in the Upper Pearl River Basin: M.L. Tagert, GeoResources Institute, Mississippi State University

The Under Lying Link Between Residential Storm Water Management Design and Development by a Managed Body of Water: Ryan Verseman, Landscape Architecture, Mississippi State University

12:00PM **LUNCHEON: State Senator Tommy Moffatt, District 52, Jackson County and Chairman of the Senate's Environmental Protection, Conservation & Water Resources Committee, and Bo Robinson, Northern District Commissioner, Mississippi Public Service Commission; Governor's Task Force on Safe Drinking Water and Waste Water; National Association of Regulatory Utility Commissioners Water Committee**

CONCURRENT SESSION A: Groundwater (Auditorium)

Moderator: Randy Reed, Mississippi Department of Environmental Quality

1:00PM **Shallow Groundwater Dynamics in the Root Zone of a Cypress Wetland:** Gregg Davidson, Geology and Geological Engineering, University of Mississippi

1:25PM **Characterizing Soil Hydraulic Properties in an Agro-Forestry Ecosystem:** Alton B. Johnson, Alcorn State University

1:50PM **Presence of Atrazine in Water in a Recharge Area of Guarany Aquifer in Brazil:** Antonio Luiz Cerdeira, Embrapa, Research Division of the Brazilian Ministry of Agriculture, Brazil

2:20PM **BREAK**

CONCURRENT SESSION B: Water Policy (Talon)

Moderator: Dean Pennington, YMD Joint Water Management District

1:00PM **Water Infrastructure:** Commissioner Bo Robinson, Public Service Commission

1:30PM **Mercury Issues in Mississippi Waters:** Phil Bass, Mississippi Department of Environmental Quality, Office of Pollution Control

2:00PM **The Alabama Sturgeon: Public Policy Repercussions:** Rob Fowler of Balch and Bingham, LLC

2:20PM **BREAK**

CONCURRENT SESSION C: Water Contaminants (Auditorium)

Moderator: Chuck Hill, GeoResources Institute, Mississippi State University

2:40PM **Status of Microbial Source Tracking in the North America:** R.D. Ellender, Biological Sciences, University of Southern Mississippi

3:00PM **Flux and Yields of Herbicides in the Yazoo River Basin, Mississippi, 1996-97:** Angela Pell, USGS

3:20PM **Pesticide Concentrations in Surface Waters of Mississippi Lakes and Reservoirs:** Charles M. Cooper, USDA-ARS, National Sedimentation Laboratory

CONCURRENT SESSION D: Surface Water (Talon)

Moderators: Ken Griffin, Pearl River Valley Water Supply District and Jonathan Pote, Mississippi State University Office of Research

2:40PM **AGNPS Runoff Model: Geospatial Applications and Predictions in the Upper Pearl River Basin:** M.L. Tagert, GeoResources Institute, Mississippi State University

3:00PM **The Demonstration Erosion Control Project: Aspects of Water Quality in Abiaca Creek, Mississippi:** Richard E. Lizotte, Jr., USDA-ARS, National Sedimentation Laboratory

3:20PM **Mississippi Embayment National Water-Quality Assessment - Cycle II: The Second Decade:** Richard Coupe, USGS

3:40PM **Chemical Mixtures (Phase I): Consequences of WNV Eradication on the Amphipod *Hyalella azteca*:** Jim Weston, Department of Pharmacognosy, University of Mississippi

4:00PM **Runoff Quality in Bermudagrass Plots Treated with Poultry Litter:** Alton B. Johnson, Alcorn State University

4:20PM **Effects of Mississippi Delta Sediment Contaminants on CYP1B-Gene Expression in Channel Catfish:** Kristie Willett, Pharmacology and Environmental Toxicology, University of Mississippi

4:40PM **Optical Fiber Chemical Sensor for Water Quality Monitoring:** Shiquan Tao, Diagnostic Instrumentation and Analysis Laboratory, Mississippi State University

CONCURRENT SESSION E: Aquatic Ecology (Auditorium)

Moderator: Fred Howell, Biological Sciences, University of Southern Mississippi

3:40PM **Habitat Assessment of Selected Streams in the Mississippi River Alluvial Plain in Northwestern Mississippi and Eastern Arkansas: Winter and Summer 2002:** Richard A. Rebich, USGS

4:00PM **Invasive Aquatic Plants: A Threat to Mississippi Water Resources:** John D. Madsen, GeoResources Institute, Mississippi State University

4:20PM **Analysis of Freshwater Sand-Dwelling Chironomid Larvae in Disturbed and Relatively Undisturbed Blackwater Streams:** Robert C. Fitch, Biological Sciences, University of Southern Mississippi

4:40PM **A Survey of Lotic Tardigrades from the Pascagoula Drainage:** Alan Niven, Biological Sciences, University of Southern Mississippi

5:00PM **SOCIAL ON THE PATIO**

WEDNESDAY, APRIL 21, 2004

7:30AM **Continental Breakfast (The Gallery Area)**

CONCURRENT SESSION F: Surface Water Management (Auditorium)

Moderator: Mark Stiles, YMD Joint Water Management District

8:00AM **Port Sedimentation Solutions:** William H. McAnally, Civil Engineering, Mississippi State University

CLOSING PLENARY SESSION (Auditorium)

Moderator: Jeff Ballweber, GeoResources Institute, Mississippi State University

8:20AM **Lewis and Clark Presentation: Dr. Bryant R. Boswell**

9:30AM **BREAK**

9:45AM – 12:15PM **PANEL**

Keith Allen-MS Department of Health, Division of Water Supply
Claiborne Barnwell – Environmental Division, MDOT
Phil Bass – Office of Pollution Control, MDEQ
Chris Bowen – Pat Harrison Waterway District
Jamie Crawford – Office of Land and Water Resources, MDEQ
Fred Deegan – MS Department of Marine Resources
Ken Griffin – Pearl River Valley Water Supply District
Jeff Ballweber – Tombigbee River Valley Water Supply District
Mark Stiles – Yazoo Mississippi Joint Water Management District
Mike Tagert – MS Department of Agriculture and Commerce
Ralph Turnbo – MS Department of Health, Division of Wastewater
Don Underwood – Mississippi Soil and Water Conservation Commission
Andrew Whitehurst – MS Department of Wildlife, Fisheries and Parks

12:15PM **LUNCHEON: Representative Jamie R. Franks, Jr., (Invited) Mississippi House of Representatives - Chairman of the Conservation and Water Resources Committee and State Representative Diane Peranich, District 121, Harrison County, and member of the Conservation and Water Resources Committee**

SPATIAL MODELING OF SOIL HYDRAULIC PROPERTIES

Peter Ampim*, Alton B. Johnson, Josepth H. Massey*, and Teferi Tsegaye*****
***Department of Plant and Soil Sciences, Mississippi State University**
****Mississippi River Research Center, Alcorn State University**
*****Center for Hydrology, Soil Climatology and Remote Sensing, Alabama A&M University**

INTRODUCTION

Interest in ground water research has provided researchers the opportunity to develop models that describe water and solute transport in variably saturated soils. Generally, unsaturated soil hydrologic models are based on numerical solutions of the Richard's equation. The key parameters needed for solving the equation are water retention values, θ(h), and hydraulic conductivity functions, K(h). Further, hydrological processes vary in space. Knowledge of spatial heterogeneity of soil hydraulic properties is essential in quantifying solute and water transport processes from a plot-scale to a regional-scale. Direct measurements of θ(h) and K(h) are time-consuming and expensive (Arya and Paris, 1981; Saxton et al., 1986; Schuh and Bauder, 1986; Wosten and van Genuchten, 1988; Kern, 1995; Scott, 2000 and Cornelis et al. 2001). Their measurements may be cost prohibitive in the short-term for large areas (Arya and Paris, 1981), and are not practical for remote sensing investigations (Saxton et al., 1986). The lack of knowledge of these parameters largely affects our ability to address hydrologic problems when modeling water and solute transport in large and complex watersheds. A progressively more popular alternative to direct measurement of soil hydraulic properties involves the use of pedotransfer functions (PTFs) (Wosten and van Genuchten, 1988, Cornelis et al. 2001, Zhu and Mohanty, 2002). In this research, we used PTFs to predict soil hydraulic properties for Memphis silt loam (fine silty, mixed, thermic, Typic Hapludalf). We further attempted to quantify spatial variability of these parameters and determined their functional relationships.

MATERIALS AND METHODS

The site investigated was a 4-ha conventionally tilled Memphis silt loam field that has undergone corn and cotton rotation for 10 years. The field was located north of Port Gibson in Claiborne County, Mississippi (32° 00' N; longitude 90° 52' W). Soil samples were collected from the 0 to 15 cm depth at 272 nodes on a 15 m x 15 m grid. Bulk density (ρ_b) data for each node was determined by the core method. Sand, silt and clay were quantified using the hydrometer method (Thien and Graveel, 1997). Unsaturated hydraulic conductivity (K_o) and saturated hydraulic conductivity (K_s) were predicted using the computer code RETC, developed by van Genuchten et al. (1990). The van Genuchten-Mualem equation

$$\theta(h) = \theta_r + \frac{\theta_s - \theta_r}{\left(1 + |\alpha h|^n\right)^m} \qquad [1]$$

$$K_\alpha = K_s S^{0.5}\left[1-\left(1-S^{\frac{1}{m}}\right)^m\right]^2 \quad [2]$$

(Mualem, 1976; van Genuchten, 1980) was used to describe soil hydraulic properties, where θ is the volumetric water content (cm cm^{-3}), h is the pressure head (cm), θ_r and θ_s are the residual and saturated water contents (cm cm^{-3}), respectively, S is the water saturation ratio $(\theta-\theta_r)/(\theta_s-\theta_r)$, m=1-(1/n), and α and n are empirically fitted parameters. Values obtained for each soil property were point kriged and mapped using the geostatistical program GS^+ version 5 (Gamma Design, Plainwell, MI). Linear regression was used to quantify the relationships between measured and model predicted soil properties.

RESULTS AND DISCUSSION

Geostatistical models and model parameters describing the soil properties studied are listed in Table 1. The semivariograms for K_o and α were described by the Gaussian model while all other parameters were described by different model. All parameters measured showed some degree of spatial dependence. The range of influence for all parameters ranged from 47.0 to 610.9 m. Only K_s had the shortest range (47.0 m) followed by silt (222.3 m). There was nugget effect for all other parameters, except for α and ρ_b. Smaller nuggets indicate that the sampling interval is proper to reflect the variance (Nielsen, 1998). The sill on the other hand, reflects the scale of random variation and is the plateau reached when the semivariance does not change significantly with increasing lag distance (Nielsen, 1998).

Variability of Soil Properties

Spatial maps for both measured and predicted soil properties are shown in Figures 1 and 2. Sand content was highest in the central to northeastern portion of the field. Areas in the field with higher sand content had lower silt content (Figs. 1a and 1b). Relatively high silt content was observed in the western portion of the field and relatively lower sand content was observed in similar location. Bulk density (Fig. 1c) followed a similar trend as the sand content. Clay on the other hand did not follow similar pattern as sand or silt. However, higher clay content was observed in the northeastern portion of the field (Fig.1d). Saturated hydraulic conductivity did not show any pattern relative to sand, silt and ρ_b; however, the map of K_o was somewhat similar to the silt content (Fig. 2a). The highest K_o values observed were scattered along the western edge of the field (Fig. 2b). Distribution of n (Fig. 2d) was similar to the distribution of sand. Lower n values were observed on the western edge of the field while higher values were observed mainly across the eastern half of the field. We suggest that the variability observed for the soil parameters investigated may be both intrinsic and extrinsic in nature. Intrinsic variability occurs as a result of soil forming processes and extrinsic variability is caused by soil management practices (Scott and Wood, 1989). The spatial patterns exhibited by the soil parameters investigated may be due to a combined effect of intrinsic and extrinsic factors. Spatial maps of sand, silt and ρ_b (Fig. 1) followed similar patterns as K_o, n and K_s in Figure 2. This implies that these soil parameters are correlated. The maps for sand and silt showed that in location where there is higher sand content, the silt content was relatively lower.

Regression parameters associated with the soil properties measured and estimated are presented in Table 2. Silt was negatively correlated with ρ_b, K_s, n and sand. Negative correlations were observed between sand and K_o and α. There was no significant correlation between clay and any of the other soil parameters. This is an indication that clay is not a good predictor of hydraulic conductivity for the soil investigated. Southhard and Buol (1988) studied subsoil hydraulic conductivity of an Ultisols in relation to soil properties. They observed that sand, silt and clay were not good predictors of K_s because these parameters by themselves did not define the geometry of pores. From a physical perspective, α in the van Genuchten equation relates to the mean pore size magnitude, whereas n relates to the degree of pore size spreading (Zhu and Mohanty, 2002). Scott (2000) suggested that pore size characteristics (size-distribution, shape, roughness and interconnectedness) could vary spatially as texture because soil porosity is influenced by texture. This observation has important implications for hydrologic studies in general.

CONCLUSION

In this study it was found that the magnitude of saturated and unsaturated hydraulic conductivities as well as α and n were influenced mainly by sand and silt. All the soil properties investigated exhibited spatial dependence and were isotropic. However, the magnitude of spatial dependence varied among the various properties. The shortest range was observed for saturated hydraulic conductivity, indicating its extensive spatial variation within an agricultural soil. The linear functions developed in this study are useful because they can provide a basis for developing more complex models for analyzing and understanding hydrologic problems spanning large areas. It must also be noted that the various relationships developed between the soil properties investigated in this study may not hold for soils with greatly different properties, particularly those with much greater clay contents. Investigations on similar and/or different soils are needed to develop a robust data base both for the purpose of comparison and development of more complex models for hydrologic studies in the State of Mississippi.

REFERENCE

Ampim, P. 2003. Spatial variability of selected properties in a thick lower loessial soil. Masters thesis. Alcorn State University, Alcorn State, Mississippi.

Arya, L. M. and J. F. Paris 1981. A physicochemical model to predict the soil moisture characteristics from particle-size distribution and bulk density data. Soil Sci. Soc. Am. J. 45:1023-1030.

Cornelis, W. M., J. Ronsyn, M. van Meirvenne and R. Hartmann. 2001. Evaluation of pedotransfer functions for predicting the soil moisture retention curve. Soil Sci. Am.J 65:638-648

Gamma Design Software. 2000. GS+ Geostatistics for Environmental Sciences version 5.0 User Manual, Plainwell, MI.

Kern, J. S. 1995. Evaluation of soil water retention models based on basic soil physical properties. Soil Sci. Soc. Am. J. 59: 1134-1141.

Nielsen, D. R. 1998. College on soil physics: Applied time series analysis and geostatistical methods, International Center for Theoritical Physics, Italy.

Saxton, K. E., W. J. Rawls, J. S. Romberger and R. I. Papendick. 1986. Estimating generalized soil-water characteristics from texture. Soil Sci. Soc. Am. J. 50: 1031-1036.

Schum, W. M. and J. W. Bauder. 1986. Effects of soil properties on hydraulic conductivity-moisture relationships. Soil Sci. Soc. Am. J. 50:848-855.

Scott, D.H. 2000. Soil Physics, Agricultural and Environmental Applications. Iowa State University Press/Ames. 421 p.

Scott, D. H. and L. S. Wood. 1989. Impact of crop production on a Typic Albaqualf. Soil Sci. Soc. Am. J. 53:1819-1825.

Southhard, R. J. and S. W. Buol. 1988. Subsoil saturated conductivity in relation to soil properties in the North Carolina Coastal Plain. Soil Sci. Soc. Am. J. 52: 1091-1094

Thien, S. J., J. G. Graveel. 1997. Laboratory Manual for Soil Science, Agricultural and Environmental Principles (7th Edition). Dubuque, IA: Wm. C. Brown.

Van Genuchten, M. Th. 1980. A closed form equation for predicting the hydraulic conductivity of unsaturated soils. Soil Sci. Soc. Am. J. 44: 892-898.

Wosten, J. H. M. and M. Th van Genuchten.1988. Using texture and other soil properties to predict the unsaturated soil hydraulic functions. Soil Sci. Soc. Am. J. 52: 1762-1770.

Zhu, J. and B. P. Mohanty. 2002. Spatial averaging of van Genuchten hydraulic parameters for steady-state flow in heterogeneous soils: A numerical study. Vadose Zone Journal 1: 261-272.

Table 1. Geostatistical model parameters describing soil properties studied.†

Soil Properties	Model	Co	Co + C	Ao	r^2
Sand	Spherical	9.4	54.5	374.9	0.99
Silt	Linear	8.4	49.5	222.3	0.99
Clay	Exponential	0.7	1.4	524.8	0.63
Bulk density	Linear to sill	0.0	0.01	526.2	0.98
K_s	Exponential	29.4	102.0	47.9	0.94
K_o	Gaussian	0.3	2.8	286.0	0.98
α	Gaussian	0.0	0.0	610.9	0.98
n	Linear to sill	0.001	0.002	520.4	0.47

†Co = nugget, Co + C = sill, Ao = range

Table 2. Correlation coefficients and slopes of regression lines when correlating sand and silt with other soil parameters quantified.

	Correlation Coefficient		Slope	
	Sand	Silt	Sand	Silt
ρ_b	0.93	0.97	0.008	-8.77
K_s	0.85	0.76	1.46	-1.29
K_o	0.88	0.93	-0.14	0.15
n	0.98	0.99	0.004	-0.004
α	0.94	0.97	-0.0002	0.0002
Sand	--	0.99	--	-0.97

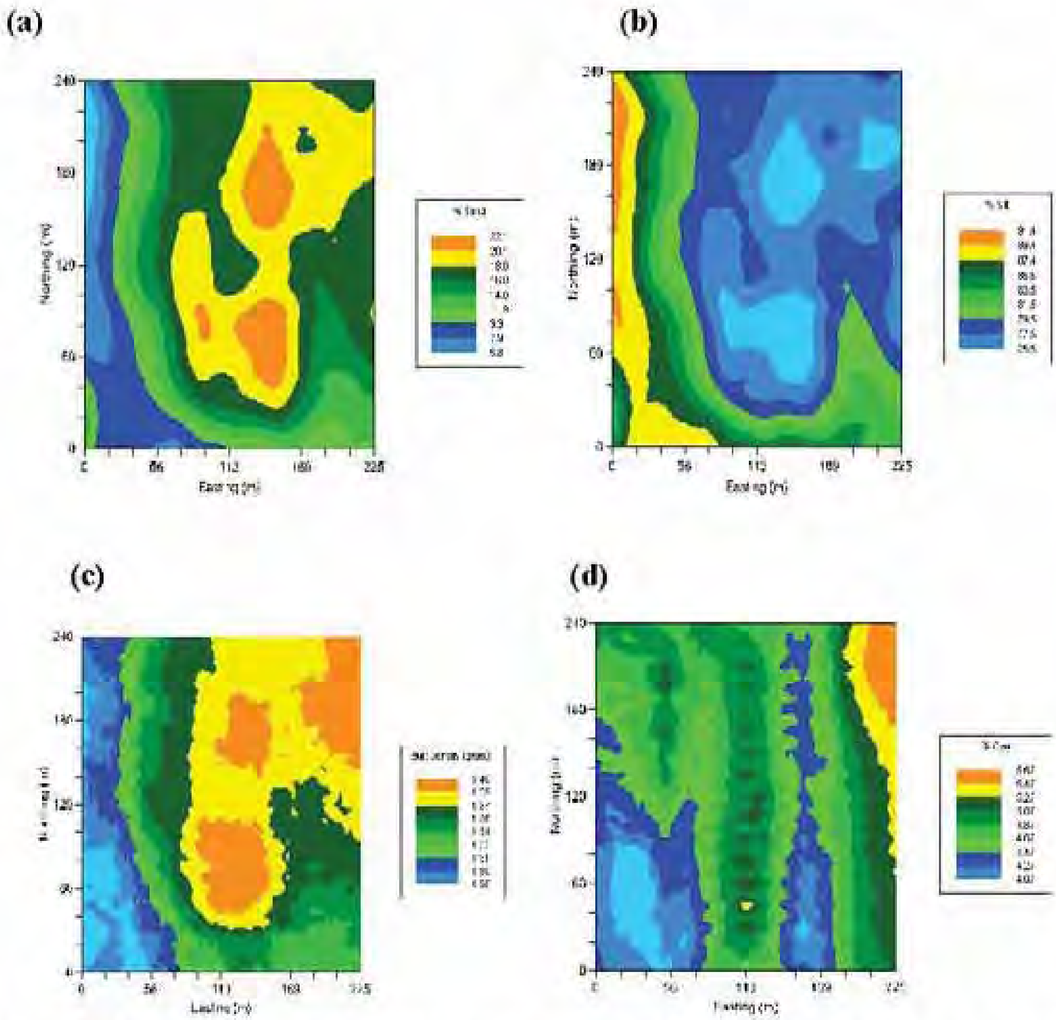


Fig. 1. Kriged maps of measured soil properties for Memphis silt loam under 10-year corn and cotton rotation: (a) sand, (b) silt, (c) bulk density and (d) clay.

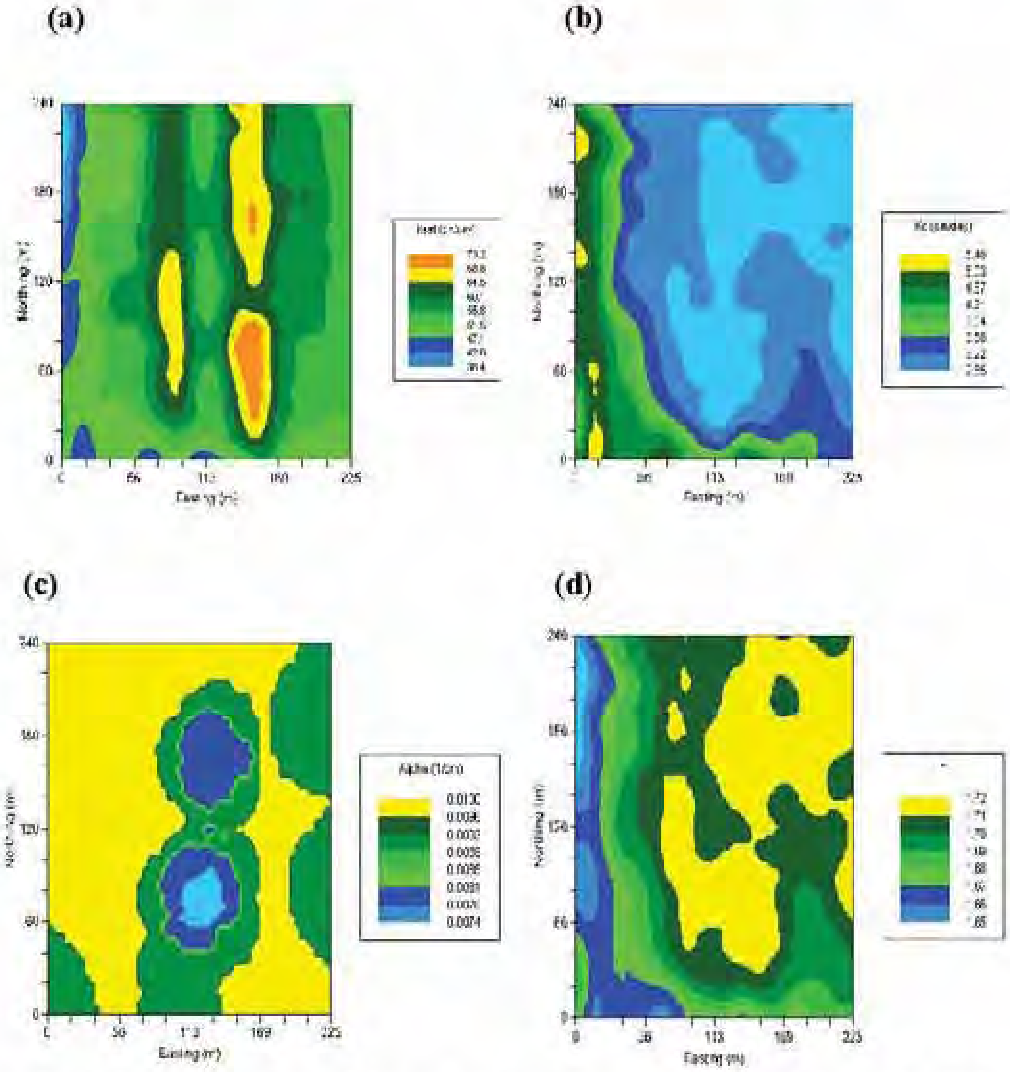


Fig 2. Kriged maps of model predicted soil parameters for Memphis silt loam under 10-year corn and cotton rotation: (a) K_s, (b) K_0, (c) α and (d) n.

How are native wetland plants useful in mitigating nutrient runoff from agricultural fields?

J. Beadle (jvbeadle@olemiss.edu, Department of Biology and University of Mississippi Field Station, University of Mississippi, University, MS)
R. Kröger (kroger@olemiss.edu, Department of Biology, University of Mississippi, University, MS)
M. M. Holland (mholland@olemiss.edu, Department of Biology, University of Mississippi, University, MS)
M. T. Moore (mtmoore@msa-oxford.ars.usda.gov, USDA-ARS, National Sedimentation Laboratory, Oxford, MS)
C. M. Cooper (ccooper@npa.ars.usda.gov, USDA-ARS, National Sedimentation Laboratory, Oxford, MS)

Introduction

Human activities have altered the global biogeochemical cycle by doubling the rate of nitrogen input into terrestrial ecosystems (Smith et al., 1999). Likewise, land use has a similar effect on phosphorus. The loading of nitrogen and phosphorus into the world's rivers, lakes, and oceans is strongly influenced by human population densities, population densities of livestock, and land use (Pringle, 2003).

Nutrients are the 3rd largest agricultural pollutant in Mississippi, following sediment and pathogens (Moore and Cooper, 2003). Wetlands serve as natural buffers for rivers, lakes, and streams (Holland, 1996). By maintaining these wetlands around agricultural landscapes, significant improvements in water quality may be achieved (Moore and Cooper, 2003).

Drainage ditches surround many agricultural fields for the primary purpose of removing water after rainfall and act as major conduits of nutrients from agricultural lands to receiving waters (Nguyen and Sukias 2002). These ditches possess many of the key characteristics that define wetlands: hydroperiods, hydrosoils, and hydrophytes

(Moore et al. 2001). Many of these ditches maintain some level of water throughout the year, although water levels are dependent on the spatial and temporal variations in precipitation events.

So how useful is native wetland vegetation in mitigating nutrient runoff, specifically, non-point source agricultural runoff, potentially high in both nitrogen and phosphorus concentrations? We report here on two experiments. The first experiment was designed to find plants suitable for planting in agricultural ditches that would serve as efficient buffers for nutrient runoff. The plants chosen for this experiment are *Juncus effusus*, soft rush, and *Paspalum urvillei*, vasey grass. These plants were chosen based on an earlier vegetation survey of dominant native plant species at the University of Mississippi Field Station (Davis and Holland 1998). *Paspalum urvillei* was not on the 1998 list, but has now replaced some of the other species collected earlier at the Field Station. Specimens of each species were planted and grown in a greenhouse, with stable climatic conditions and controlled precipitation events.

The second experiment moves away from a greenhouse-based experiment to a field experiment. This experiment examines *Paspalum urvillei* and another common drainage ditch species *Leersia oryzoides* and assesses the levels of total nitrogen assimilation under stimulated nutrient runoff levels in the field. The goal of the second experiment is to determine, under simulated field conditions, whether or not plants are assimilating nutrients, and if so where?

Methods

Experiment 1

Twelve 55-gallon drums were cut in half and positioned within the University of Mississippi Field Station (UMFS) greenhouse. Soil was collected from the UMFS and placed in the drums. The plants were also collected from the UMFS and planted in the soil in the greenhouse. Ten of the drum-halves were planted with *J. effusus* and ten planted with *P. urvillei*. Four drums were left unvegetated. A five gallon aquarium doser was purchased for each of the 24 drums. A hole was drilled into the side of each of the drum-halves 12 cm above the soil surface to serve as a water outlet. Each drum was filled with water to the outlet point, and all drums contained standing water thought the experiment.

The plants were watered from non-chlorinated well water, by filling each of the dosers and allowing them to drip water into the drums at a rate of 3 L/day. A treatment of five mg/L nitrate, and 0.15 mg/L phosphate was added to half of the dosers: five drums containing each species and two drums without plants. The other seven drums received untreated well water.

The experiment ran for a period of 18 weeks from July 14, 2003 to November 14, 2003. Plant height was measured thought the experiment by measuring the height of the tallest plant. Plant cover was measured by estimating the percent of the drum covered by aboveground tissue.

Experiment 2

Plants for the second experiment were collected in the fall of 2003 from four mesocosms at The University of Mississippi Field Station. The four mesocosms were ponds 210, 212, 216 and 218. Ponds 216 and 218 were regularly subjected to simulated nutrient runoff conditions (25 acre field runoff over a year). Nutrients associated with the runoff were nitrate, ammonia and orthophosphorus. Nutrient levels were below 5mg/L to distinguish between background nutrient concentrations. Ponds 212 and 210 were similar sized mesocosms which were untreated. Nutrient runoff into these ponds, if any, was a factor of natural conditions. *Paspalum urvillei* and *L. oryzoides* were sampled as a bulk sample from each pond.

A comparison of nutrient levels between plant species in these two treatments will suggest whether plants under nutrient enriched conditions have higher levels of nutrients within their above and belowground tissues. Thus, these data will determine whether or not vegetation is assimilating nutrients associated with nutrient enriched runoff.

The water samples were analyzed using a Dionex DX-600 Ion Chromatograph. The plant tissue samples and soil samples were analyzed for phosphorus using a Perkin-Elmer 4300 DV Inductively Coupled Plasma-Optical Emission Spectrometer. The nitrogen in the plant tissue and soil samples was analyzed using a Costech Elemental Analyzer.

Results

Experiment I

There was no difference in the height of either *J. effusus* or *P. urvillei* between the control and treatment groups. There was no difference in cover between the *P. urvillei* control and treatment groups, but there was a significant difference in cover between the control and treatment groups of *J. effusus*, with the treatment group growing to cover more area than the control (Figure 1). Weeks 7-12 (August 24-October 5, 2003) show that the cover of the treatment groups of *J. effuses* was significantly greater then the cover of the control groups, but weeks 1-6 and 13-18 show no difference in cover.

Experiment 2

There were significant differences between the total nitrogen tissue concentrations between ponds exposed to elevated levels of nutrient runoff than the control treatment (Figure 2). This suggests that plants under elevated nutrient conditions are indeed assimilating high concentrations of nutrients, in above and belowground tissues. Interestingly there was a slight significant difference ($p < 0.01$) between the tissue nitrogen concentrations of *P.urvillei* and *L.oryzoides*. Thus, *L.oryzoides* was more effective at assimilating nitrogen than *P.urvillei*. This might be as a result of its extensive, shallow root network and prolific above ground biomass production, and that it was situated in the middle of the ditches, while *P.urvillei* was often encountered on the edge of the ditch/water level. The results also suggest that there was no significant difference between the total nitrogen concentrations of above and below ground tissue.

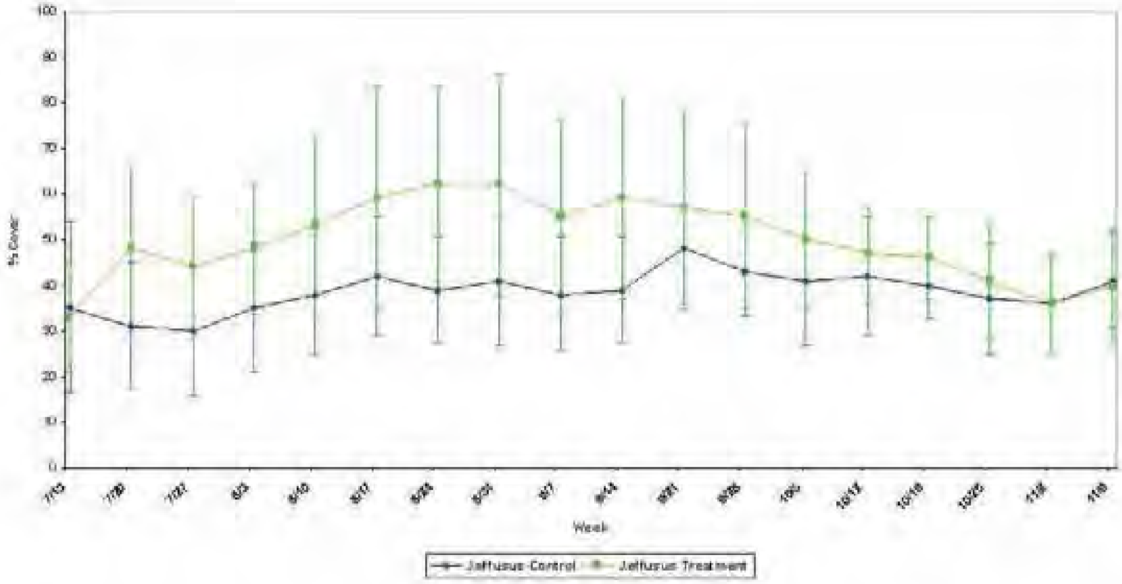


Figure 1. Average percent cover of *Juncus effusus* for Experiment 1. There is a significant difference from August 24-October 5, 2003. Error bars are standard deviation.

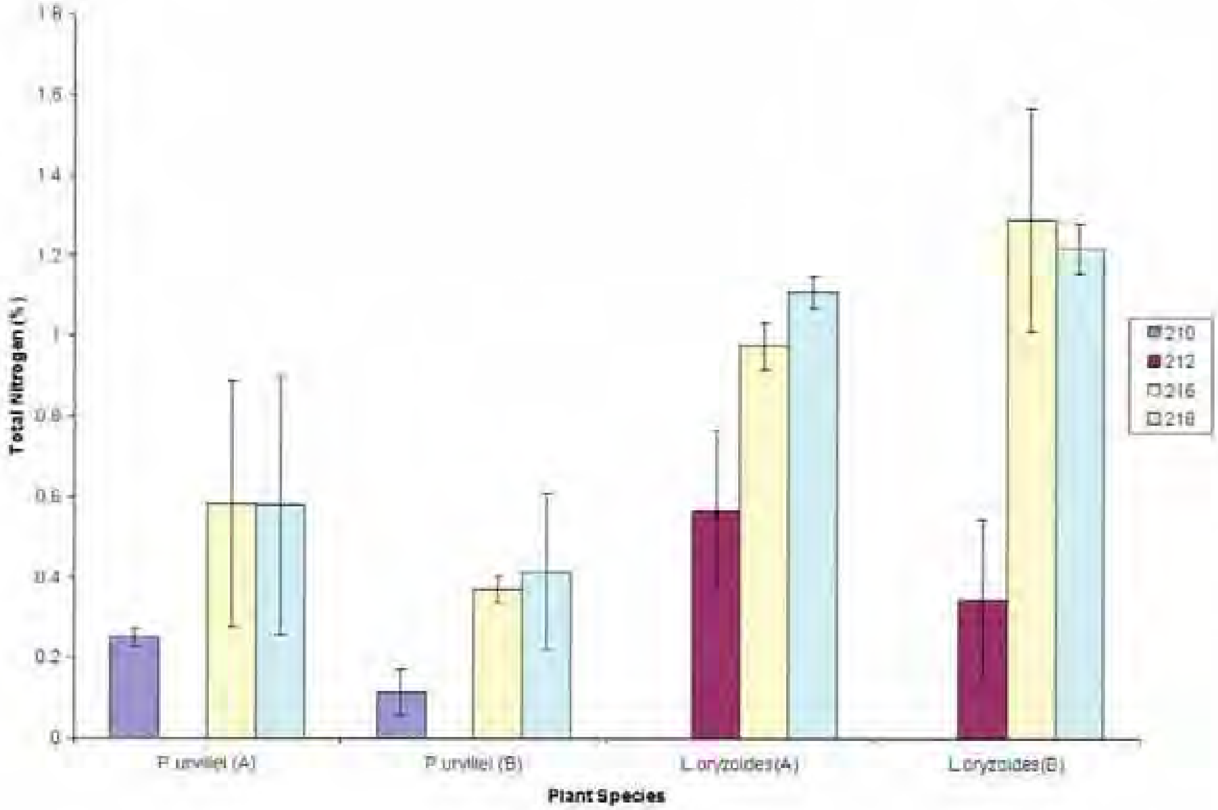


Figure 2. Percentage total nitrogen in above (A) and below (B) ground tissue of two plant species sampled from four mesocosm ponds at the University of Mississippi Field Station.

Conclusion

Experiment 1

When exposed to elevated concentrations of nutrients the aboveground parts of *J. effusus* responds by growing to cover more area. If used in ditches to control runoff, this could provide a double benefit of providing more plant mass to assimilate nutrients, and a greater surface area to slow down the water and trap sediment.

Experiment 2

Plants subjected to elevated nutrient runoff levels, for example in non-point source agricultural runoff, have capability of assimilating a large proportion or concentration of nutrients. Both, *Leersia oryzoides* and *Paspalum urvillei* are plants that occur in drainage ditches and are good candidates in mitigating nutrient runoff.

Next steps? Future research?

There are many further steps that could be done in order to gain a better understanding of this issue: Other wetland plant species could be looked at, both individually and in combinations. Research into the microbial and chemical activities surrounding the rhizosphere of different wetland plants could yield a better understanding of processes such that influence plant uptake of nutrients as well as microbial-basic chemical reactions. On a larger scale it would be useful to evaluate and describe the seasonal nutrient dynamics within drainage ditches in a field experiment. This would be necessary to assess feasibility of utilizing drainage ditches to effectively mitigate nutrient runoff.

References

Cooper, C.M. and M.T. Moore. 2003. Wetlands and agriculture. Pp. 221-235 in *Achieving Sustainable Freshwater Systems*, edited by Holland, M.M., E.R. Blood, and L.R. Shaffer, Washington, D.C.: Island Press.

Davis, S.A. 1998. Vegetation and Substrate Types for Wastewater Treatment Wetlands. MS in Biology, The University of Mississippi.

Davis, S. A., and M. M. Holland. 1998. Vascular plant species native to Northern Mississippi for use in constructed wetlands for wastewater treatment in B. J. Daniel, ed. *Mississippi Water Resources Conference*.

Holland, M.M. 1996. Ensuring sustainability of natural resources: focus on institutional arrangements. Canadian Journal of Fisheries and Aquatic Sciences. 53 (Suppl.1): 432-439.

Holland, M.M., E.R. Blood, and L.R. Shaffer, Washington, D.C.: Island Press. Smith V.H., G.D. Tilman, and J.C. Nekola. 1999. Eutrophication: impacts of excess nutrient inputs on freshwater, marine, and terrestrial ecosystems. *Environmental Pollution* 100:179-196.

Moore M.T., E.R. Bennett, C.M. Cooper, S. Smith Jr., F.D. Shields Jr., C.D. Milam, and J.L. Farris. 2001. Transport and fate of atrazine and lambda-cyhalothrin in a agricultural drainage ditch in the Mississippi Delta, USA. *Agriculture, Ecosystem and Environment* 87 (3):309-314.

Moore, M. T., J. J. H. Rodgers, J. S. Smith, and C. M. Cooper. 2001. Mitigation of metolachlor-associated agricultural runoff using constructed wetlands in Mississippi, USA. *Agriculture, Ecosystems and Environment* 84: 169 - 176.

Nguyen, L., and J. Sukias. 2002. Phosphorus fractions and retention in drainage ditch sediments receiving surface runoff and subsurface drainage from agricultural catchments in the North Island, New Zealand. *Agriculture, Ecosystems and Environment* 92: 49 - 69.

Pringle C.M. 2003. The ecological effects of altered hydrology and contaminant transport. Pp 85-107 in *Achieving Sustainable Freshwater Systems*, edited by

Constructed Wetlands:
An Edge-of-field Management Practice for Reduction of Coliforms

C.M. Cooper, S.S. Knight and S. Testa, III
USDA-ARS-National Sedimentation Laboratory, Oxford, MS

INTRODUCTION

Coliform bacteria represent the majority of pathogens comprising the most commonly listed cause for stream impairment in the United States. While human sources of coliform contamination to streams have decreased from improved wastewater treatment plant efficiency and replacement of failed septic treatment systems, agricultural sources in North America have increased with more concentrated animal farming practices (Molnar et al. 1997, Beaulieu et al. 2001). Even diffuse grazing of pastures and rangeland without direct contact to surface waters can contribute significant pollutant loads to aquatic systems (Line et al. 2000). As public concern and resulting legislative controls regulating water pollution increase, the use of constructed wetlands as a cost-effective, low maintenance technology to treat contaminated waters has flourished. Constructed wetlands have been shown to provide excellent treatment to reduce coliform bacteria in waters before entering receiving streams. Even so, as of 1995, few studies of the usefulness of constructed wetlands for treatment of agricultural non-point source pollution had been reported (WQIC 1998).

A three year study evaluated a constructed wetland system located southeast of Hernando, Mississippi, built for treatment of dairy farm wastes that flowed indirectly into the Coldwater River upstream of Arkabutla Reservoir. These dairy wastes contained excessive concentrations of fecal coliform bacteria that potentially could harm humans using the river and reservoir for recreation and fishing. In Mississippi, as nationally, coliforms are a predominant reason for waterbody impairment, and Mississippi's 2002 Clean Water Act section 303(d) list included 15 impaired segments within the Coldwater River watershed due to pathogen contamination. Our study exemplifies the great potential for small size constructed wetlands to mitigate coliform bacteria pollution from cattle production areas.

METHODS

The constructed wetland was built by the USDA Natural Resources Conservation Service (formally Soil Conservation Service) and the Agricultural Research Service in central DeSoto County, MS. Three parallel wetland cells, planted with softstem bulrush (*Scirpus validus*), were monitored for 36 months while receiving wastewater inputs from a medium sized (<100-head) dairy operation. Measures of physical and chemical water quality, biological oxygen demand, chemical oxygen demand, and fecal coliform bacteria were recorded, and average pollutant-trapping efficiencies for the constructed wetland cells were calculated.

A maximum of 100 cattle were confined twice daily in a concentrated milking operation. Total runoff area for the milking parlor and concrete loafing area where animals were confined during milking was 351.5 m^2. Wastes drained through 15.24 cm (6 inch) diameter PVC pipe to a 42 x 52 x 3 m deep settling lagoon. The lagoon received input from milking equipment and tank cleanings, milking barn washings, loafing area runoff, and rainfall. Total waste production in this area was estimated at 10,336 L/d.

Exports from the lagoon, representing highly concentrated cattle waste, had previously drained overland into an agricultural ditch that drained into the Coldwater River by Short Fork Creek about 24.1 km above Arkabutla Lake. Wastes were diverted to three parallel constructed wetland cells, each 6 m wide and 24 m long (Figure 1) that allowed results to be examined in triplicate. For computing loading rates of pollutants, hydraulic load on individual cells was 1440 L/d (1 cm over 144 m^2 per day).

Coliform bacteria were quantified monthly using the fecal coliform membrane filter procedure (APHA 1992), with modifications of sample volumes for sewage water sources. Ultraviolet sterilization techniques were used for apparatus, and pre-sterilized membrane filters and absorbent pads certified by the manufacturer were used for filtering and incubation. Incubation occurred in a water bath with a gabled top at a temperature of 44.5 ± 2° C for 24 ± 2h. Measurements were conducted according to general laboratory procedures and are, therefore, not suitable for regulatory purpose. Mention of a regulatory limit is intended for general comparison only and does not imply the bearing of data obtained during this study on attainment or non-attainment of regulatory levels for any waterbody.

RESULTS

The constructed wetland totally eliminated discharge at 43% of observations (78 of 181 observation dates). Inflow rates to the cells for most of the study period were targeted at 1.0 L/min. Actual inflows fell between 0.75 and 1.25 L/min at 84% of our sampling visits. Outflow was observed during 103 of 181 sampling visits (57% frequency). Of these 103 discharge observations, 57 (55%) were at a rate of less than 0.75 L/min, and 83 (81%) at less than 1.25 L/min. Discharges in excess of 1.0 L/min were always associated with rainfall events.

During discharge, the constructed wetland reduced the coliform bacterial counts by an average of 89%. Average fecal coliform count in water from the dairy farm entering the constructed wetland system was 14,525 colonies/100ml, more than 70 times the minimum numeric criteria adopted by the State of Mississippi for acceptable levels in surface waters (200 colonies/100ml). The average coliform count leaving the constructed wetland system was 1,585 colonies/100ml water, still above the minimum acceptable level for surface waters, but dramatically reduced from initial concentrations. Constructed wetland effluent flowed overland through a 50 m grassed buffer and an agricultural ditch (several hundred meters long) further reducing fecal coliform bacterial levels prior to entering natural surface waters (Short Fork Creek and Coldwater River).

A moderate difference in fecal coliform trapping by the constructed wetland was observed between warm (May through October) and cool (November through April) seasons. Average concentrations of coliforms leaving the constructed wetland during warm weather (1797 colonies/100ml) were somewhat higher than cold weather exports (1251 colonies/100ml), and cold weather trapping efficiency was much higher than during the warm season (Table 1). This was true although warm season inflow concentrations were less than half the mean number of coliforms observed for cool temperature months.

DISCUSSION

Constructed wetlands can play a significant role in USDA and other farm-oriented programs to promote American agriculture's progress in enhancing water quality (Swader et al. 1994). Pollutant load from non-point sources such as agricultural and urban lands may exceed 65% of our total fresh water pollutant loads (USEPA 1989; Clark et al. 1985). Removal of natural wetlands from their location between terrestrial and aquatic systems has also removed their physical, chemical and biological mechanisms that were naturally efficient means for preventing contamination of our rivers and streams. Construction of wetlands to replace those that have been lost is now a world-wide phenomenon, and these replacements range in size from residential lot runoff ponds to systems encompassing more than 16,000 ha (Guardo et al. 1995).

Through total elimination of greater than 43% of discharge and a reduction of more than 89% of fecal coliforms entering the system, an average of only slightly more than 6% of fecal coliforms from the dairy operation exited the constructed wetland ponds. Our estimates are conservative since we did not include information from tests when counts were zero to correct for potential extinction effects due to sub-sampling. Other studies have reported coliform removal efficiencies well above those reported here (Coombs and Collett 1995, Rivera et al. 1995, Tanner et al. 1995). Design of this system included discharge through a grass filter strip and a vegetated agricultural ditch before effluent entered Short Fork Creek. While we could not measure coliforms where water entered the creek, it is likely that only a diminutive fraction of fecal coliforms survived to enter the natural surface water body. We did find that discharge could be totally eliminated at more than 61% of observations (nearly 20% further reduction of discharge) by doubling the length of the constructed wetland cell from 24 to 48 m.

Development of design criteria and plant culture for constructed wetlands at edge-of-field locations is still in its infancy and optimal configurations for specific regions of the United States and types of pollution will require extensive study. Elimination of coliform bacteria in constructed wetlands is dependent on several factors including solar radiation, diurnal variations in pH and dissolved oxygen, and water retention times (Tanner et al. 1995). Conditions that remove suspended solids have also been shown to greatly reduce coliform bacteria concentrations (Palmateer et al. 1993).

Solar radiation has been proven to effectively disinfect water contaminated with coliform bacteria and other pathogens. Tests conducted to examine the efficacy of solar disinfection for drinking water in undeveloped regions have shown that better than 98% inactivation of fecal coliform bacteria can be obtained by exposure to sunlight for only one to two days (Wegelin et al. 1994, McGuigan et al. 1999). Both the heat and violet-ultraviolet radiation provided by sunlight inactivate coliforms, but a temperature threshold of ~ 50 ^{0}C was observed for heightened bacterial inactivation. The relatively weaker effect of temperature on coliform reductions was also observed by Zdragas et al. (2002) when they examined environmental conditions related to disinfection of wastewaters. Solar treatment is so effective that the World Health Organization (WHO) has endorsed it as a "Point-of-Use" method for drinking water treatment, using only sunlight and clear plastic (PET) bottles (McGuigan et al. 1999).

In this study, the much larger numbers of fecal coliforms leaving the dairy farm during cool months could be related to several factors, including tendency of cattle to remain longer in the milking and loafing area during cooler temperatures and decreased intensity of sunlight exposure on lagoon wastewater. Better trapping efficiency during cool months, despite heightened inputs, is most likely associated with increased sunlight penetration into the water column in the constructed wetland treatment ponds during months when aquatic vegetation is dormant. Zdragas et al. (2002) found that the ability of solar radiation to reduce coliforms is much greater at lower temperatures encountered during winter months.

The role of aquatic plants in water quality improvement has been thoroughly documented with respect to removing many offending water contaminants (Tanner 1996). Plants may play a role in coliform bacteria reduction also, but no precise action is known. Tanner (2001) summarized pathogen removal rates between paired vegetated and non-vegetated subsurface-flow constructed wetland studies and reported that slightly better removal of bacteria and viruses occurred in vegetated wetlands. Differences were attributed to settling, adsorption, protozoan grazing, and possible release of anti-microbial compounds by plants. The generally more oxygenated state of vegetated wetlands can favor bacterial-feeding ciliate protozoan communities (Decamp et al. 1999). Rivera et al. (1995) found that even though coliform removal in un-vegetated constructed wetlands is greater in gravel-beds than soil-beds, differences due to substrate were not significant in the presence of aquatic vegetation.

The placement of the constructed wetland in this study took advantage of local landscape features and used overland flow through a grass buffer strip and a vegetated agricultural ditch. Although partly fortuitous, these processing features should be considered as aspects of a holistic design strategy for edge-of-field wetlands. Initial scoping of wetland designs should seek to creatively leverage all local landscape features to enhance coliform processing. Low cost drainage net modifications that reduce concentrated flow, allow opportunity for vegetative contact, lengthen water residence time by increased travel length or ponding, or provide for greater solar radiation should always be considered.

Both scientists and regulators need more efficient molecular methods for pathogen and indicator organism detection (methods currently require extensive sample processing and purification before application). Future tracking techniques will provide more specificity in determining sources and such identification will allow more specific and appropriate remediation efforts. Innovative and promising new ideas include: fiber optic biosensors, hand-held advanced nucleic acid analyzers, biochips, DNA micro-array, and real-time PCR. These techniques could also assist us in tracing coliform bacteria observed from unexpected locations (Rivera et al. 1988). However, until these techniques are more economical and available, we will continue to rely on culture-based assays to alert us to waterbody contamination. In either case we can make use of existing generalized and affordable preventative measures placed at strategic locations to protect our waters, including use of edge-of-field constructed wetlands.

CONCLUSION

Major improvements have been made in controlling point sources of coliform bacteria entering our surface waters since the passage of the Clean Water Act in 1972. It is increasingly evident that non-point sources, including agricultural animal production lands, are responsible for continued widespread presence of pollutants, including coliform bacteria, in our surface waters (USEPA 1995, Payne Engineering and CH2M Hill 1997). Until advances in microbial source tracking allow us to differentiate between watershed sources of coliform bacteria, we will continue to conjecture at determinations of waterbody impairment and appropriate response. In the future, source tracking will make it possible to quantitatively determine sources of coliform bacteria and allow us to better target domestic sites with installation of edge-of-field constructed wetlands or other suitable mitigation techniques. Despite early recommendations for research into the use of artificial wetlands to control nonpoint source pollution (van der Valk and Jolly 1992), little specific research has been developed and implemented within the landscape for that purpose.

Placement of constructed wetlands at strategic locations on cattle grazing lands and other locations where elevated fecal coliform bacteria concentrations occur in runoff would be extremely beneficial in lowering their concentrations in surface waters throughout the state, reducing hazards to humans. A 94% reduction in total fecal coliform counts in effluent water from a dairy farm, with an effective constructed wetland size of only 6 m x 24 m and inputs representing worst-case conditions, points toward a very affordable, feasible option for landowners. In addition to mitigation of coliforms and other non-point source contaminants that threaten our surface waters, use of constructed wetlands for edge-of-field protection of water quality also provides us with opportunities to provide additional wildlife habitat and restore ecological function that has been lost.

REFERENCES

APHA. 1992. Standard methods for the examination of water and wastewater. 18[th] edition. American Public Health Association, American Water Works Association, Water Environment Foundation. Washington, DC.

Beaulieu, M.S., F. Bedard and P. Lanciault. 2001. Distribution and concentration of Canadian livestock. Agriculture and Rural Working Paper Series Working Paper No. 47. Catalogue No. 21-601-MIE01047. Minister of Industry, Statistics Canada, Agriculture Division. Ottawa, Ontario, Canada.

Clark, E.H. II, J.A. Haverkamp, and W. Chapman. 1985. Eroding Soils : the Off-Farm impacts. The Conservation Foundation, Washington,DC. 252p.

Coombs, C. and P.J. Collett. 1995. Use of constructed wetland to protect bathing water quality. Water Science and Technology 32: 149-158.

Decamp, O., A. Warren and R. Sanchez. 1999. The role of ciliated protozoa in subsurface flow wetlands and their potential as bioindicators. Water Science and Technology 40: 91-98.

Guardo, M., L. Fink, T.D. Fontaine, S. Newman, M. Chimney, R. Bearzotti, and G. Goforth. 1995. Large-scale constructed wetlands for nutrient removal from stormwater runoff: an everglades restoration project. Environmental Management 19: 879-889.

Line, D. E., W. A. Harman, G. D. Jennings, E. J. Thompson and D. L. Osmond. 2000. Nonpoint-source pollutant load reductions associated with livestock exclusion. Journal of Environmental Quality 29: 1882-1890.

McGuigan, K. G., T. M. Joyce and R. M. Conroy. 1999. Solar disinfection: use of sunlight to decontaminate drinking water in developing countries. J. Medical Microbiology 48: 785-787.

Molnar, J.J., T. Hoban, J.D. Parrish and M. Futreal. 1997. Industrialization of Agriculture: Trends, Spatial Patterns, and Implications for Field-Level Application by the Natural Resources Conservation Service. Technical Report 5.2 to the USDA, Natural Resources

Conservation Service, Social Science Institute. Auburn University, Auburn, Alabama.

Palmateer, G.A., D.E. McLean, W.L. Kutas and S.M. Meissner. Suspended particulate/bacterial interaction in agricultural drains. *In:* Rao, S.S. Ed. Particulate matter and aquatic contaminants. Lewis Publishers. CRC Press, Inc. Boca Raton, Florida, USA.

Payne Engineering and CH2M Hill. 1997. Constructed wetlands for animal waste treatment: A manual on performance, design, and operation with case histories. Prepared for the USEPA Gulf of Mexico Program - Nutrient Enrichment Committee. Alabama Soil and Water Conservation Committee and NCASI. Montgomery, Alabama. National Agricultural Library call #: TD930.2-.C64-1997.

Rivera, F., A. Warren, E. Ramirez, O. Decamp, P. Bonilla, E. Gallegos, A. Calderon and J.T. Sanchez. 1995. Removal of pathogens from wastewaters by the root zone method (RZM). Water Science and Technology 32: 211-218.

Rivera, S.C., T.C. Hazen, G.A. Toranzos. 1988. Isolation of fecal coliforms from pristine sites in a tropical rain forest. Applied and Environmental Microbiology 54: 513-517.

Swader, F.N., L.D. Adams and J.W. Meek. 1994. USDA's Water Quality Program – Environmentally Sound Agriculture. Pages 86-92, In: Campbell, K.L., W.D. Graham and A.B. Bottcher. Environmentally Sound Agriculture. Proceedings of the Second Conference, 20-22 April 1994, Orlando, Florida. Amer. Soc. Agric. Engineers. ASAE Publication 04-94. ISBN 0-929355-47-4.

Tanner, C.C., J.S. Clayton and M.P. Upsdell. 1995. Effect of loading rate and planting on treatment of dairy farm wastewaters in constructed wetlands - I. Removal of oxygen demand, suspended solids and faecal coliforms. Water Research 29: 17-26.

Tanner, C.C. 1996. Plants for constructed wetland treatment systems – A comparison of the growth and nutrient uptake of eight emergent species. Ecological Engineering 7: 59-83.

Tanner, C.C. 2001. Plants as ecosystem engineers in subsurface-flow treatment wetlands. Water Science and Technology 44: 9-17.

USEPA. 1989. A Report to Congress : Activities and Programs Implemented Under Section 319 of the Clean Water Act-Fiscal year 1988. United States Environmental Protection Agency, Office of Water, Washington, D.C. EPA Rep. 506/9-89/003.

USEPA. 1995. National Water Quality Inventory: 1994 Report to Congress (Appendixes). United States Environmental Protection Agency, Office of Water, Washington, DC. EPA841-R-95-006.

Van der Valk, A. and R.W. Jolly. 1992. Recommendation for research to develop guidelines for the use of wetlands to control rural nonpoint source pollution. Ecological Engineering 1: 115-134.

Wegelin, M., S. Canonica, K. Mechsner, T. Fleischmann, F. Pesaro and A. Metzler. 1994. Solar water disinfection: scope of the process and analysis of radiation experiments. J. Water SRT – Aqua 43: 154-169.

WQIC. 1998. Constructed Wetlands Bibliography, Part I: Agricultural Nonpoint Source Pollution. Water Quality Information Center of the National Agricultural Library Agricultural Research Service, U.S. Department of Agriculture. http://www.nalusda.gov /wqic/Constructed_Wetlands_all/cwagnps.html.

Zdragas A., G. C. Zalidis, V. Takavakoglou, K. Eskridge, Sotiria Katsavouni, A. Panoras and E.T. Anastasiadis. 2002. The effect of Environmental conditions on the ability of a constructed wetland to disinfect municipal wastewaters. Environmental Management 29: 510-515.

ACKNOWLEGEMENTS

This paper was prepared as part of the water quality and ecological processes research of the Agricultural Research Service at the National Sedimentation Laboratory, Oxford, Mississippi. Partial funding was received from the USDA Natural Resources Conservation Service (NRCS – Jackson, Mississippi). Technical assistance from NRCS to make this study possible came from: Ross Ulmer, Lon Strong, and Bill Lipe. NRCS DeSoto County and New Albany Area office staff provided assistance with construction, and wetland design was by Jimmy Wilson, (former) District Engineer, USDA - NRCS, New Albany, MS. The farm cooperator, Alan Scott, provided sustained assistance. ARS personnel; Patricia McCoy, Terry Welch, Barry Gillespie, Bill Westling, Stan Crider, Belynda Garraway, and Jennifer Bowen, assisted with numerous aspects of completing this research, and their help is appreciated. Helpful suggestions and ideas concerning this manuscript were received from several reviewers.

Table 1. Fecal coliform counts (mean number of colonies/100ml water) entering and leaving the constructed wetland ponds and percent reduction over the 36 month study period.

	ALL MONTHS	WARM MONTHS	COOL MONTHS
INFLOW	14525	8795	20268
OUTFLOW	1585	1797	1251
% REDUCTION	88.09%	79.54%	93.83%

Figure 1. Photograph of the three parallel constructed wetland cells studied for efficiency of removal of coliforms from dairy farm waste. Each wetland cell is 6 m wide by 24 m long.

USE OF MISSISSIPPI RIVER ALLUVIAL AQUIFER DECLINE RATES FOR ALLOCATION OF EQIP FUNDS

F. ELIZABETH LAMASTUS-STANFORD AND DEAN A. PENNINGTON
MISSISSIPPI DELTA JOINT WATER MANAGEMENT DISTRICT

The Farm Security and Rural Investment Act of 2002 reinstated the Environmental Quality Incentives Program (EQIP) to provide a conservation programs that promote agricultural production and environmental quality as harmonious goals. EQIP provides financial and technical assistance to producers who implement structural and management conservation practices on agricultural land. The Mississippi Natural Resources Conservation Service (NRCS) identifies resource concerns and assessments that determine the focus of EQIP funds allocated to the state. In 2003 $11 million was allocated to Mississippi for conservation practices and an additional $1.1 million was allocated for the specific concern of groundwater conservation. The water quantity resource concern is concentrated primarily in the north and central portion of the Mississippi Delta. To allocate the $1.1 specifically for water quantity conservation, certain areas were targeted based on the decline rate of the Mississippi River Valley Alluvial Aquifer (MRVA), which ranged from 0.13 ft to 0.88 ft loss per year. Based on the decline rate of the MRVA, the region was divided into quartile and assigned a severity index (weighting factor) ranging from 1, for the least sever decline to 4, for the most severe decline. To determine the allocation per acre, the total number of acres in each region was multiplied by the severity index, the products totaled, and divided by 1.1 million. This resulted in $0.62, $0.42, $0.31, and $0.16 per acre for region 4, 3, 2, and 1, respectively. Because no definitive boundaries for ground water planning units exist, to plan for effective distribution of the allocated funds, the regions were merged with five major surface watershed planning units, including the Upper Sunflower, Lower Sunflower, Bogue Phalia, Steele Bayou, Yazoo River, and Quiver River. Based on the number of acres in each region that fell within the watershed planning unit a total allocation amount was determined for each planning unit. However, because EQIP funds are distributed and allocated through county offices, the watershed planning units were subdivided by county, with a specific amount being allocated to each county for a specific watershed.

Assessment of Bio-Contaminants in the Porter Creek Basin of the Homochitto National Forest

Key Words: Hydrology, Nonpoint Source Pollution, Surface Water, Water Quality
Presenter's Name: Stanly Mason, Alcorn State University
Presentation Type: Poster
Presenter's Address: 1000 ASU Drive #750, Alcorn State, MS 39096
Phone: (601) 384-8576; E-mail: stanleymason06@yahoo.com
Co-Authors: Will Frymire, USDA-Forest Service
Carol Boll, USDA-Forest Service
Alton B. Johnson, Alcorn State University
Charles S. Price, USDA-Forest Service
Presenter is a Graduate Student in Agronomy (Soil Physics)

ABSTRACT

Total coliform and/or *Escherichia coli* (*E. coli*) contamination of surface water is often attributed to loading of fecal material from agricultural, urban and residential areas or warm-blooded wildlife. The Homochitto Ranger District of the US Forest Service in southwest Mississippi is developing a 1000-acre lake (Okhissa Lake) in the Porter Creek sub-basin. The lake is being created by damming Porter Creek, which flows north to the Homochitto River. This lake will be used mainly for recreation and is projected to receive 235,000 visitors annually. Clean, high quality water is necessary to support this use. Private residences are located along roads in the headwaters of the sub-basin. Public sewage treatment is not available and many of the residences have no or ineffective septic systems. To evaluate the potential effects of the current residential development with respect to State and the US Environmental Protection Agency water quality standards for coliform bacteria and *E. coli*, we embarked on a monitoring program prior to damming of Porter Creek. Ten monitoring stations were established within the Porter Creek sub-basin where grab water samples were collected weekly in pre-sterilized bottles. Samples were then analyzed for total coliform and *E. coli* using colilert® substrates. Samples were enumerated by the absence or presence in Quanti-Tray™ cells and the data expressed as most probable number (MPN) per 100 mL. To determine saturated, K_{sat}, and unsaturated hydraulic, K(h), conductivities, double ring and tension infiltrometers were used, respectively. Results indicated spatial and temporal distribution of either total coliform or *E. coli* in the sub-basin. Total coliform and *E. coli* were consistently higher ($p<0.05$) in the northern tributaries than those in the south. Hydrologic characterization of soils in the sub-basin showed significantly higher K_{sat} and K(h) in the south of the sub-basin than the north ($p<0.05$). Preliminary results indicated that the presence of consistently higher number of total coliform and *E. coli* in the northern portion of the sub-basin was due in part to subsurface transport through the coarse texture soils in the south since the direction of flow is north. Further studies are underway to measure *E. coli* travel time and to characterize subsurface hydrology using non-invasive techniques.

Improved Estimation of Nutrient and Pesticide Runoff Losses from Golf Courses and Residential Lawns in the South Atlantic-Gulf Region

Joe Massey*, Barry Stewart*, Kevin Armbrust*, Alton Johnson**, and Cade Smith*

*Mississippi State University; Mississippi State, MS 39762
**Alcorn State University, Alcorn State, MS 39096

Turfgrass is the most intensively managed biological system in metropolitan areas. Currently, over 40 million acres of turf are estimated to be growing in the U.S. Following the national trend, turf acreage in Mississippi is expanding at a steady pace. Mississippi currently has an estimated 800,000 residential lawns comprising 300,000 acres and over 2,500 athletic fields. These figures do not include turf maintained at city parks, schools, churches, cemeteries, airports and industrial/commercial sites. An estimated 170 golf courses (ca. 15,000 A) are also in operation in MS. In addition, about 2 million A of highway roadsides are maintained in Mississippi, a significant portion of which are treated with one or more herbicides each year. In terms of residential lawns, homeowners tend to apply more chemical than is necessary for effective pest control. As a result, the use of pesticides by homeowners may be as high as 5 to 10 lbs. per acre, almost ten times more chemical per acre than is used by farmers. The intensity of pesticide and nutrient use, coupled with the anticipated continued growth in turf acreage, suggests that concerns over the impacts of turf chemicals on surface water quality will likely increase over time. Unfortunately, current models used to estimate runoff from managed turf are not accurate, making it difficult to allocate between agricultural and urban sources of contamination and to assess overall turf impacts on water quality. This project is designed to improve the estimation of turf chemical runoff from warm-season turf managed according to conditions found on golf course fairways and residential lawns. Runoff plots planted in Bermudagrass and Zoysiagrass are being established at MSU's Blackbelt Experiment Station and will be used to study the effects of grass species and management regime on turf chemical runoff using simulated rainfall. Laboratory studies are being conducted to assess the role of thatch on pesticide runoff. This research is part of a larger study that includes Maryland, Oklahoma, and Minnesota that is designed to determine regional differences in turf chemical runoff. Each study site will use the same EPA-approved field protocol that involves the application of 2,4-D herbicide, flutolanil fungicide, and chlorpyrifos insecticide.

Paper Title: Water Quality Analysis of an Intensively Used Agricultural Reservoir

Key Words: Agriculture, Conservation, Ecology, Water Quality

Oral or Poster Presentation Acceptable (prefer poster assuming a paper can still be submitted)

Presenter: Matthew T. Moore
Ecologist
USDA-ARS National Sedimentation Laboratory

Presenter Address: PO Box 1157
Oxford, MS 38655
T(662) 232-2955
F(662) 232-2988
mtmoore@ars.usda.gov

Co-Authors and Affiliation: Jon R. Pierce, University of North Carolina
Jerry L. Farris, Arkansas State University

ABSTRACT
The use of farm reservoirs for irrigation is gaining popularity in the Mississippi River Alluvial Plain (MRAP). Due to depletions of several aquifers, many counties within the MRAP have been labeled as critical-use groundwater areas. To alleviate the stress on these aquifers, many farmers are implementing storage reservoirs for economic reasons. Their benefits, however, extend into the surrounding environment. When used with a tailwater recovery system, reservoirs have the potential to accumulate nutrients, which decreases the need for fertilizer application with irrigation water. Also, potentially harmful contaminants (e.g. pesticides) are trapped and transformed within the reservoir, rather than being released through drainage into receiving systems such as lakes, rivers, and streams. Roberts Reservoir is an intensively used, 49 ha storage reservoir, located in Poinsett County, Arkansas. Water quality analyses and toxicity assessments of the reservoir and surrounding ditches indicated a stable water quality environment, with no observed toxic effects. The results of this study suggest that water released into a local receiving stream poses no contaminant risk and could be maintained for irrigation purposes, thereby reducing the need for groundwater depletion.

Title: Planform Changes in the Pascagoula River and Tributaries, Mississippi

Key Words: Geomorphological and Geochemical Processes, Surface Water, Methods, Management and Planning

Paper Presentation Style: Both Oral and Poster

Presenter: Joann Mossa, Department of Geography, University of Florida

Address: P.O. Box 117315, 3141 Turlington Hall, Gainesville, FL 32611-7315

Phone: 352-392-0494, Fax: 352-392-8855, E-Mail: mossa@geog.ufl.edu

Co-authors: David Coley, Department of Geography, University of Florida and Marilyn Ogbugwo, Department of Geological Sciences, University of Florida

ABSTRACT

This paper examines planform changes in the Pascagoula River and tributaries in southeastern Mississippi, and its relationship to natural factors and human modifications in the basin. Planform changes were examined on the Pascagoula River and for portions of the Leaf River, Chickasawhay River, Bowie River, Thompson Creek and other tributaries that are wide enough to have two banklines visible on multiple series of maps and aerial photography. The planform changes are evaluated for a minimum of three periods including historic maps from 1947-51 (partial coverage), aerial photographs from 1955-1960, maps from 1982-86, and digital orthoquadrangles from 1992-96. In this large basin, floodplain land use/land cover is diverse, including national forests, commercial forestry, mining, urbanization, and agriculture. Spatial patterns and temporal relationships of floodplain changes and channel instability will be used to evaluate which locations are most unstable, whether modified portions are experiencing more instability than less modified portions, and evaluate cause and effect interactions. To better quantify change, we have developed and applied various methods to determine migration and changes in channel morphology using Geographic Information Systems.

Our preliminary assessment suggests that, especially in the upper portions of the Leaf and Chickasawhay Rivers, there is more channel migration and cutoff formation in areas of high sinuosity and abundant sand bar area than in straight reaches with limited sand bar area. Such variations in sinuosity and sand bar formation, in turn, are likely influenced by geologic factors, including lithology and structure. Reaches with sand and gravel mining, either in the adjacent floodplain, channel or a major tributary, show more channel change than other land uses. Notable examples include the Bowie River, altered from direct mining of the channel bed and margins, the Leaf River, which shows changes just upstream of Hattiesburg and the confluence with the mined Bowie River, and Thompson Creek, where floodplain mining has facilitated channel change by pit diversions. Research on spatial patterns and temporal relationships of floodplain and channel changes is important it because channel instability has numerous ramifications to the environment and private and public properties. Elucidating and quantifying these relationships is important in defining and refining state regulations regarding floodplain activities.

COASTAL DEVELOPMENT AND WATER QUALITY: ASSESSING THE HEALTH OF MISSISSIPPI'S ESTUARINE WATERS

Christine Trigg and Harriet Perry. Center for Fisheries Research and Development, Gulf Coast Research Laboratory, University of Southern Mississippi, Ocean Springs, Mississippi 39566.

During 1968/69 a large-scale study was conducted to provide baseline data on the hydrological and biological characteristics of coastal waters of the Mississippi Sound (Gulf of Mexico Estuarine Inventory and Study, Mississippi). In 2000/01 forty-two of the original 1968/69 stations were re-visited and water and fauna were sampled using protocols developed during the earlier study. Data from the two studies were used to assess changes in water quality and to evaluate the environmental health of coastal waters. Monthly samples were taken (May through April) in the Pascagoula, Biloxi, Bay St Louis, and Pearl River estuaries at five salinity zones. Hydrological parameters measured at each site were temperature, salinity, and dissolved oxygen. Ammonia, nitrite, nitrate, orthophosphate, and total phosphate concentrations in surface and bottom water samples were analyzed at the Gulf Coast Research Laboratory. Water quality parameters were evaluated by study, estuary, and salinity zone. Salinities were significantly higher at most stations in 1968/69 than in 2000/01 and in both studies salinities were generally lowest in the western Sound. Nitrate and nitrite concentrations were significantly higher while total phosphate and orthophosphate levels were lower in 2000/01 when compared to the earlier study. In 2000/01, salinity, pH, and dissolved oxygen levels increased and nitrate and nitrite levels decreased from inshore to offshore stations. Increased nitrogen loading is apparent and related to industrialization and rapid population growth in south Mississippi. Observed decreases in levels of phosphate may be attributed to the ban of these compounds in detergents. Data from these and other studies will be used to develop numeric water quality criteria that can be incorporated into State water quality standards.

Water Saving Irrigation: A Vital Step in Improving the Sustainability of Rice (*Oryza sativa*) Production in the Mississippi Delta.

M. Cade Smith*, Joe Massey*, Jim Thomas*, Martin Locke[+], Justin Norris[++], Dean Pennington[#], and Alton Johnson[##]

*Mississippi State University, Mississippi State, MS 39762; [+]USDA-ARS, Oxford, MS 38655; [++]USDA-NRCS, Clarksdale, MS 38614; [#]Yazoo-Mississippi Delta Joint Water Management District, Stoneville, MS 38776; [##]Alcorn State University, Alcorn State, MS 39096.

The 2002 Yazoo-Mississippi Joint Water Management District (YMD) water use survey data suggest that Mississippi rice producers use on average 9,600 m^3 water ha^{-1} yr^{-1} (38 A-in yr^{-1}). Rice accounts for only 14% of the irrigate crop area in Mississippi but consumes approximately 40% of the water dedicated to crop irrigation. Slow aquifer recharge rates combined with intense agricultural withdrawals have resulted in a 27 cm yr^{-1} (10.5 in yr^{-1}) average decline in the alluvial aquifer in parts of the Mississippi Delta.

In 'conventional' rice cultivation, water is distributed through levee gates. This requires that each preceding paddy be overfilled to deliver water to each subsequent down-slope paddy. An artifact of levee-gate water distribution is that rice fields remain filled beyond holding capacity for a large portion of the growing season, resulting in negligible rain-holding capacity. Therefore, conventional rice water management may result in excessive water consumption, tailwater runoff, and non-point source pollution.

This project aims to reduce water use and non-point source pollution in rice production by coupling **multiple-inlet irrigation with intermittent flooding**. Multiple-inlet irrigation uses gated polypropylene pipe to distribute water to each paddy individually. With intermittent flooding, the paddy water is allowed to naturally decline through evapotranspiration until approximately ½ of the soil surface of each paddy is exposed. Extension and research personnel have introduced the combined irrigation practices to Arkansas and Mississippi producers and are adapting the practices to the grower's requirements so as to better understand soil and climatic effects on season-long water use, pumping costs, pest levels, and rough rice yields.

In 2002, adjacent production fields in Coahoma County were managed using either **multiple-inlet irrigation with continuous flooding** or **multiple-inlet irrigation with intermittent flooding**. Mid-season leaf tissue analyses from each flooding system suggest that intermittent flooding did not affect rice fertility requirements. Flood management also did not affect weed, insect, and disease pests. **Multiple-inlet irrigation with continuous flooding** consumed 7,100 m^3 water ha^{-1} yr^{-1} (28 A-in yr^{-1}). This represents a 27% reduction in water consumption compared to the Mississippi average. **Multiple-inlet irrigation with intermittent flooding** consumed 4,600 m^3 water ha^{-1} yr^{-1} (18 A-in yr^{-1}) and represents a 50% reduction in water consumption compared to the state average. Continuously flooded rice production yielded 10,300 kg ha^{-1} (183 bu A^{-1}). Intermittently flooded rice yielded 10,600 kg ha-1 (189 bu A^{-1}). These preliminary results suggest that multiple-inlet irrigation with intermittent flooding could reduce the amount of water consumed in rice production, reduce production costs, increase rain-holding capacity and, therefore, decrease non-point source runoff, while maintaining acceptable rice yields.

Understanding the Link between an Aquatic Shoreline and an Urban Development: A Mission of Planning and Management.

Over the past 15 years, the issue of water quality and wastewater management surrounding an urban environment has lead to changes in the way urban areas are dealing with its surface water and control over drainage patterns. Cities and developments that sit along aquatic shorelines are beginning to see the need for management and planning of their water, but have to deal with issues that have a direct correlation to design elements within the city itself. However, a new urban development along an aquatic shoreline can be designed with water management and planning strategies in place to help protect water quality.

In July of 2003, a preliminary master plan was presented to state and local leaders of Smith, Rankin, Jasper, Jones County for the development of a recreational facility including a lake. The 900 acre lake and surrounding infrastructure will be a mixture of business, residential, and traditional park atmospheres within the Bienville National Forest, and will be planned with the ideas of sustainable management and planning practices to ensure a high water quality within the lake and the surrounding creeks and tributaries. This project will be devoted to the development of a marina and commercial area and will mimic the ideas of New Urbanism while paying attention to the issues of water management and planning along the aquatic shoreline. A fully designed master and water management plan will be developed for the lake.

Keywords: Water Quality, Management and Planning, Sustainability, Wastewater, & Conservation

Presentation: Poster & Presentation

Presenter: Jonathan Sobley
Undergraduate Senior
Department of Landscape Architecture
Mail stop 9725
Mississippi State University
662-325-3012
662-325-7893
oliverdos@aol.com

Co-Authors: Ryan Verseman, Meg Bailey, Jeremy Murdock

Partial Sources:

Brooks, R. Gene. *Site Planning: Environment, Process, and Development.* Prentice Hall: New Jersey, 1988.

Chiara, Joseph De and Lee E. Koppelman. *Time-Saver Standards for Site Planning.* McGraw Hill Book Company: New York, 1984.

Grigg, Neil S., *Water Resources Management, Principles, Regulations and Cases.* McGraw Hill: New York, NY: 1996.

Geospatial Applications for Water Management Agencies in the Upper Pearl River Basin. M.L. Tagert, J.A. Ballweber, and D.R. Shaw. GeoResources Institute, Mississippi State University, Mississippi State, MS 39762.

Mississippi State University's GeoResources Institute (GRI) has been cooperating with state and regional agencies to apply geospatial technologies to address diverse water quality and public health concerns in Mississippi. The GRI is working primarily with the Pearl River Valley Water Supply District (PRVWSD), but also with other state agencies including county governments, rural water associations, private landowners, and others on a growing effort in the Upper Pearl River Basin to demonstrate the potential of geospatial technologies for improving the efficiency and effectiveness of land and water resources management. Much of the information necessary for watershed planning and management has a spatial context and is ideal for inclusion in a geographical information system (GIS). Also, much of the same data are important for decision-making regarding both water quality and public health protection. Many national GIS data sets are available from the Environmental Protection Agency and other agencies. Although these large-scale data sets are often helpful, the GRI has focused on data layers that are very site-specific. Examples of such data layers are water and wastewater infrastructure features, locations of National Pollution Discharge Elimination System (NPDES) permits, impaired waters on the 303(d) list, and high-resolution, orthorectified imagery, to name a few. This project is allowing the GRI to work cooperatively with the PRVWSD and other Upper Pearl River Basin stakeholders to obtain and organize remotely sensed imagery and other relevant data into themes that can be layered in a GIS. Furthermore, as data layers are obtained and developed, they can be shared with other local stakeholders, such as county GIS personnel. The GRI has learned that, as other agencies voluntarily share geospatial data, it is an ideal opportunity to build or expand locally led watershed advisory groups. In the Upper Pearl River Basin, geospatial technologies are already leading to increased efficiency, better planning, and more accurate decisions regarding water quality, water quantity, and public health concerns.

Keywords: Management and Planning, Water Quality, Water Supply

Poster

Presenter: Mary Love Tagert, Extension Associate, GeoResources Institute at Mississippi State University

Address: Box 9652
Mississippi State, MS 39762

Graduate Student: Plant and Soil Sciences

The Under Lying Link Between Residential Storm Water Management Design and Development By A Managed Body Of Water.

Since the beginning of time, basic human needs have not changed. There is still a need for water, food, energy, and air. So, then why is the phase of "sustainability" becoming such a presence in our society? Two contributing factors are an increase in the world's population and consumption practices that are exceeding the carrying capacity of the world's ecosystems. These problems are damaging the natural systems that once supported the world. Research needs to be conducted to review current development methodologies and identify areas that could be improved, especially with regard to impacts on water quality.

This study will focus on a potential development in Smith County, Mississippi. The site is located in the Bienville National Forest, where a preliminary master plan for a 900 acre recreational lake has been designed. The lake will offer features that include a high and low impact development types. The activities associated with the high impact include a conference center, traditional and RV camping, picnicking, small cabins and lodging, and a marina. The low impact activities include fishing, boating, swimming, biking, hiking, horseback riding, and primitive camping.

The design will examine infrastructure practices as they apply to sustainable residential design. This report will be part of an undergraduate capstone project in the Department of Landscape Architecture at Mississippi State University which will focus on the research and implementation of storm water and waste water practices as they apply to residential community design. This presentation will provide specifics on how new design practices can be incorporated into future master planning approaches that will be sustainable and functional.

Keywords: Water Quality, Hydrology, Sustainability, Wastewater, and Surface Water
Presentation: Poster and Presentation
Presenter: Ryan Verseman
Undergraduate Senior
Department of Landscape Architecture
Mail Stop 9725
662-325-3012
662-325-7893
dunkenbobno41@hotmail.com

Co-Authors: Jonathan Sobley, Meg Bailey, Jeremy Murdock

Cathcart, Tom and Pete Melby. *Regenerative Design Technologies*. New York; John Wiley & Sons.

McHarg, Ian. *Design with Nature* (New York: Natural History Press, 1969; reprint New York: John Wiley & Sons, Inc., 1992).

Otterpohl, Ralf, Matthias Grottker, and Jorg Lange, "Sustainable Water and Waste Management in Urban Areas," Water Science Technology 35, no. 9 (1997):122-123.

Steiner, Fredrick, Gerald Young, and Erwin Zube. "Ecological Planning: Retrospect and Prospect," in Landscape Journal 7, no. 1 (1988): 31.

Shallow groundwater dynamics in the root zone of a cypress wetland

Brian Laine, Gregg Davidson and Stephanie Rice
University of Mississippi, Department of Geology and Geological Engineering, Carrier 118, University, MS 38677

The hydrology of the root zone in a forested wetland is being studied as part of a larger investigation of the hydrologic controls on wetland tree growth. Previous studies have shown that bald cypress trees (*Taxodium distichum*) undergo accelerated growth during years of high precipitation, including trees growing in saturated sediments where water should not be a growth-limiting factor. The primary cause of growth may be a precipitation induced influx of nutrients into the wetland or alteration of root-zone chemistry that enhances nutrient uptake.

The work is being conducted in Sky Lake in the Delta north of Belzoni, Mississippi. Sky Lake is an oxbow lake surrounded by a cypress dominated wetland. Outflow is ephemeral, and occasional backflow from the Yazoo River results in fluctuations in lake level in excess of 4 m creating the potential for seasonal reversals in shallow groundwater flow. A series of nested piezometers are employed to measure spatial and temporal trends in bulk chemistry, oxygen isotopic composition, and hydraulic gradient in the upper 3 m of sediment. The potential for differentiating lake and regional groundwater sources in the root zone is enhanced by seasonal changes in the chemistry and isotopic composition of the lake water. During the summer the lake level falls below the outlet resulting in evaporative concentration of dissolved solids and isotopic enrichment of ^{18}O. During the previous winter, the $\delta^{18}O$ of lake water was similar to mean precipitation (near -5‰ VSMOW), but rose above 3‰ in the summer.

Preliminary results indicate that the shallow flow system is complex. During the previous year, the lake level remained higher than the hydraulic head in all the deeper piezometers, but the vertical gradient within the top 3 m of sediment partially reversed on multiple occasions. Several partial reversals in the horizontal gradient have also been observed. The partial reversals suggest that pockets of higher permeability exist within the sediment with variable connection with the surface. Observed changes have correlated more with lake level than with precipitation. Significant changes in the chemistry and isotopic composition of piezometer samples have been observed, but thus far without a clear indication of the source or transit time of the water present. Slug tests and tritium analyses are planned to help determine sources and travel times.

Characterizing Soil Hydraulic Properties in an Agro-Forestry Ecosystem

Key Words: Hydrology, Models, Soil quality
Presentation Type: Oral
Presenter: Alton B. Johnson, Alcorn State University
Presenter's Address: 1000 ASU Drive # 852, Alcorn State, MS 39096
Phone: (601) 877-6529; Fax: (601) 877-3743; E-mail: bjohnson@lorman.alcorn.edu
Co-Authors: Regional D. Burks, Mississipi Department of Environmental Quality
Teferi Tsegaye, Alabama A&M University
Peter Ampim, Alcorn State University

ABSTRACT

Land use impacts on soil quality may be characterized by changes in soil hydraulic properties. These properties directly influence infiltration as well as runoff and erosion. Soils in the major land resource area, the Southern Mississippi Valley Silty Uplands (MLRA 134), have high erosion potential and land use practices affect soil loss. We measured hydraulic properties of the dominant soil (Memphis silt loam) in MLRA 134 on adjacent mixed forest and pasture sites at six locations each in the Rodney Lake sub-basin of the Coles Creek watershed. The forest and pasture have been in existence for 100 and 30 years, respectively. Unconfined infiltration measurements were carried out in a rang of descending tensions, 15, 10, 6, 3 cm of water, using 20 cm disc tension infiltrometers. The Wooding's model for steady state flow was used to estimate soil hydraulic conductivity, K(h). Soil cores were also extracted from the 0-15 and 15-30 depths to determine bulk density (ρ_b). The WP4 PotentiaMeter® was used to measure soil water retention values, θ(h), at the two soil depths and the van Genuchten-Maulem model was fitted to the experimental data using the optimization computer code, RETC. Results from this study showed significantly higher K(h) in the forest than the pasture for both experimental and fitted data ($P<0.05$). Water content from 0 to -33 kPa was significantly higher in the forest than the pasture, however, water retention in the forest was significantly higher at all water potentials at the 30-cm depth ($P<0.05$). The van Genuchten-Maulem model showed a good fit to the experimental water retention data for both land use with root-mean-squares errors (rmse) of 0.0201 and 0.0249 in the forest at the 0-15 cm and 15-30 cm soil depths, respectively. Respective rmse for the pasture for the 0-15 cm and 15-30 cm soil depths were 0.0464 and 0.0357.

PRESENCE OF ATRAZINE IN WATER IN A RECHARGE AREA OF GUARANY AQUIFER IN BRAZIL

A. L. Cerdeira[1], N. A. G. Santos[2], M. C. P. Y. Pessoa[1], S. Smith Jr[3], V. L. Lanchote[2].

[1]Embrapa, Research Division of the Brazilian Ministry of Agriculture, Jaguariuna, SP, Brazil. (cerdeira@cnpma.embrapa.br)
[2]Pharmacy School of Sao Paulo University, USP, Ribeirao Preto, SP, 14100, Brazil.
[3]USDA-ARS- National Sedimentation Laboratory, Oxford MS, USA.

ABSTRACT. The region of Ribeirao Preto City located in Sao Paulo State, southeastern Brazil, is an important sugarcane, soybean and corn producing area. This region is also an important recharge area for groundwater of the Guarany aquifer, a water supply source of the city and region. The cultivation of grain and sugar cane in this area demands the frequent use of the herbicide atrazine (2-chloro-4- (ethylamino)-6-(isopropylamino)-S-triazine). This research was conducted to characterize the potential contamination of groundwater with atrazine. Surface water samples were collected in the Espraiado stream in a selected watershed on the area, during the years of 1995-1998. Groundwater was also collected in wells located at the edge of the watershed during the years of 1999 to 2002. The water samples were analyzed by HPLC (High Performance Liquid Chromatography) procedure followed by GC-MS for confirmation. To predict the atrazine leaching in the area, the CMLS-94 (Chemical Movement Layered Soil) simulation model was also used. Only four atrazine detections in surface water were found, however, none of them were confirmed with GC-MS. No atrazine was detected in groundwater samples. The results obtained by the CMLS-94 simulations predicted that atrazine, after four years from the application date, would not have reached the depth of the confined aquifer (40m).

INTRODUCATION

Ribeirao Preto City, Sao Paulo State, Brazil, is an important sugarcane, soybean and corn producing area (Fig. 1). This region is also an important recharge area for groundwater of the Guarany aquifer, a water supply source of the city and region. It has an intercontinental extension that reaches areas of eight Brazilian states, as well as significant portion of other South American countries like Argentina, Uruguay, and Paraguay, with a total area of approximately 1,200,000 Km^2.

Figure 1. Map of South America showing the city of Ribeirao Preto, Brazil, where the watershed is located.

Due to the high permeability of some soils present in this region, the high mobility of the herbicides and fertilizers applied, and being a recharge area, it is important to investigate the potential transport of applied herbicides to underlying aquifer. Since the crops in this area demand the frequent use of the herbicide atrazine (2-chloro-4- (ethylamino)-6-(isopropylamino)-S-triazine), this research was conducted to characterize the potential of the herbicide leaching to groundwater.

MATERIAL AND METHODS

Nine surface water sample points were selected in the Espraiado stream in the watershed. Samples were collected, during the years of 1995-1998, in the months of October, November, December, January, March, May, and July of each year. Four replications were collected at each site for a total of 252 surface water samples per year. Groundwater was also collected during the same months from county groundwater wells located at the edge of the watershed during the years of 1999 and 2002. The following seven wells were studied: Palmares, Sao Jose, Sao Sebastiao Velho, JP, Higienopolis, Schimidt, Jardim Recreio, and DAERP Central. The water samples were analyzed using an HPLC (High Performance Liquid Chromatography) procedure followed by GC-MS for confirmation.

The water samples (1-liter) were stored in amber flasks and kept at 4°C until analysis using the following HPLC (High Performance Liquid Chromatography) procedure: A standard solution of atrazine (100%, Supelco) was prepared in HPLC-grade methanol (Merck) at a concentration of 1.0 mg/ml. Working solutions at concentrations of 0.08, 0.20, 0.32, and 0.40 µg/ml, were prepared by appropriate dilution. A caffeine solution (used as the internal standard) for confirmation of herbicide residues by GC-MS was prepared in methanol at a concentration of 5.0 µg/ml.

HPLC analysis were performed with a Shimadzu liquid chromatograph (Kyoto, Japan) consisting of an LC-10AD pump, a UV detector (SPD-10AV) operating at 220 nm, an automatic injector (SIL 10A) with a 100 μl loop and a Chromatopac C-R6A integrator. The presence of atrazine in water samples was confirmed using a Shimadzu GC-MS system model QP5000 (Kyoto, Japan) that consists of a gas chromatograph equipped with a split/splitless injector (t_V = 240°C, splitless, 0.75 min sampling time) and coupled to a mass selective detector operating in the SIM mode. The calibration curves were obtained by spiking 100 mL aliquots of water purified in a MILLI Q®-plus system (Millipore) with 25.0 μL of each standard solution, resulting in concentrations of 0.02 to 0.1 μg/L water. In the GC-MS analysis the water samples were also spiked with 25.0 μL of internal standard solution, caffeine 5 μg/mL (Lanchote et al., 2000).

To predict the atrazine leaching in the area, the CMLS-94, Chemical Movement Layered Soil, (Nofziger and Hornsby, 1994) simulation model was used. Data obtained by the simulations were then evaluated with those of depths of the groundwater depths. The input data used were: a) crop cultural coefficient (Kc); b) soil type by levels: percent of organic carbon, density (Mg m^{-3}), volumetric content of water (%), field capacity, wilting point, and saturation; c) weather: daily maximum and minimum temperatures, rainfall and evaporation, for a period of four years; d) atrazine properties: K_{OC} and half life (t½). Different simulation scenarios were made to evaluate the atrazine movement in the vertical profile of Clayey Eutroferric Red Latosol (LVefb), Psamitic Distrofic Red Latosol (LVdfq), and Quartzarenic Neosol (RQ), (EMBRAPA, 1999).

RESULTS AND DISCUSSION

Only four atrazine detections in surface water were found in the year 1996, with residues varying from 0.02 to 0.09 ppb. However, none of them were confirmed with GC-MS. No atrazine was detected in groundwater samples.

The results obtained by the CMLS-94 simulations predicted that atrazine, after four years from the application date, would not have reached the depth of the confined aquifer (40m). However, as a non-confined more superficial watertable exists in the study area (with depths varying between zero and 20 m) it was shown that there is a risk of the herbicide reaching the aquifer (Table 1).

Since the half-life ($t_{1/2}$) of atrazine is highly influenced by the soil pH and by organic matter content (Walker and Blacklow, 1994), also Quartzarenic Neosol (RQ) has pH values varying from 7.3 at 0-50 cm to 7.0 at 50-60 cm (Cerdeira et al. 2000), those characteristics would favor the mobilization of the atrazine molecules and result in leaching to greater depths (Table 1). In Clayey Eutroferric Red Latosol (LVefb) and Psamitic Distrofic Red Latosol (LVdq), the respective values of pH remained acidic and favored a little movement of atrazine in those soils (Table 1). In that situation, the final amount projected by simulation scenarios was mainly influenced by t½ values of atrazine in the respective soil type. Atrazine has shown no potential to reach groundwater when evaluated by the CMLS-94. This result agrees with the information obtained by means of monitoring wells located in the study area, where atrazine was not detected in the water.

Table 1. Partition Coefficient (Koc), half-life (t½) of atrazine, depth values (DPT, m) and amount (AMT, kg/ha) reached at the end of simulations for each type of soil.

SOIL TYPE	ATRAZINE			
	characteristics		movement	
	Koc(L/kg)	t½(days)	DPT	AMT
LVdq (Psamitic Distrofic Red Latosol)	224.3	54	1.67	9.2×10^{-7}
Lvefb (Clayey Eutroferric Red Latosol)	187.1	262	1.43	1.4×10^{-1}
RQ (Quartzarenic Neosol)	305.7	181	2.88	3.4×10^{-2}

LITERATURE CITED

Cerdeira AL, Gomes MA, Pessoa MCPY, Queiroz RC, Bonato PS, Lanchote VL. 2000. Tebuthiuron in soil and groundwater in sugarcane area in Brazil. Boll Chim Igien. 51: 51-57.

EMBRAPA. 1999. Sistema Brasileiro de classificação de solos. CNPS, Embrapa; Rio de Janeiro, Brazil. 412 p.

Lanchote VL, Bonato PS, Cerdeira AL, Santos NAG, DeCarvalho D, Gomes MAF. 2000. HPLC screening and GC-MS confirmation of triazine herbicide residues in drinking water from sugar cane area in Brazil. Water Air Soil Pollut. 118: 329-337.

Nofziger DL, Hornsby AG. 1994. CMLS-94-Chemical movement in layered soils. Oklahoma:University of Florida, Department of Agronomy 1994 76 p

Walker SR, Blacklow WM. 1994. Adsorption and degradation of triazine herbicides in soils used for Lupin production in Western Australia: Laboratory studies and simulation model. Austral. J Soil Res. 32:1189-1205.

Abstract 2004 MS Water Resources Conference: April 20-24.

Status of Microbial Source Tracking in the North America

R.D. Ellender and Shiao Wang
University of Southern Mississippi, Hattiesburg, MS

In the United States and Canada, microbial source tracking is being investigated and used to identify source(s) of fecal pollution of water. Several events of the last year highlighted the advantages and present limitations of this field of research. Of importance to our state are the results and observations obtained during the first national investigation of present-day MST methods and target organisms. This study, conducted by the Southern California Coastal Water Research Project Authority, cataloged and compared the list of methods under consideration, compared similarities and differences between phenotypic and genotypic procedures, discussed the value of library vs. non-library based methods, evaluated different microbial targets (fecal coliforms, Escherichia coli, Enterococcus sp., Bacteroides, human, animal and bacterial viruses), and conducted a blind sample investigation in research laboratories in the United States. A United States Geological Survey investigation of the reliability of library-based source tracking results with *Escherichia coli* as the reference organism, was conducted by a team of researchers led by Don Stoeckel of the USGS, Ohio District. Investigators created a library of isolates from 9 different animals and compared blind and replicate sample isolates to this library. Data was examined for reproducibility, accuracy and robustness. Data was also examined to assist in the identify of methods that could be used in a specific location, to examine the method in a defined setting, or to understand how the method(s) would address a local issue(s). In the summer of 2003, a series of MST presentations at the biannual meeting of the US EPA Gulf of Mexico Program summarized the state of the art of MST research in the southeastern states. These presentations focused on new methods and approaches to MST and included discussions on the use of fluorescent whiting agents as targets of source tracking, the reliability of microbial source assignment using rep-PCR methods, targeted sampling using enterococci, commercial applications of MST, the implication of E. coli diversity for MST success and future prospects for MST research. This presentation will summarize these recent collaborations and discuss/suggest new or modified approaches in the search for reliable and valid methods of microbial source tracking.

Key Words: Water Quality, Wastewater, Non Point source pollution
Oral Presentation requested
Presenter: R.D. Ellender, Professor of Microbiology, Department of Biological Sciences, University of Southern Mississippi, Hattiesburg, MS 39406
Telephone:(601) 266-4720; FAX (601) 266-5797
Co-Author: Shiao Wang, Associate Professor, Department of Biological Sciences, University of Southern Mississippi, Hattiesburg, MS 39406.

The Flux of Herbicides in the Yazoo River Basin, Mississippi, 1996-97

By H.L. Welch, A. B. Pell, and R.H. Coupe
U.S. Geological Survey, Jackson, Mississippi

Introduction

The Yazoo River Basin (fig. 1), the largest river basin in Mississippi, covers an area of approximately 34,700 km^2 in northwestern Mississippi. The basin is divided almost equally between the alluvial plain, a rich agricultural area that is relatively flat and is characterized by poorly drained soils on the west side of the Yazoo River, and the bluff hills east of the river, an area where the principal land use is small farms, pasture, and forest. The basin is sparsely populated, with no major metropolitan areas (Coupe, 1998).

Herbicides are used heavily in the Yazoo River Basin to protect crops, especially cotton, corn, rice, and soybean, from weed infestation. Although the majority of the herbicides used dissipate quickly, there is concern for offsite movement of a small amount of applied herbicide and subsequent contamination of the environment. In the 1990's, several researchers investigated the occurrence of herbicides in the atmosphere (Coupe and others, 2000; Majewski and others, 1998) and in surface waters (Coupe and others, 1998; Coupe, 1999; Pennington, 1996; and Pereira and Hosteller, 1993) of the Yazoo River Basin. All of these researchers detected small amounts of the heavily used herbicides. With the exception of Pereira and Hosteller (1993), there was no attempt to quantify the annual flux of herbicides in the streams and rivers of the Yazoo River Basin. Pereira and Hosteller (1993) estimated the flux of herbicides from the Yazoo River Basin; however, their estimates were made using limited discharge data and with only a small number of samples.

In order to quantify the flux of herbicides in the Yazoo River Basin, surface-water samples were collected from five sites in the basin (fig. 1): (1) Bogue Phalia near Leland, which represents 3.6 percent of the basin; (2) Big Sunflower River near Anguilla, 19.3 percent; (3) Skuna River at Bruce, 1.9 percent; (4) Steele Bayou near Rolling Fork, 3.1 percent; and (5) Yazoo River below Steele Bayou, which drains the entire basin. The drainage area of these sites is 1,250, 6,680, 660, 1,080, and 34,590 km^2, respectively.

The Bogue Phalia, Big Sunflower River, and Steele Bayou are located in the alluvial plain, and the Skuna River is in the bluff hills. The Bogue Phalia drainage basin is wholly contained within the Big Sunflower Basin. The Yazoo River below Steele Bayou site is located near the mouth of the Yazoo River and integrates land use across the entire basin (Coupe, 1998).

The confluence of the Tallahatchie and Yalobusha Rivers forms the Yazoo River. The Yazoo River flows southward from Greenwood along the eastern edge of the alluvial plain until it reaches the Mississippi River at Vicksburg. Discharge from more than 11,400 km^2 of drainage area within the basin is controlled by four flood-control reservoirs (Arkabutla, Sardis, Enid, and Grenada Lakes) located in the uplands. Runoff and flooding in the Delta are controlled by two structures, one located at Steele Bayou and the other at the Little Sunflower River. In 1996 and 1997, the gates of both structures were closed continuously for more than one month during March – June, and for shorter periods throughout the spring and summer (Plunkett and others, 1997; Plunkett and others, 1998).

Purpose and Scope

The purpose of this study was to characterize the occurrence and to document the flux of selected herbicides in five rivers of the Yazoo River Basin during 1996 and 1997. From January 1996 through December 1997 a total of 232 water samples were collected from five rivers in the Yazoo River Basin: the Bogue Phalia, the Big Sunflower River, the Skuna River, Steele Bayou, and the Yazoo River. The number of samples collected from the rivers ranged from 21 for the Skuna River to 62 for the Bogue Phalia.

Methods

For the Bogue Phalia and the Skuna River, mean daily discharge was calculated and reported by the U.S. Geological Survey (USGS) according to standard procedures (Rantz and others, 1982). Because of backwater effects from the Mississippi River, measurement of flow is more difficult in the Yazoo River; the procedures used are documented by Runner and others (2002). The Steele Bayou and Big Sunflower gaging stations are operated by the U.S. Army Corps of Engineers (USACOE) as stage-only stations (U.S. Army Corps of Engineers, 1996; U.S. Army Corps of Engineers, 1997). A rating curve was developed for the Steele Bayou based on discharge measurements made by the USACOE and applied to the reported gage heights to calculate a daily discharge. For the Big Sunflower River, a rating curve was developed from discharge measurements made by the USACOE and the USGS. This rating curve could not be applied to every time period however, because of backwater effects caused by the closure of the control structures during periods of high flow on the Mississippi River. The rating curve was used only when there was greater than a 1.2m drop in the water level between the gaging station at the Big Sunflower near Anguilla and the Little Sunflower control structure. Otherwise, the discharge from the Bogue Phalia and an upstream site on the Big Sunflower at Sunflower, was combined, and discharge for the Anguilla site was calculated using a drainage basin ratio (Telis, 1992). The stage data reported by the USACOE was an 8:00 a.m. reading, and therefore is an approximation of the mean daily stage.

Sampling Frequency

The sampling frequency varied annually, seasonally, and between sites, depending upon the sampling objectives at each site, the expected streamflow variability of the site, and the resources available to conduct the sampling. The Yazoo River, given its large basin size and slow response to hydrologic events, was sampled every other week throughout the sampling period. The Bogue Phalia, the Big Sunflower River, and Steele Bayou were sampled twice monthly with extra samples collected occasionally during high-flow events. In March 1997, the sampling frequency was increased to weekly through September 1997 and decreased to twice monthly for the remainder of 1997. Because the land use in the Skuna River Basin is small farms, pasture, and forest, pesticides were not expected to be detected frequently nor in high concentrations from the Skuna River. Therefore, samples were collected only monthly from this river.

Sample Collection

Water samples from the Bogue Phalia, the Skuna River, and Yazoo River were flow-weighted and depth- and width-integrated according to the procedures described in Shelton (1994) to ensure that samples were representative of the stream. Samples were analyzed for constituents that are known to be unevenly distributed in the water column, such as total nitrogen, total phosphorous, and sediment. In some cases, because of the low gradient in the alluvial plain, flow-weighted samples were not possible. For the Big Sunflower River and the Steele Bayou, water samples were analyzed only for dissolved pesticides, which were assumed to be evenly mixed throughout the stream; hence, samples were collected in an open bottle at the center of flow. All equipment that came into contact with the sample water was made of Teflon, glass, or stainless steel and was cleaned with a 0.2-percent non-phosphate detergent, rinsed with deionized water, rinsed with pesticide-grade methanol, air dried, wrapped in aluminum foil, and stored in a dust-free environment prior to sample collection.

Sample Processing and Analytical Procedures

Water samples were filtered onsite using an aluminum filter plate with a baked 0.7-micrometer pore size glass fiber filter into 1-L baked amber bottles. The samples were shipped on ice to the USGS Organic Geochemistry Laboratory (OGRL) in Lawrence, Kansas, for analysis. The analytical method is documented in a report by Lee and others (2002). Samples were extracted using a preconditioned graphitized carbon column and then eluted from the column using a solution of methylene chloride, methanol, and ammonium hydroxide. The sample components were separated, identified, and measured by injecting the sample into a high-performance liquid chromatograph equipped with a diode array detector and a mass spectrometer detector operated in selected-ion monitoring mode. Compounds were identified by comparing the retention times of the mass spectral signals to the retention times of standards. Further identification was made using selected fragment ions for those compounds that produce fragment ions. The concentration was calculated by determining the ratio of the compound's response to the response produced by an internal standard. This value was compared to the ratio of the responses to the primary standard analyzed using the same method. All samples were analyzed for 14 herbicides and 9 degradates with a reporting level of 0.05 micrograms per liter (table 1).

Quality Assurance/Quality Control

The field quality-assurance/quality-control program consisted of the collection and analysis of periodic equipment and field blanks and sample replicates. There were no detections of any pesticides in any blank samples, and the sample replicates (data not shown) indicated good precision. The OGRL also analyzed laboratory blanks as part of this study, and there were no detections of pesticides in any sample. Every 10th sample was analyzed in replicate, and results (not shown) indicated good analytical precision.

Flux Calculations

Linear interpolation was used to estimate the herbicide flux in five rivers and streams in the Yazoo River Basin. Herbicide concentrations on nonsampled days were estimated by interpolating between concentrations measured on sampled days. Measured or interpolated daily concentrations were multiplied by the mean daily discharge to estimate a daily flux. Daily fluxes were summed to estimate a total flux over a specified period of time.

For herbicide concentrations of less than reporting limits (censored data), the concentrations were set to zero for flux calculations. This is a conservative estimate of the herbicide concentration and possibly could bias the flux estimates low. Zero was considered by the authors to be an appropriate value (rather than 1/10 or ½ of the method report level as used by other authors), because annual fluxes are being calculated and it is likely that during at least part of the year the concentrations would be zero. Flux was calculated for 10 herbicides and 7 degradates (table 1). These included atrazine and fluometuron and two degradates of each; norflurazon and cyanazine and one degradate of each; as well as, alachlor, metolachlor, metribuzin, molinate, prometryn, simazine and a degradate of propanil.

Herbicide Occurrence and Concentrations

Of the 14 herbicides, all were detected in at least one sample, but 4 were detected infrequently (in 15 percent or less of samples at any site); acetochlor, propanil, propazine, and trifluralin (table 1). Fluxes were not calculated for these herbicides. Other herbicides, such as atrazine, cyanazine, fluometuron, metolachlor, and metribuzin, were detected frequently (generally greater than 20 percent of the samples) at all sites. Some herbicides such as acetochlor, molinate, norflurazon, prometryn, and simazine were detected frequently in some of the alluvial plain rivers and the Yazoo River, but not in the bluff hills site on the Skuna River. This probably is a reflection of the differing land use (less agriculture, more forest) in the Skuna River Basin (table 2).

Of the nine degradates analyzed, seven were frequently (greater than 20 percent of the samples) detected in water samples from the alluvial plain rivers and the Yazoo River (table 1). Demethyl fluometuron was the only degradate detected in more than 15 percent of the samples from the Skuna River. Two degradates, 3-(trifluoromethyl)phenylurea and deisopropyl prometryn, were detected only in a few samples from one or two rivers. For the degradates of atrazine, cyanazine, and fluometuron, the frequency of occurrence and the median and maximum concentrations were less than those of the parent compounds. The reverse is true for norflurazon and propanil however; the median and maximum degradate concentration and frequency of occurrence is greater than those of the parent compound.

The total herbicide concentration (sum of all herbicides and degradates) in the five rivers varied seasonally (fig. 2). Herbicide concentrations were greatest from April through August at all of the sites and showed a bimodal distribution with higher concentrations in the early spring and in late summer. Thurman and others (1991) referred to the peak concentration in streams of the Midwest in the spring as the "spring flush," where pre-emergent herbicides are applied to fields and are moved offsite in rainfall runoff. Unlike the Midwest, streams in the Yazoo River Basin had a second peak concentration in late summer, probably as a result of a longer growing season (with different herbicide application times for different crops) and the use of post-emergent herbicides.

The total herbicide concentrations were highest from the three streams located in the alluvial plain; the Big Sunflower River, the Steele Bayou, and the Bogue Phalia. The lowest total herbicide concentrations were found at the site located in the bluff hills: the Skuna River. The total herbicide concentrations in the Yazoo River were intermediate between the alluvial plain sites and the bluff hills site. The largest component of the total herbicide concentration for samples from the alluvial plain sites was atrazine and/or metolachlor in the spring and molinate in the summer.

Herbicides and degradates detected in more than 50 percent of the samples in 1996-97 were atrazine, cyanazine, demethyl fluometuron, demethyl norflurazon, 3,4-dichloroaniline, fluometuron, metolachlor, and molinate. These compounds also had the highest concentrations.

Herbicide Flux

The majority (greater than 90 percent) of the herbicide flux occurred during the months from April through July in both 1996 and 1997 (fig. 3). The highest monthly flux for 1996 occurred in April; the highest monthly flux in 1997occurred in June. For most herbicides the total flux for 1996 was less than the total flux for 1997 due to increased rainfall in 1997 (table 3). The exception was the herbicide alachlor, which generally had lower fluxes in 1997 compared to 1996, probably because alachlor use was being discontinued.

With the exception of molinate, the Yazoo River Basin herbicide flux as a percentage of use (FAPU) was very similar between 1996 and 1997 (fig. 4). The molinate FAPU was 2.1 in 1996 and 9.9 in 1997. The FAPU of atrazine and metolachlor was nearly 10 percent annually. In other studies from the Midwest, these values generally fall into the 1 to 5 percent range (Clark and others, 1999; Larson and others, 1995). Capel and Larson (2001) showed that the FAPU for atrazine was relatively invariant of watershed size, but that weather, especially substantial rainfall in the spring and early summer, and the percentage of soils in the watershed with fine texture could increase the FAPU. High rainfall amounts and fine textured soils are characteristic of the Yazoo River Basin.

Adding the flux of the atrazine degradates to the atrazine flux from the Yazoo River increased the total atrazine flux by about 13 percent in 1996 and about 16 percent in 1997. The fluometuron degradates increased the total flux by about 7 percent in 1996 and

13 percent in 1997. The flux of norflurazon from the Yazoo River increased by 82 percent in 1996 when the flux of the demethyl degradate was added to the flux of the parent compound, and in 1997 the flux increased by about 171 percent. The cyanazine degradate increased the cyanazine flux by approximately 12 and 25 percent for 1996 and 1997, respectively.

References

Capel, P.D., and Larson, S.J., 2001, Effect of scale on the behavior of atrazine in surface waters: Environmental Science & Technology v. 35, no. 4, p. 648-657.

Clark, G.M., Goolsby D.A., and Battaglin, W.A., 1999, Seasonal and annual load of herbicides from the Mississippi River Basin to the Gulf of Mexico: Environmental Science & Technology, v. 33, no. 7, p. 981-986.

Coupe, R.H., 1998, Concentrations and loads of nitrogen and phosphorus in the Yazoo River, northwestern Mississippi, 1996-97: U.S. Geological Survey Water-Resources Investigations Report 98-4219, p. 3.

Coupe, R.H., 1999, Occurrence of pesticides in five rivers of the Mississippi Embayment Study Unit, 1996-98: U.S. Geological Survey Water-Resources Investigations Report 99-4159, p. 55.

Coupe, R.H., Manning, M.A., Foreman, W.T., Goolsby, D.A., and Majewski, M.S., 2000, Occurrence of pesticides in rain and air in urban and agricultural areas of Mississippi, April-September, 1995: The Science of the Total Environment, v. 248, p. 227-240.

Coupe, R.H., Thurman, E.M., and Zimmerman, L.R., 1998, Relation of usage to the occurrence of cotton and rice herbicides in three streams of the Mississippi Delta. Environmental Science & Technology, v. 32, p. 3673-3680.

Larson, S.J., Capel, P.D., Goolsby, D.A., Zaugg, S.D., and Sandstrom, M.W., 1995, Relations between pesticide use and riverine flux in the Mississippi River Basin: Chemosphere, v. 31, no. 5, p. 3305-3321.

Lee, E.A., Strahan, A.P., and Thurman, E.M., 2002, Methods of analysis by the U.S. Geological Survey Organic Geochemistry Research Group—Determination of triazine and pheylurea herbicides and their degradation products in water using solid-phase extraction and liquid chromatography/mass spectrometry: U.S. Geological Survey Open-File Report 02-436, 19 p.

Majewski, M.S., Foreman, W.T., Goolsby, D.A., and Nakagaki, N., 1998, Airborne pesticides residues along the Mississippi River: Environmental Science & Technology, v. 32, n. 23, p. 3689-3598.

Pennington, K., 1996, Mississippi Delta surface water quality, a summary: Proceedings 26th Mississippi Water Resources Conference, Jackson, MS: Water Resources Institute: Starkville, MS, p. 187-195.

Pereira, W.E., and Hosteller, F.D., 1993, Nonpoint source contamination of the Mississippi River and its tributaries by herbicides: Environmental Science & Technology v. 27, no. 8, p. 1542-1552.

Plunkett, M.L., Morris, Fred, Oakley, W.T., and Turnipseed, D.P., 1997, Water resources data for Mississippi, water year 1996: U.S. Geological Survey Water-Data Report MS-96-1.

----1998, Water resources data for Mississippi, water year 1997: U.S. Geological Survey Water-Data Report MS- 97-1.

Rantz, S.E., and others, 1982, Measurement and computation of streamflow: Volume 1. Measurement of stage and discharge, and Volume 2. Computation of discharge: U.S. Geological Survey Water-Supply Paper 2175, 681 p.

Runner, M.S., Turnipseed, D.P., and Coupe, R.H., 2002, Streamflow and nutrient data for the Yazoo River below Steele Bayou near Long Lake, Mississippi, 1996-2000: U.S. Geological Survey Water-Resources Investigations Report 02-4215, 35 p.

Shelton, L.R., 1994, Field guide for collecting and processing stream-water samples for the National Water-Quality Assessment Program: U.S. Geological Survey Open-File Report 94-455, 42 p.

Telis, P.A., 1992, Techniques for estimating 7-day, 10-year low-flow characteristics for ungaged sites on streams in Mississippi: U.S. Geological Survey Water-Resources Investigations Reprort 91-4130, 143 p.

Thurman, E.M., Goolsby, D.A., Meyer, M.T., and Kolpin, D.W., 1991, Herbicides in surface water of the Midwestern United States: The effects of the spring flush: Environmental Science & Technology, v. 20, p. 540-547.

U.S. Army Corps of Engineers, 1996, Stages and discharges of the Mississippi River and tributaries in the Vicksburg District: U.S. Army Engineer District, Vicksburg, MS., 328 p.

U.S. Army Corps of Engineers, 1997, Stages and discharges of the Mississippi River and tributaries in the Vicksburg District: U.S. Army Engineer District, Vicksburg, MS., 288 p.

Table 1.-- List of herbicides and degradates
[(), number of samples; H, herbicide; D, degradate; ND, not detected; concentrations in micrograms per liter (µg/L)]

Compound	Type	River: Big Sunflower River (52)	Bogue Phalia (62)	Skuna River (21)	Steele Bayou (50)	Yazoo River (43)
		Statistics: The values below represent the percent of samples with concentrations above the reporting level, the maximum concentration, and the median concentration.				
Acetochlor	H	15, 1.68, 0.05	10, 1.91, 0.05	ND	ND	6, 0.13, 0.05
Alachlor	H	13, 0.98, 0.05	5, 0.4, 0.05	14, 0.76, 0.05	4, 0.11, 0.05	16, 0.25, 0.05
Atrazine	H	71, 8.49, 0.07	41, 16.6, 0.05	62, 0.92, 0.06	82, 9.21, 0.13	86, 3.74, 0.25
Deethyl atrazine	D	35, 0.42, 0.05	33, 0.37, 0.05	14, 0.1, 0.05	48, 0.61, 0.05	58, 0.34, 0.07
Deisopropyl atrazine	D	42, 0.59, 0.05	28, 0.29, 0.05	10, 0.1, 0.05	50, 0.87, 0.05	42, 0.27, 0.05
Cyanazine	H	85, 5.77, 0.205	52, 2.31, 0.05	10, 0.12, 0.05	90, 6.05, 0.33	51, 1.04, 0.07
Cyanazine amide	D	60, 0.84, 0.08	31, 0.36, 0.05	5, 0.05, 0.05	72, 1.01, 0.12	28, 0.25, 0.05
Fluometuron	H	90, 6.33, 0.26	64, 6.42, 0.08	43, 0.99, 0.05	94, 5.78, 0.435	81, 2.95, 0.21
Demethyl fluometuron	D	49, 0.84, 0.05	69, 1.82, 0.05	33, 0.28, 0.05	60, 1.11, 0.13	74, 0.38, 0.05
3-(Trifluoromethyl)aniline	D	25, 0.45, 0.05	17, 0.14, 0.05	10, 0.21, 0.05	28, 0.2, 0.05	14, 0.3, 0.05
3-(Trifluoromethyl)phenylurea	D	ND	ND	ND	2, 0.14, 0.05	ND
Metolachlor	H	98, 9.32, 0.21	76, 8.79, 0.1	71, 4.24, 0.12	88, 8.19, 0.19	81, 3.48, 0.2
Metribuzin	H	42, 2.23, 0.05	29, 2.77, 0.05	19, 0.17, 0.05	34, 1.07, 0.05	26, 0.67, 0.05
Molinate	H	63, 53.3, 0.07	72, 63.1, 0.225	ND	60, 27.4, 0.07	30, 4.32, 0.05
Norflurazon	H	94, 1.54, 0.185	71, 2.24, 0.075	ND	92, 0.93, 0.185	77, 0.91, 0.07
Demethyl norflurazon	D	96, 1.71, 0.24	78, 1.41, 0.13	ND	90, 1.27, 0.21	77, 0.74, 0.11
Prometryn	H	42, 0.73, 0.05	24, 3.73, 0.05	5, 0.07, 0.05	46, 2.29, 0.05	35, 0.36, 0.05
Deisopropyl prometryn	D	ND	1, 0.1, 0.05	ND	4, 0.11, 0.05	ND
Propanil	H	4, 1.66, 0.05	3, 2.73, 0.05	ND	4, 0.11, 0.05	ND
3,4-Dichloroaniline	D	79, 2.6, 0.175	79, 26.3, 0.14	ND	72, 5.05, 0.125	21, 0.3, 0.05
Propazine	H	12, 0.11, 0.05	9, 0.11, 0.05	ND	4, 0.09, 0.05	2, 0.05, 0.05
Simazine	H	46, 0.35, 0.05	29, 0.37, 0.05	ND	64, 1.16, 0.08	35, 0.29, 0.05
Trifluralin	H	2, 0.06, 0.05	10, 0.12, 0.05	ND	10, 0.2, 0.05	2, 0.7, 0.05

Table 2.-- Drainage basin characteristics for rivers in the Yazoo River Basin
[km^2, square kilometers; ft^3/s cubic feet per second]

River	Drainage Area (km^2)	Percent of Yazoo Basin	Percent of basin in row crop	1996 Discharge (ft^3/s)	1997 Discharge (ft^3/s)
Skuna	660	1.9	18.9	381	670
Steele Bayou	1,080	3.1	53.6	514	1,325
Bogue Phalia	1,250	3.6	71.2	443	929
Big Sunflower	6,680	19.3	65.4	1,908	5,100
Yazoo	34,590	100	36.8	14,240	24,590

Table 3.– Flux of selected herbicides from five rivers in the Yazoo River Basin, 1996 and 1997
[TFMA, 3-(trifluoromethyl)aniline]; values in kilograms per year

River	Year	Alachlor	Atrazine	Deethyl Atrazine	Deisopropyl Atrazine	Cyanazine	Cyanazine Amide	Fluometuron	Demethyl Fluometuron	TFMA	Metolachlor	Metribuzin	Molinate	Norflurazon	Demethyl Norflurazon	Prometryn	3,4- Dichloro-aniline	Simazine
Skuna	1996	3.4	53.8	5.7	3	0.4	0.4	10.1	2.2	0.6	81	2.5	0	0	0	0.5	0	0
	1997	13.7	71	3.1	11.4	0.5	0	23.9	9.6	23.9	80	0.4	0	0	0	0	0	0
Steele Bayou	1996	1.7	449	52.8	50.3	401	66.1	460	107	8.4	812	26.3	1,660	123	130	111	73.8	141
	1997	0	1134	79	76.7	322	74.7	472	178	19.6	1,037	146	286	212	527	7.9	244	161
Bogue Phalia	1996	0	193	15.6	19.1	55.5	11.3	63.5	24.8	0.5	527	33.3	1,258	57.6	57.6	26.2	102	41.9
	1997	5.6	1039	38.1	29.2	126	28.1	574	154	18.3	919	305	2,490	182	195	36.1	419	60.7
Big Sunflower	1996	253	2,482	128	164	899	279	1,750	426	44.9	3,620	305	3,840	835	835	143	451	210
	1997	44	3,817	377	312	1,480	281	3,000	390	130	7,340	1,839	12,293	1,120	1,760	156	1,911	495
Yazoo	1996	451	13,390	905	824	2,030	239	5,240	355	18	13,820	3,120	2,180	2,330	1,910	516	131	744
	1997	291	11,490	1,100	743	2,010	493	8,290	493	581	10,730	2,050	10,050	2,320	3,960	380	747	682

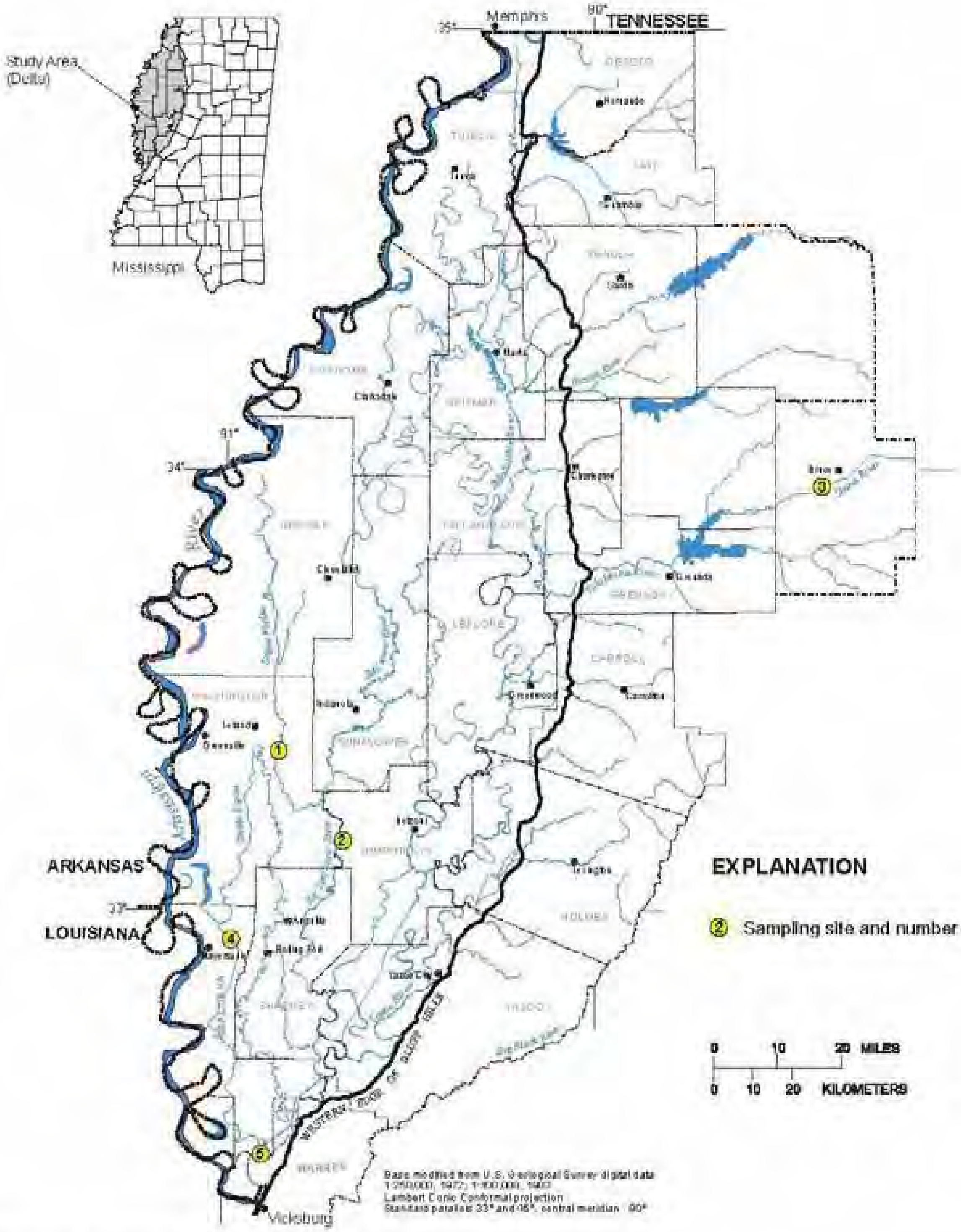


Figure 1. Location of study area, northwestern Mississippi and sampling sites.

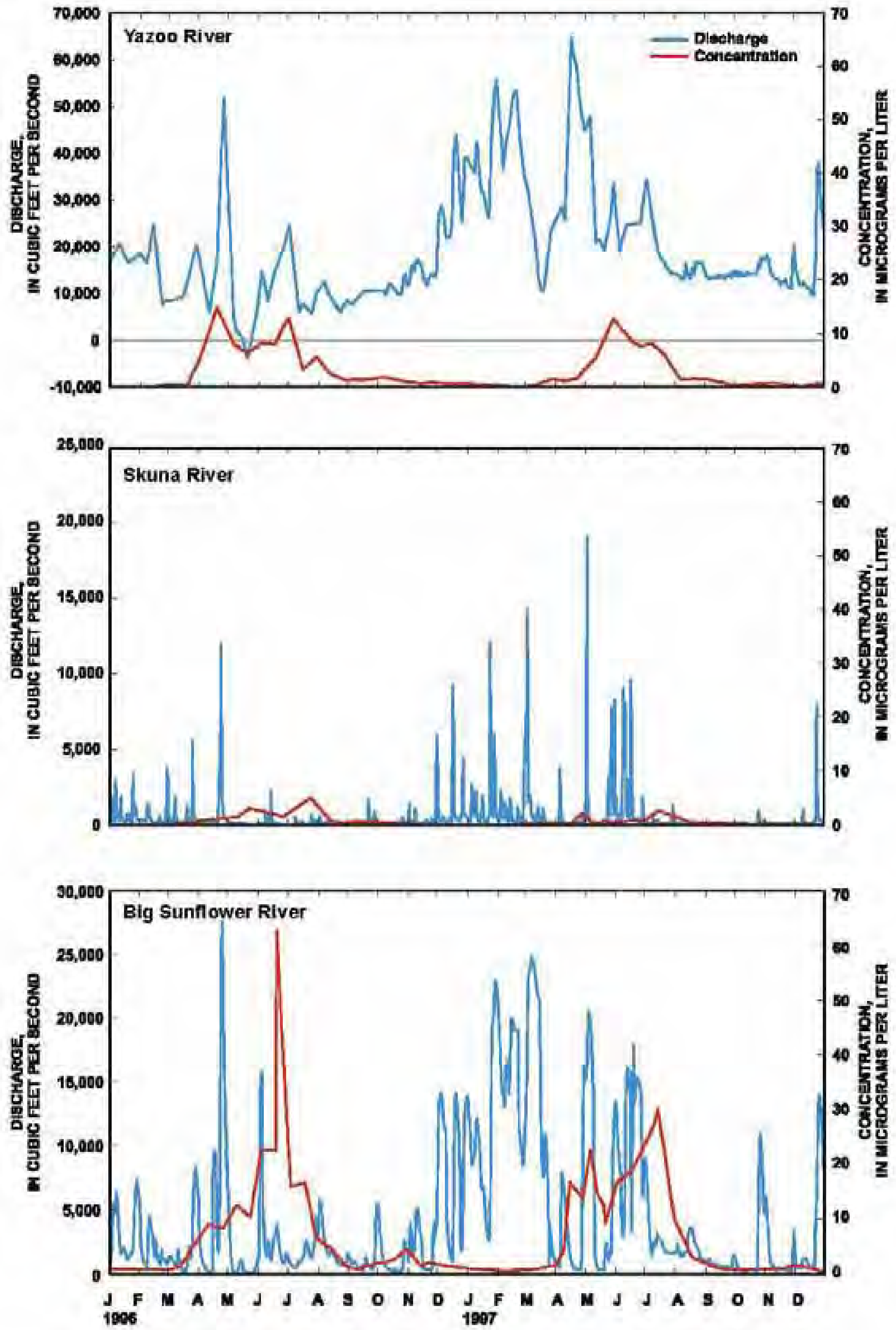


Figure 2. Steam discharge and total herbicide concentration in five rivers of the Yazoo River Basin, MS, 1996-97; Yazoo River, Skuna River, Big Sunflower River, Bogue Phalia, and Steele Bayou.

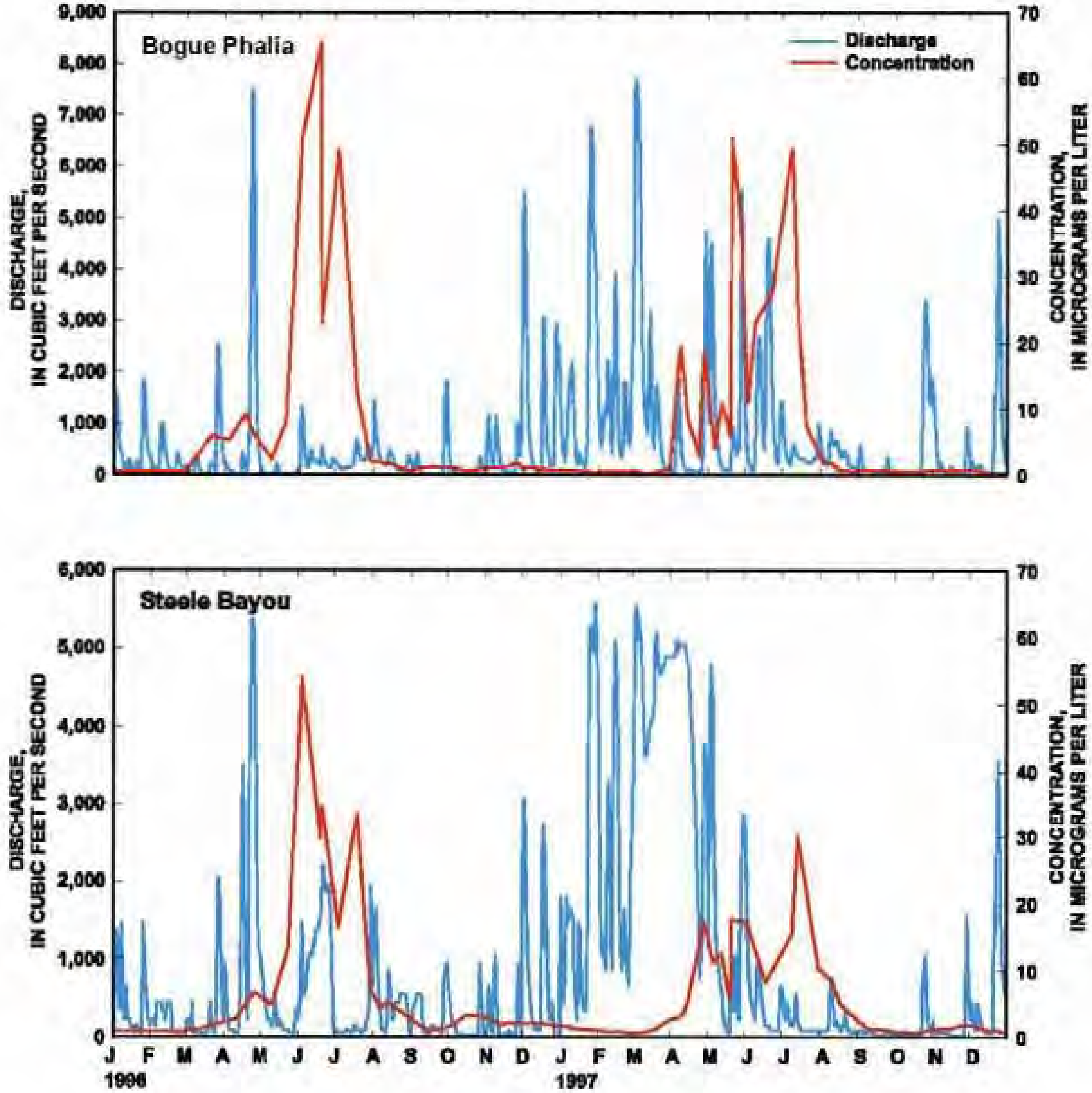


Figure 2. Steam discharge and total herbicide concentration in five rivers of the Yazoo River Basin, MS, 1996-97–Continued; Yazoo River, Skuna River, Big Sunflower River, Bogue Phalia, and Steele Bayou.

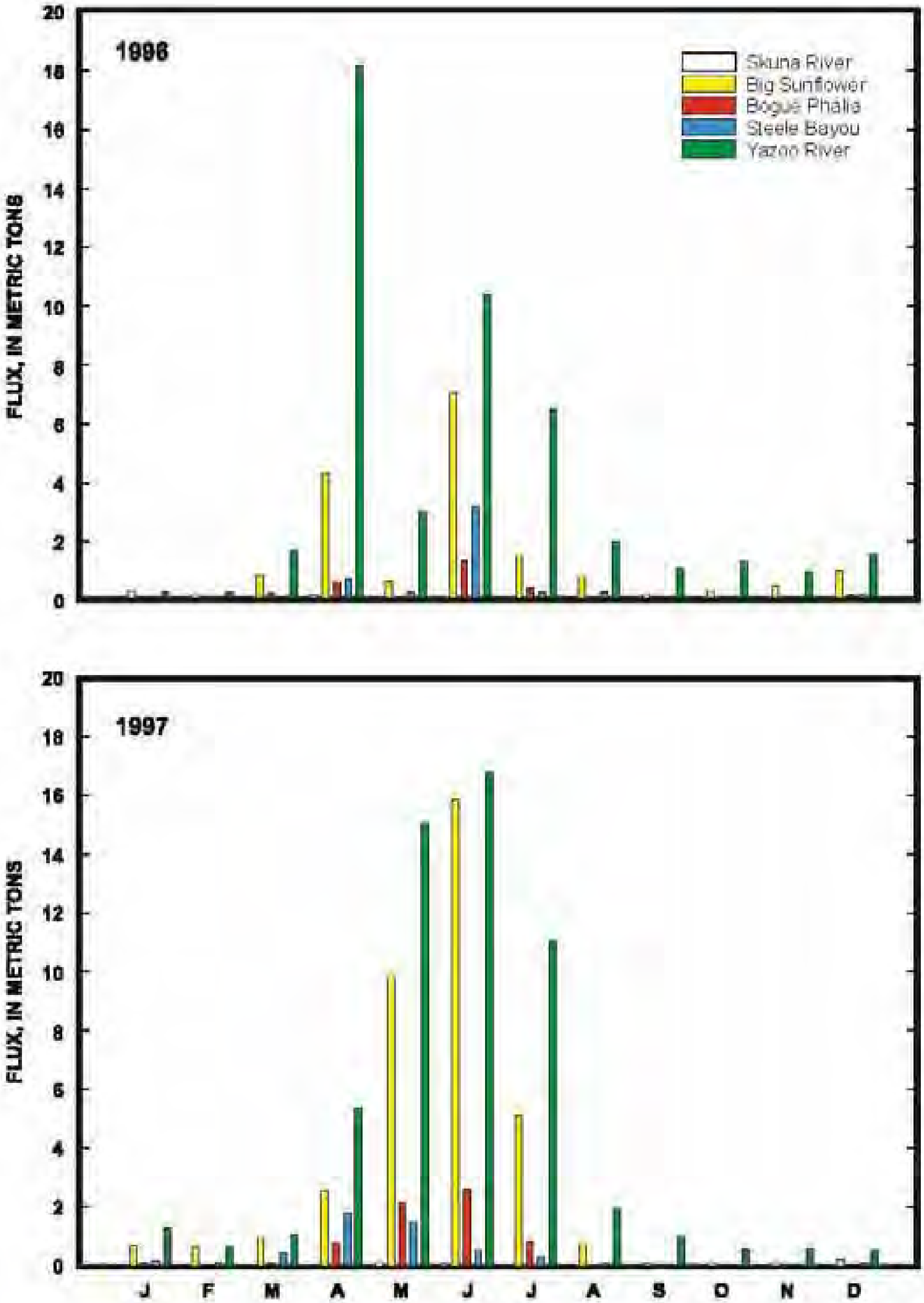


Figure 3. Monthly total herbicide fluxes for 1996 and 1997 from the Yazoo River Basin.

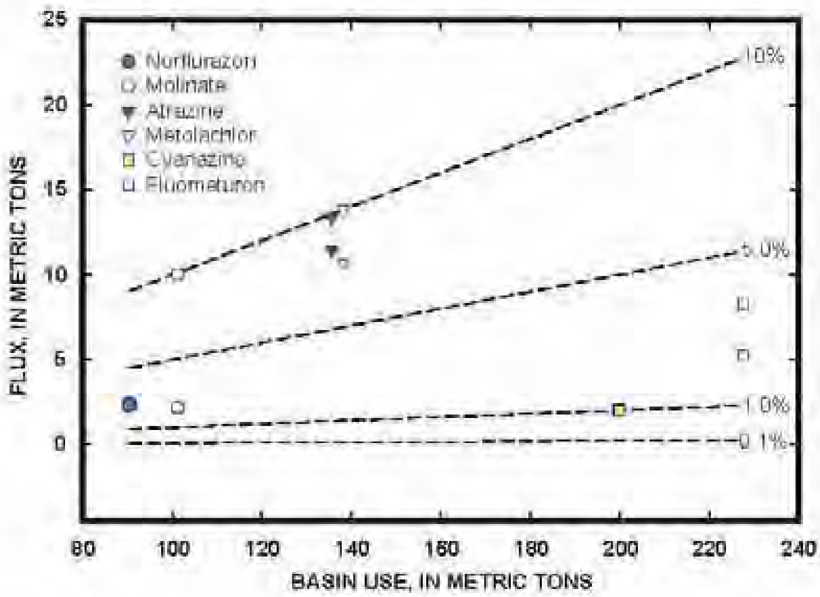


Figure 4. Relation of flux and basin use in the Yazoo River Basin, 1996-97
(Dashed lines represent percentage of basin use, load values are from Yazoo River below Steele Bayou 1996-97.)

Pesticide Concentrations in Surface Waters of Mississippi Lakes and Reservoirs

Charles M. Cooper[1], Sammie Smith, Jr.[1] and Henry Folmar[2]
[1] United States Department of Agriculture, Agricultural Research Service, National Sedimentation Laboratory, Oxford, MS
[2] Mississippi Department of Environmental Quality, Office of Pollution Control, Biological Services Section, Pearl, MS

ABSTRACT

Surface water samples from lakes and reservoirs throughout Mississippi were collected and analyzed on a seasonal basis during 2002-2003 as part of a water quality survey. The purpose of the pesticide study was to produce a significant addition of baseline information to 1) ascertain current conditions and 2) provide concentrations of selected mainstream current-use and legacy pesticides for future comparisons. Over 100 sites were sampled during the year-long period, resulting in over 8000 individual analyses from 473 collections throughout the state. Temporal analysis reflected application timing, general runoff patterns and pesticide dissipation. Although the frequency of pesticide detection increased greatly from winter to spring (mean occurrence of analytes increased from 17% to 46%), concentrations above 0.1 µg/L were uncommon. Summer detections were also significantly fewer (20% mean occurrence) than spring for almost all compounds. Low concentrations (mean = 0.0474 µg/L) of ∑DDT were ubiquitous (95.8% occurrence). Detections of bifenthrin and λ-cyhalothrin, pyrethroid insecticides; methyl parathion, an organophosphate insecticide; atrazine, a triazine herbicide used primarily for corn; fipronil, a new residential, industrial and agricultural insecticide; and chlorfenapyr, a termiticide-insecticide, were widespread in the state, especially in spring samples. Overall, frequency of pesticide occurrence (97% of samples) was high, but concentrations were quite low (0.0301 µg/L). Of the pesticides that have United States Environmental Protection Agency (U.S. EPA) or state of Mississippi water quality criteria, only ten collections were excessive. Survey collections are not intended as substitutes for the robust sampling protocol needed for regulatory purposes, but they serve as an adequate screening tool for specific sites or pesticides. Understanding trends in pesticide presence could result in more effective methods to prevent environmental contamination.

INTRODUCTION

Use of pesticides plays a key role in preventing disease and producing food and fiber for our world, and is deemed a necessity in our modern culture. Pesticides are also used extensively in homes and businesses for pest control. Use of pesticides in agriculture has remained historically high for economic reasons. Consumer costs of agricultural commodities would double or triple without pesticide use (Caro, 1976). The combined domestic application of pesticide products in the United States totals about 2 billion lbs. of active ingredients annually (Lyon, 1996).

The first pesticides were actually metals such as arsenic and mercury, and crop dusting on cotton began in the Mississippi Delta in 1922. DDT was discovered in 1939, and, soon after, the organophosphate parathion was synthesized during World War II by German scientists experimenting with nerve gas. Early compounds were highly residual, and many of them are still measurable in one or more ecosystem components. Public awareness and concern over potential environmental hazards has risen greatly in recent decades. Residual organochlorines have been replaced with less persistent compounds, but some of these also find their way from their area of application into the environment. Federal and state activities associated with contaminant Total Maximum Daily Loads (TMDLs) created by the Clean Water Act have shown pesticide contamination to be a major factor in preventing attainment of functional ecosystems.

An opportunity to sample Mississippi's lakes was presented in 2002 when the Mississippi Department of Environmental Quality (MDEQ) began its lake and reservoir nutrient sampling program. USDA National Sedimentation Laboratory (NSL) personnel have conducted over 30 years of pesticide research and, thus, have acquired advanced analytical capacity as well as historical data at many aquatic sites in Mississippi. By combining efforts, the two agencies shared costs and acquired surface water pesticide concentrations that depict conditions in Mississippi lakes greater than 200 acres in size. The purpose of this pesticide study was to produce a significant addition of baseline information about large lakes of Mississippi to 1) describe current conditions of lake water pesticide presence and concentration and 2) provide measures of selected mainstream current-use and legacy pesticides for future comparisons.

Study Area

The state of Mississippi lies in temperate and subtropical zones of North America. The summer season has average temperatures in the low 80s ($^{\circ}$F) with daytime highs commonly reach 90-100°F. Mild winters have mean temperatures that range from 40F in the north to 50F on the Gulf of Mexico coast. Annual rainfall averages about 50 inches in the northwest to 65 inches in the southeast. This climate of mild temperatures and a long growing season is conducive to both agriculture and forestry in the state.

Population centers include the Gulf coast, the capitol of Jackson and the northernmost region of the state that borders Memphis, Tennessee. The estimated year 2000 population of the state was 2,844,658 (US Census Bureau, 2002). State residents were housed in 1,161,953 housing units across the state. Census figures recorded a 10.5 percent population increase over 1990.

The 2002 Census of Agriculture (U.S. Department of Agriculture, 2002) showed there were 42,167 farms operating in Mississippi during 2002, virtually the same as 1997. Land in farms, at 11.1 million acres, was down 3 percent from 1997, and the average farm size, at 264 acres, was down 7 acres. Ninety-two percent of Mississippi agricultural operations are still run by individuals or families and most are still small farms. Seventy-four percent of operations had less than $10,000 in sales of agricultural products in 2002. Part-time farming continues to be a major part of Mississippi agriculture, as 29 percent of the principal farm operators worked 200 days or more off the farm, a 9 percent decline from 1997.

Global and National Pesticide Use

World pesticide usage amount exceeded 5.6 billion pounds in 1998 and 1999 (U.S.EPA 2001). Herbicides accounted for the largest proportion of total usage, followed by other pesticide usage, insecticide usage, and fungicide usage. Total world pesticide amount used was up slightly in 1999, due mainly to an increase in the use of non-conventional pesticides. Pesticide use in the United States in 1999 exceeded 2 billion pounds (Table 1) and accounted for more than 20% of total world pesticide use.

Table 1. Amount of U.S. pesticide usage. Estimates adapted from U.S. EPA, 2001.

Pesticide Group	Total (Mil lbs)	
Year	1998	1999
Conventional Pesticides	912	912
Other Pesticides	294	332
Specialty Biocides	309	343
Chlorine/Hypochlorites	2,532	2,609
Wood Preservatives	820	801
Total	4,867	4,997

Table 2 lists the most commonly used conventional pesticide active ingredients in the agricultural sector, home and garden market, and industry/commercial/government sector during 1999. 2,4-D was the most used active ingredient in non-agricultural markets, with between seven and nine million pounds used in the home and garden sector and between 17 and 20 million pounds used in the industry/commercial/government sector. Six of the top ten pesticides in the home and garden sector are herbicides and four are insecticides. Six of the top ten in the industry/commercial/government sector are herbicides, two are fungicides, and two are insecticides.

Residential Use

Household pesticide use is pervasive across North America. The U.S. Environmental Protection Agency (U.S. EPA, 2001) estimates that approximately 80 million pounds of pesticide active ingredients (9 percent of total conventional pesticide use in the United States) were used in homes and gardens in 1999. A 1992 survey conducted by the EPA found that 85 percent of households nationwide had at least one pesticide product stored in the home. The average number of pesticide products stored in homes is between three and four, and insecticides are the most common type of pesticide used in homes (U.S. EPA, 1997a). Many households still store banned, highly persistent and dangerous pesticides. An estimated one million households have products containing chlordane; 150,000 still have DDT; 70,000 have heptachlor, and approximately 85,000 still have Silvex® which contains dioxin (U.S. EPA, 1997b).

Most storage practices take few or no precautions to protect children from exposure. An estimated 47 percent of households with children under the age of five stored at least one pesticide within reach of small children (U.S. EPA, 1997c). Only 25 percent of all homes stored all pesticides securely (U.S. EPA, 1997d). A survey of pesticide use in 51 households in Sarasota County, Florida, found that the most common use of pesticides was direct application to carpets for control of fleas (Moses, 1995). This is particularly hazardous for children, who spend considerable time at ground level and can inhale pesticides in air and absorb pesticides from the carpet directly through their skin.

In an infamous case of misuse, state and federal officials evacuated 1,100 people from homes in Mississippi, Alabama, Louisiana, and Arkansas after residences and public facilities were treated with methyl parathion, a restricted use agricultural pesticide. In addition to homes, twelve businesses were closed, including eight daycare centers, a restaurant, and a hotel. Two unlicensed exterminators had sprayed the chemical in businesses and residences although it is only registered for agricultural use (U.S. EPA, 1996).

Even normal exposure to pesticides results in measurable concentrations in humans. In a National Institute of Environmental Health Sciences study quoted by Tvedten (2001), researchers reported that in a large random sample of the general population, DDT was found in 100% of the blood samples tested at an average level of 3.3 micrograms per liter (μg/L). Chlordane (a pesticide sprayed underneath homes for termite control and found to seep into the living airspace) was found in the blood of approximately 95% of the population. Other pesticides and chemicals found in over 90% of the population included dieldrin and lindane.

Table 2. National rank in prevalence of pesticides by weight of active ingredient applied during 1999 by type (H = herbicide, I = insecticide) and market (Agric. = agricultural, H&G = home and garden, I/C/G = industrial/commercial/government). Data were taken from public and proprietary U.S. EPA databases.

Active Ingredient	Type	Agric.	H&G	I/C/G
Atrazine	H	1		
Glyphosate	H	2	2	2
Acetochlor	H	4		
2,4-D	H	6	1	1
Malathion	I	7	9	9
Metolachlor	H	8		
Trifluralin	H	9		
Pendimethalin	H	10		4
Metolachlor-s	H	12		
Chlorpyrifos	I	16	6	5
MCPP	H		3	
Dicamba	H		4	
Diazinon	I		5	
Carbaryl	I		7	
Benefin	H		8	
DCPA	H		10	
MSMA	H			6
Diuron	H			8
Triclopyr	H			10

Note: Table 2 does not include the following fungicides and fumigants in the top 10 most common pesticides used in agricultural and industrial/commercial/government markets (and rank): Metam Sodium (agric. #3), Methyl Bromide (agric. #5), Copper Sulfate (I/C/G #3), and Chlorothalonil (I/C/G #7). No fungicides or fumigant information occurred for the home and garden market.

Pesticide residues in soft-drink samples were measured recently in India (CSE 2003). Lindane and chlorpyrifos were present in 100 percent of the samples analyzed. Lindane exceeded regulation limits in 33% of the samples, and chlorpyrifos exceeded the limit in 75% of the samples. DDT and its metabolites were present in 58% of soft-drink samples. Unknown compounds provide another challenge in the areas of both safety and contamination. Products may enter the U.S. from other countries with little or no labeling. EPA investigated an insecticide call "Miraculous Chinese Chalk" which was sold in stores featuring oriental products. No warning could be placed on the package because the maker changed active ingredient from batch to batch.

Table 3. Share of agricultural and non-agricultural market sector pounds of active ingredient during 1998 and 1999.

Year	U.S.	Agricultural Market		Non-agricultural Market	
	Mil lbs of a.i.	Mil lbs of a.i.	% of U.S.	Mil lbs of a.i.	% of U.S.
1998	912	724	79%	188	21%
1999	912	706	77%	206	23%

Agricultural Use

Agriculture accounted for 79% of the pesticides used in the U.S. during 1999 (Table 3). Since 1980, agricultural pesticide use has declined slightly from 1053 million pounds of active ingredient to 985 million pounds per year. In Mississippi in 2002, 1,410,000 acres planted in soybeans produced 1.37 million bushels while 1.87 million bales of cotton were harvested from 1.15 million acres. Rice (253,000 ac.), sorghum (83,000 ac.), and corn (53,000 ac.) were also major commodities. Catfish (23.9 million pounds) were sold from 390 operations (110,000 acres) in 2002. In livestock operations scattered across the state, Mississippi raised 63.88 million chickens in 2002. Two hundred and eighty-nine dairy farms produced milk. Red meat production was 25.2 million pounds in November alone. Fifteen hundred hog operations produced 0.46 percent of the nation's hogs. This diversity of crops in a warm, moist environment provides conditions for use of a suite of insecticides and herbicides.

METHODS

Study Sites and Field Methods

Sampling was conducted by three MDEQ teams, one team based at the Oxford office, one based at the Biloxi office, and one based at the central laboratory in Pearl, MS. Data collections began during November 2002 and continued through September 2003. Six total samples per site were anticipated, one each during the sampling visits in November 2002, and April, June, July, August and September 2003, but not all samples were analyzed from all sites due to factors precluding sample acquisition or loss of samples after collection. Sampling periods targeted the bulk of collections during peak agricultural activities. Samples were taken by boat as surface grabs into specially cleaned and solvent rinsed glass jars according to U.S. EPA recommendations and transported on ice to the NSL within 48 hours.

Table 4. Targeted pesticides and levels (ng/L) of detection (LOD) and quantitation limits (LOQ).

Pesticide	LOD	LOQ
Alachlor	0.5	5
Atrazine	1	10
Bifenthrin	0.1	1
Chlorfenapyr	0.5	5
Chlorpyrifos	0.1	1
Cyanazine	0.5	5
Dieldrin	0.1	1
Fipronil	0.1	1
Fipronil sulfone	0.1	1
l-Cyhalothrin	0.1	1
Methyl parathion	1	10
Metolachlor	1	10
Pendimethalin	0.5	5
Trifluralin	0.1	1
p,p'-DDD	0.1	10
p,p'-DDE	0.1	1
p,p'-DDT	1	10

Pesticide Analyses

The pesticides initially targeted for analysis, along with their levels of detection and quantitation, are shown in Table 4. Heptachlor, aldrin, endosulfan, dieldrin, endrin, methoxychlor and p,p'-DDT (metabolites p,p'-DDE and p,p'-DDD) are relatively persistent, chlorinated hydrocarbon insecticides with some history of past use throughout much of the Mississippi Delta. The other compounds are generally less persistent herbicides and insecticides that have been or are in current use. Analysis of water samples was similar to the method of Smith et al. (1994), with modifications by Bennett et al. (2000). Water samples were allowed to come to room temperature (about 25°C) and the volume measured and recorded. The entire sample was extracted by sonification (1 min/pulse mode/80% duty cycle) with 1g reagent-grade KCl and 100 mL pesticide-grade EtOAc, partitioning in a separatory funnel with the water phase discarded. The EtOAc phase was dried over anhydrous Na_2SO_4 and concentrated by rotary evaporation to near dryness. The extract was taken up in about 5mL pesticide-grade hexane, subjected to cleanup by silica gel column chromatography, and concentrated to 1mL for GC analysis. Mean extraction efficiencies, based on fortified samples, were >87% for all pesticides.

A multi-level calibration procedure was used with standards and samples injected in triplicate. Calibration curves were updated every tenth sample. Two Hewlett Packard model 6890™ gas chromatographs equipped with dual HP 7683 ALS autoinjectors, dual split-splitless inlets, dual capillary columns, a HP Kayak XA chemstation™, and a HP LaserJet 4000 printer™ were used to analyze water for pesticides. One HP 6890 was fitted with two HP µECDs and the other 6890 with one HP µECD, one HP nitrogen/phosphorus detector, and a HP 5973 mass selective detector (MSD).

RESULTS AND DISCUSSION

Occurrence

Over 100 sites representing 50 Mississippi lakes and reservoirs (Fig. 1) yielded 473 collections and 8,041 individual analyses from samples obtained during November, 2002 and in April, June, July, August, and September, 2003. Pesticides were present in 96.62 % of the samples analyzed, but concentrations were generally quite low (mean=0.0301 µg/L). Of the 16 samplings that did not have any pesticide detections, 13 were in August, 2003, the period of least runoff. While both herbicides and insecticides were present in sub-µg/L concentrations during all sampling periods, highest mean concentrations were present for both pesticide groups in spring sampling (0.1101 µg/L for herbicides; 0.0188 µg/L for insecticides).

Mississippi does not have an uncommonly high rate of detection statewide. The National Water Quality Assessment (NAWQA) Program of the U.S. Geological Survey (USGS) found one or more pesticides in almost every stream sample collected across the United States. More than 95 percent of the samples collected from streams and almost 50 percent of samples collected from wells during that study contained at least one pesticide. Seventy-four of the 83 pesticide compounds analyzed in that study were detected at least once in streams or groundwater. Major rivers, as well as agricultural and urban streams, had relatively similar high frequencies of detection (Gilliom et al. 1999).

Figure 1. Locations of lake and reservoirs greater than 200 acres in size sampled for pesticide occurrence and concentration during 2002-2003.

As for occurrence of specific compounds in this study, low concentrations (mean = 0.0474 µg/L) of ∑DDT were present in almost all samples (95.8% occurrence). Use of DDT was banned in 1972; use actually peaked in 1968, but its application was so widespread from 1945 to 1972 that it is found in every watershed in the state of Mississippi. Cooper et al. (2002) observed that concentrations in lake water and sediment are gradually declining, but documented sources and sinks are common.

Bifenthrin, a pyrethroid insecticide, was found in 39.1 % of samples. Bifenthrin is sometimes applied to cotton and is labeled for use as an acaricide. It is, however, a common fire ant bait and home use insecticide.

Atrazine, a widely-used pre-emerge herbicide occurred in 37.8 % of the samples. Atrazine, a selective triazine herbicide, is the most commonly applied herbicide in the United States. It is used as a broadleaf and grass herbicide in both row-crop agriculture and silviculture and also as a non-selective herbicide on non-crop land. Between 74 and 80 million pounds were applied in the U.S. in 1999, nearly 90% of which was used on corn. It is also registered for lawn and turf use. It does not dissipate quickly and is the most common pesticide found in ground and surface water.

Chlorfenapyr was detected in 30.0 % of collections. It is a member of the chemical family "pyrroles" and was the first pyrrole submitted for U.S. registration. Chlorfenapyr has a unique mode of action. It is a pro-insecticide that is converted (or metabolized) to the active form by mixed function oxidases in the target pest. The active form acts on the mitochondria and uncouples oxidative phosphorylation which stops the production of ATP, the primary source of cellular energy. This action causes cell death, and ultimately, death of the target organism, the insect. However, the process interrupted is a process common to all living organisms, and so is of concern for non-target organisms. Chlorfenapyr, known in agriculture by its trade name Pirate®, was allowed a special use exemption in Mississippi in 1995-1999 for the treatment of beet armyworms and tobacco budworms in cotton. EPA cancelled requests from its manufacturer in 2000 because of evidence that showed detrimental effects on birds. Chlorfenapyr is currently registered and commonly used as a termiticide for residences and businesses and has been used on vegetables.

Lambda cyhalothrin (24.5 % occurrence) is a synthetic pyrethroid insecticide and acaricide registered to control a wide range of pests in a variety of applications. Controlled pests include aphids, Colorado beetles and butterfly larvae on cotton, cereals, hops, ornamentals, potatoes, vegetables or others (Kidd and James, 1991). It may also be used for structural pest management or in public health applications to control insects such as cockroaches, mosquitoes, ticks and flies which may act as disease vectors.

Methyl parathion, an orthophosphate and the most commonly used insecticide in cotton, was sixth in occurrence (21 %) across the state. It is restricted to agriculture only. An estimated 4.5 million pounds of methyl parathion are used annually in the U.S. Approximately 95 percent of this is used on cotton, soybeans, field corn, peaches, wheat, barley and rice.

Fipronil occurred in 20.5 % of the 473 samples. It is a member of the phenyl pyrazole class of pesticides, which are principally chemicals with a herbicidal effect. Fipronil, however, acts as an insecticide with contact and stomach action. Fipronil disrupts the insect's central nervous system by blocking the passage of chloride ions through the GABA receptor, an inhibitor of the central nervous system which causes hyper-excitation of contaminated insects' nerves and muscles. While many classes of insecticides affect the central nervous system, no other class has this specific effect. At this time, there is no known target resistance to fipronil. It is registered for insect control in corn, indoor pests and turf grass, and is gaining popularity for termite control (Termidor®). It is also the active ingredient in tick and flea collars (Frontline Plus®).

Occurrence and Land Use

To no one's surprise, U.S. Geological Survey (U.S.G.S.) analysis of patterns in pesticide use across the nation as part of the National Water Quality Assessment (NAWQA) program (Gilliom et al. 1999) revealed that concentrations of herbicides and insecticides in agricultural streams of the nation followed use patterns. Herbicide concentrations were greatest in central U.S. streams, where use is most extensive. Urban streams had the highest insecticide concentrations; 7 of 11 urban streams had total insecticide concentrations in the upper 25% of all streams sampled, although some agricultural streams in irrigated agricultural areas of the western United States also had high levels. Total pesticide concentrations in streams draining urban areas are generally lower than concentrations in agricultural areas, but seasonal pulses may last longer and the concentrations are more dominated by insecticides. Preliminary analysis of Mississippi data during this study indicated low predictability of contamination by land use.

Frequency of detection of pesticides increased predictably from winter to spring and then declined as vegetative ground cover increased and rainfall amount declined. Oddly, occurrence increased in September. Information on pesticide occurrences, concentrations of specific pesticides, farming practices and rainfall patterns in July, August, and September highlighted late August and September field conditions somewhat similar to conditions found in spring. Early spring generally produces minimum ground cover, maximum runoff, and both the greatest occurrence and highest concentrations of pesticides (Cooper 1990). In most agricultural areas, the highest concentrations of pesticides occur as seasonal pulses--usually during spring and summer--lasting from weeks to months during and following high-use periods.

Nationwide, a relatively small number of heavily used compounds accounted for most detections. The combined use of three most commonly applied herbicides, atrazine, metolachlor, and alachlor, in 1993 was 175-190 million pounds. This represented about 27% to 29% of all the herbicides used in the U.S. The combined use of the three most commonly used insecticides chlorpyrifos, diazinon, and malathion, in 1993, was approximately 23-33 million pounds or 9 to 13% of the total amount of insecticides used in the U.S. (Aspelin 1994).

In the U.S.G.S. NAWQA program the most frequently detected pesticide compounds in agricultural areas were the herbicides atrazine, metolachlor, cyanazine, and alachlor, ranked first, second, fourth, and fifth in national herbicide use for agriculture. The most heavily used herbicides also accounted for most of the detections in rivers and major aquifers and many of the detections in urban streams and shallow groundwater (Gilliom et al. 1999). In our Mississippi study, atrazine was the only herbicide found in more than 20 % of the collections. Several pesticides that are used extensively in agriculture were infrequently detected. These include the herbicides metolachlor, cyanazine, trifluralin, alachlor and the insecticide chlorpyrifos.

Concentrations – The Worst and the Best

Eighty-five percent of pesticide detections were <0.01µg/L. These low concentrations were similar for herbicides (89 %) and insecticides (82 %). Ninety-three percent of all detections were <0.05 µg/L. Only two percent of detections were ≥0.1 µg/L and less than 1.0 µg/L. Detections >1.0 µg/L comprised only 0.20 % (16 observations) of the 8,041 analyses. When pesticides with the highest concentrations were compared to occurrence, atrazine (mean = 0.1639 µg/L) replaced ∑DDT (mean = 0.0474 µg/L) as the compound with the highest detection reading. Of the currently used compounds examined, metolachlor, a grass and broadleaf herbicide was third, moving the pyrethroid bifenthrin to fourth. Fipronil sulfone, a degradation product of fipronil, replaced the parent compound. Lambda cyhalothrin remained in the top group in fifth and pendimethalin (Prowl®), an annual grass and broadleaf herbicide used in both agriculture and urban settings was sixth. Most pesticides had frequent occurrence but low concentrations. Mean values were elevated by a few high concentrations. Fipronil and fipronil sulfone were exceptions. In both agricultural and urban watersheds, a large proportion of observed concentrations of these two compounds were distributed medially, unlike patterns seen for other analytes.

Mean concentrations of each pesticide analyte were calculated separately for each lake. Lakes having the top 10 highest mean concentrations of each analyte were tabulated, and frequency of occurrence for each lake was calculated. Overall, two lakes had highest occurrence of high mean concentrations of pesticides; Aberdeen Lake and Horseshoe Lake. Aberdeen Lake data was in the highest 10 mean concentrations of each analyte for 12 of the 17 pesticides studied. Horseshoe Lake data was among the highest 10 concentrations of analytes for 10 pesticides. Other lakes with frequent occurrence of high concentrations of pesticides (frequency in parentheses) included Montgomery Pool of the Tennessee-Tombigbee (Tenn-Tom) Waterway (6 analytes), Turkey Fork Reservoir (6 analytes), Lake Bolivar (5 analytes), Tchula Lake (5 analytes), and Wasp Lake (5 analytes).

Aberdeen Lake has a very large watershed area of over 1.26 million acres that is predominantly in pasture (46%) and forest (37%), with smaller portions in agriculture (10%) and urban (1.5%) uses. The 1600 acre watershed of Horseshoe Lake is predominantly wetlands and water (77%), with an almost even mix of agriculture (13%) and pasture (10%) making up the remainder. Montgomery Pool of the Tenn-Tom Waterway includes nearly 40,000 acres of mostly forest (53%) and pasture (43%), with very small relative influences of agriculture (0.95%) and urban (0.12%) land uses. Turkey Fork Reservoir is very similar to Montgomery pool, with 56% of land use in forest and 42% in pasture. The 6,600 acre watershed has little or no agricultural and urban use. Agriculture is the predominant use in both Lake Bolivar (73% of 14,200 acres) and Wasp Lake (70% of 83,000 acres). Lake Bolivar has a small percent of land in pasture (6%) and the rest is either water or wetlands. No data were available for land use in Tchula Lake watershed.

Sources

Cooper (1990) found agricultural soils to be a continuing source of DDT in Mississippi. Coupe et al. (2000) studied pesticide occurrence in air and rain from an urban site and an agricultural site in Mississippi. Every sample collected from either site had detections of multiple pesticides although total concentration was five to 10 times higher at the agricultural site. Methyl parathion had the highest concentration in rain at both sites. It also had the highest concentration in air at the agricultural site. However, the urban site's highest concentration was from diazinon followed by chlorpyrifos. The DDT metabolite *p,p'*-DDE was present in all air samples collected from the agricultural site and in more than half on the air samples from the urban site.

There were six pesticides in current use that were found in more than 20 % of the samples taken. Of those six, all but one were insecticides. The herbicide was atrazine, the most-used herbicide in the United States. The University of California Berkeley (2002) provided quotes that expressed "there seems to be no atrazine-free environment." The European Union recently withdrew regulatory approval for atrazine due to groundwater contamination. Conversely, U.S. EPA re-approved the registration of atrazine in January, 2003.

Of the five most common insecticides, in order of occurrence, the pyrethroid bifenthrin is used in agriculture on cotton. It is one of the most common household insecticides and is a common turf, nursery, and fire ant insecticide. Chlorfenapyr is used in residential/industrial applications, especially as a household termiticide and insect pesticide (Raid Roach and Ant Killer®). It is not registered for row crop agriculture. Lambda-cyhalothrin, another pyrethroid, is a broadly used agricultural compound used to control a wide range of pest in a variety of applications. Methyl parathion is totally restricted to agriculture and is used on 63 percent of the cotton and 70 percent of the rice in Mississippi (Crop Life America, 2003). The last of the group, fipronil is the latest termiticide and fire ant bait to be marketed and is also gaining market share in agriculture. To summarize, only one of the top five insecticides is restricted to agriculture. One compound is gaining popularity in both agriculture and urban settings. Two insecticides have common residential/industrial applications, and one is almost entirely residential/industrial.

Environmental Significance

Pesticides are a concern for human health if they affect a drinking water source or occur where there is recreational use. They also are a potential concern for aquatic life in streams and lakes. Primary issues include toxicity, drinking water quality, and cancer or other illnesses. For protection of drinking water and aquatic life, water quality criteria have been established for some pesticides. Of the pesticides that have EPA or state of Mississippi water quality criteria, only ten collections from this study were excessive. Criteria only provide starting points for evaluating the potential effects of exposure, and most pesticides still do not have criteria.

Concerns over pesticide persistence and effects on wildlife are also environmental focal points. The story of DDT and its consequences when accumulated is still cause for concern. Chlorfenapyr was not registered but was cancelled for possible agricultural use in 2002 because of its detrimental effects on avian metabolism.

Misuse provides both regulatory and environmental challenges. The example of methyl parathion which has been used illegally in the Mississippi to rid homes and businesses of insect infestations highlights the need for greater awareness. In previous years, two similar events occurred. In 1994, homes and businesses were sprayed with methyl parathion in Lorain County, Ohio. EPA "decontaminated" 232 homes to "habitable conditions" at a cost of more than US$20 million. In April, 1995, another incident was discovered in Detroit, Michigan. Four residences, including a homeless mission, required "decontamination and restoration," costing approximately US$1 million. EPA staff compiled records of 22 accidental deaths since the mid-1960s caused by illegal home use of methyl parathion or ethyl parathion.

REFERENCES

Aspelin, A.L. 1994. Pesticide industry sales and usage: 1992 and 1993 market estimates. Biological and Economic Analysis Division, Office of Pesticide Programs, Office of Prevention, Pesticides, and Toxic Substances, U. S. Environmental Protection Agency. Washington, D.C.

Bennett, E.R., M.T. Moore, C.M. Cooper, and S. Smith, Jr. 2000. Method for the simultaneous extraction and analysis of two current-use pesticides, atrazine and λ-cyhalothrin, in sediment and aquatic plants. Bulletin of Environmental Contamination And Toxicology 64:825-833.

Caro, J.H. 1976. Pesticides in agricultural runoff. *In*: Steward, B. (Ed) Control of water pollution from cropland. An Overview. USDA Report No. ARS-H-5-2 2: 91-119.

Cooper, C.M. 1990. Persistent organochlorines and current use insecticide concentration in major watershed components of Moon Lake, Mississippi, USA. Archiv Für Hydrobiologie 121:103-113.

Cooper, C.M., S. Smith, Jr., S. Testa, III, J.C. Ritchie and T.D. Welch. 2002. A Mississippi USA flood control reservoir: Life Expectancy and Contamination. International Journal of Ecology and Environmental Science 28: 151-160.

Coupe, R.H., M.A. Manning, W.T. Foreman, D.A. Goolsby, and M.S. Majewski. 2000. Occurrence of pesticides in rain and air in urban and agricultural areas of the Mississippi, April – September, 1995. Science of the Total Environment 48: 227 - 240.

Crop Life America, 2003. Insecticide Use-Mississippi. (URL address: http://www.croplifeamerica.org/public/issues/fqpa/index.html).

CSE. 2003. Analysis of pesticide residues in soft drinks. Centre for Science and Environment, Pollution Monitoring Laboratory, New Delhi, India. (URL address: http://www.cseindia.org/html/cola-indepth/softdrinks_report.pdf)

Gilliom, R.J., J.E. Barbash, D.W. Kolpin, and S.J. Larson. 1999. Testing Water Quality for Pesticide Pollution. Environmental Science and Technology 33(7):164 A-169 A.

Kidd, H. and D.R. James, Eds. 1991. The Agrochemicals Handbook, Third Edition. Royal Society of Chemistry Information Services, Cambridge, UK, pp.2-13.

Lyon, L. 1996. Pesticide Impacts. Endangered species Bulletin 21(2): Organic Consumer Association. 2003. EU bands toxic atrazine herbicide still widely used in US corn belt. (URL address: http://www.organicconsumers.org/foodsafety/atrazine102703.cfm).

Moses, M. 1995. Home Pesticide Use and Storage in Sarasota County, Florida, Pesticide Education Center, November 24, 1995, p. 11.

University of California Berkeley. 2002. UC Berkeley Media Relations Press Release. 04 April 2002.

Smith, S., Jr., R.F. Cullum, and J.D. Schreiber. 1994. Pesticides in runoff and shallow groundwater from upland corn production in north Mississippi, USA. Second International Conf. on Groundwater Ecology. TSP94-1. Jack Stanford & Maurice Vallett (eds.). AWRA, Herdon, VA. Pp.247-258.

Tvedten, S. 2001. Pesticide Exposure During Pregnancy. Get Set Inc. 4pp. (URL address: www.getipm.com)

U.S. Census Bureau. 2002. Mississippi: 2000 summary population and housing characteristics. 2000 census of population and housing. PHC-1-26. United States Department of Commerce. 321 pp.

U.S. Department of Agriculture. 2002. Census of Agriculture. Preliminary Report AC-02-A-PR, pp. 73-75.

U.S. Environmental Protection Agency. 1996. "EPA Considers Suspending Pesticide Used in Illicit Spraying in South," Inside EPA, November 29, 1996.

U.S. Environmental Protection Agency. 1997a. National Home and Garden Pesticide Use Survey, March 1992, p. 6.

U.S. Environmental Protection Agency. 1997b. ibid, p. 16.

U.S. Environmental Protection Agency. 1997c. ibid, p. 9.

U.S. Environmental Protection Agency. 1997d. ibid, p. 12.

U.S. EPA. 2001. About pesticides. 1998-1999 pesticide market estimates: usage. Section: 3.1-3.10. URL address: http://www.epa.gov/oppbead1/pestsales/99pestsales/usage1999_4.html.

ACKNOWLEGEMENTS

Recognition is given to MDEQ staff who braved the elements to obtain these samples, including; Emily Cotton, Ann-Marie Denman, Barbara Viskup, D. Barnes, Al Gibson, Jenny Ulmer, Alice Dossett, Otis Clark, Charles Thompson, Will Green, Mike Beiser and Chip Bray. Alisa Liggins, Amanda White, Michelle Burns, (MDEQ), Charles Bryant, Terry Welch and Sam Testa (NSL) assisted with sample routing and delivery. Jennifer Swint meticulously handled sample extraction and cataloguing at the NSL. Sam Testa assisted with data analysis.

AGNPS Runoff Model: Geospatial Applications and Predictions in the Upper Pearl River Basin.

M.L. Tagert[1], D.R. Shaw[1], J.H. Massey[2], R.L. Bingner[3], and M.C. Smith[2]. [1]GeoResources Institute, Mississippi State University, Mississippi State, MS 39762; [2]Department of Plant and Soil Sciences, Mississippi State University, Mississippi State, MS 39762; [3]USDA-ARS National Sedimentation Laboratory, Oxford, MS 38655.

The Upper Pearl River Basin (UPRB) drains into the Ross Barnett Reservoir, which is the largest of Mississippi's three surface drinking water sources and supplies approximately 90% of the City of Jackson's drinking water. Thus, the UPRB is an area of particular interest with respect to water quality and the establishment of Total Maximum Daily Loads (TMDLs). The USDA Agricultural Nonpoint Source (AGNPS) runoff pollution model, in combination with geographical information systems and remote sensing, is being used to predict water, sediment, and pesticide nonpoint source runoff in the UPRB. GIS software was used to process a digital soils layer, digital elevation models (DEM), digital land cover from Landsat satellite imagery, and other inputs to the AGNPS model. The digital soils information was obtained from the USDA-NRCS State Soil Geographic Database (STATSGO) at a scale of 1:250,000, and the DEMs are from the USGS National Elevation Dataset (NED). The TopAGNPS module of AGNPS, using the DEM as the main input, performed a topographic evaluation of the watershed as well as drainage area identification, synthetic channel networks, watershed segmentation, and subcatchment parameters. AGNPS model predictions for sediment and pesticide runoff in a Mississippi watershed are being compared to water and sediment samples taken at seven USGS-gauged locations within the watershed. Samples were collected weekly from May-August 2002 and monthly thereafter through May 2003. The samples were analyzed for fifteen different pesticides using a multi-residue method. Fluometuron and diuron were analyzed by high performance liquid chromatography – ultraviolet (HPLC-UV), while tebuthiuron, simazine, atrazine, cyanazine, metribuzin, alachlor, metolachlor, pendimethalin, p,p'-DDE, norflurazon, and hexazinone were analyzed by gas chromatography – mass spectrometry (GCMS). Triclopyr and 2,4-D were derivatized and then analyzed by GCMS. Metolachlor was detected in 47 out of 77 samples, followed by tebuthiuron with 45 detections and atrazine with 35 detections. Hexazinone was also frequently detected. The highest concentrations detected were 1.05 ppb for 2,4-D, followed by 0.67 ppb for triclopyr and 0.62 ppb for diuron. The detected concentrations were all below current lifetime health advisory levels (HAL) established by the EPA for each compound. The pesticide concentration and water flow measurements are being used to estimate pesticide loads as a function of land use in the UPRB. In turn, these results are being compared with pesticide loads predicted by AGNPS based on remotely sensed land use patterns.

Keywords: Management and Planning, Water Quality, Water Supply
Poster
Presenter: Mary Love Tagert, Extension Associate, GeoResources Institute at Mississippi State University
Address: Box 9652
Mississippi State, MS 39762
Graduate Student: Plant and Soil Sciences

THE DEMONSTRATION EROSION CONTROL PROJECT: ASPECTS OF WATER QUALITY IN ABIACA CREEK, MISSISSIPPI

C. M. Cooper, R. E. Lizotte, Jr., S. S. Knight, and M. T. Moore
United States Department of Agriculture, Agricultural Research Service
National Sedimentation Laboratory, Oxford, Mississippi

ABSTRACT

Landscape-scale stream channel erosion and ensuing incision in north Mississippi hill lands have been responsible for loss of arable land and degradation of aquatic habitats and water quality. Because of this, in 1983, Congress mandated a federal interagency demonstration project focusing on channel erosion in the upper Yazoo River drainage basin. As part of the Demonstration Erosion Control project (DEC), water quality in Abiaca Creek and six additional watersheds are routinely monitored to observe potential improvements after channel stabilization / flood control / rehabilitation technologies were implemented. Abiaca Creek watershed, located in portions of Caroll, Holmes, and Leflore Counties, Mississippi, is part of the upper Yazoo River drainage basin in north Mississippi and flows through Matthews Brake National Wildlife Refuge (MBNWR). From 1993-1996 setback levees were constructed along the lower reach of Abiaca Creek to mitigate sedimentation within MBNWR. The purpose of this study was to examine selected water quality parameters both spatially and temporally in Abiaca Creek using univariate and multivariate analyses to elucidate trends. The watershed was monitored monthly at eight sites from 1992-2002 for 14 water quality parameters. Results of spatial univariate analysis showed significant differences among sites for 13 of 14 water quality variables, whereas temporal analysis revealed differences among years for 12 of 14 variables. Exploratory multivariate analysis revealed spatial trends in water quality with upstream sites having overall better water quality than downstream ones. Observed spatial trends in water quality are influenced by localized geographic characteristics (e.g. localized land use practices, gravel mining, flood control structures, etc.). Temporal results showed a greater complexity in annual water quality with trends less evident and most likely associated with fluctuations in annual climatic conditions. Changes in water quality were cumulative due to major watershed inputs with instream reservoirs resetting dissolved oxygen and ammonia levels.

INTRODUCTION

Stream channel instability and erosion due to cultivation and land-development practices in the north Mississippi hill-land region have presented water quality and habitat degradation problems at a landscape scale (Cooper, Knight and Shields 1997). As a result, in-stream suspended sediments and bedload materials are, by volume, one of the largest pollutants in the United States (Fowler and Heady 1981). Agricultural lands are a significant source of sediments and cause concern for several reasons. They indicate the loss of productive agricultural soil, carry nutrients and pesticides that can adversely affect water quality and aquatic organisms, and degrade habitats via deposition and accumulation in streams and reservoirs (Cooper and Knight 1991).

Because of this, in 1983, Congress mandated a federal interagency demonstration project focusing on channel erosion in the north Mississippi hill land region that compose the upper Yazoo River drainage basin. In 1984, the U.S. Army Corps of Engineers, Vicksburg District and the USDA Natural Resources Conservation Service were directed to establish demonstration watersheds addressing critical erosion problems within the north Mississippi hill lands and develop measures to control flooding, reduce erosion, and stabilize stream channels (Cooper and Knight 1991; Lizotte et al. 2003a). As part of the Demonstration Erosion Control project (DEC), the USDA-ARS National Sedimentation Laboratory was requested by the U.S. Army Corps of Engineers, Vicksburg District to characterize and routinely monitor water quality in seven watersheds to assess potential improvements after flood control, rehabilitation, and channel stabilization, technologies were implemented.

Abiaca Creek, while not originally part of the DEC project (being authorized by the Energy and Water Development Appropriation Act of 1990), has similar goals as those for other DEC watersheds and has become integrated within the DEC project. Historically, the watershed has had problems of stream channel instability, erosion, habitat degradation, and loss of valuable agricultural topsoil. From 1993 to 1996, setback levees were constructed along the lower reach of Abiaca Creek to mitigate sediment deposition within Matthews Brake National Wildlife Refuge (MBNWR) caused by upstream gravel mining operations (Cooper and Davis 2000).

The purpose of this study was to examine and describe selected water quality parameters both spatially and temporally in Abiaca Creek to elucidate trends.

MATERIALS AND METHODS

Study Site

Abiaca Creek watershed (Fig. 1), a tributary of the Yazoo River, has a drainage area of approximately 246 km^2 (Cooper and Davis 2000). The watershed, located in portions of Caroll, Holmes, and Leflore Counties, Mississippi, is part of the upper Yazoo River drainage basin in the north Mississippi hill-land region and flows through MBNWR.

Sample Collection and Analysis

Surface water samples (1 L) from Abiaca Creek were collected and preserved (via ice) monthly. *In-situ* water chemistry measurements of temperature, conductivity, dissolved oxygen, and pH were conducted at each site using calibrated electronic instruments.

Aqueous samples were transported to the USDA-ARS National Sedimentation Laboratory, Oxford, Mississippi for further physical, chemical and biological analyses. Selected water parameters measured were total solids, dissolved solids (dried at 180° C), suspended solids (dried at 103-105° C), total ammonium-N (phenate method), total nitrate-N (cadmium reduction method), soluble (filterable) phosphorus (ascorbic acid), total phosphorus (persulfate digestion + ascorbic acid), chlorophyll *a* (pigment extraction and spectrophotometric determination), fecal coliforms (membrane filter technique), and enterococci (membrane filter technique). All water quality parameters were analyzed using standard methods (APHA, 1998).

Data Analysis

Descriptive statistics were used to provide means and standard deviations for all water quality parameters measured. Univariate analysis was conducted using a one-way analysis of variance (ANOVA) with Tukey's multiple range tests to ascertain significant differences among sites (spatial) and years (temporal) within Abiaca Creek for all water quality parameters (Steel, Torrie, and Dickey 1997). When assumptions for parametric tests (normality and equal variance) could not be met, a nonparametric Kruskal-Wallis ANOVA on ranks with Dunn's multiple range tests was performed to test for significance (Steel, Torrie, and Dickey 1997). Parameters were tested for significance at the 5% level. All univariate statistical analyses were completed using SigmaStat statistical software (SPSS 1997).

Multivariate exploratory analysis was performed using a principal components analysis on spatial and temporal data. Matrices of Pearson's product-moment correlation coefficients were computed and distance coefficients were derived for standardized water quality variables. A matrix of correlations among water quality variables was computed and the first two principal components extracted (Berenson, Levine, and Goldstein 1983). All multivariate statistical analyses were completed using the Numerical Taxonomy System of programs (NTSYS-pc; Rohlf 1990).

RESULTS AND DISCUSSION

Spatial Analysis

Complete description of all water quality parameters measured at each site in Abiaca Creek watershed appears in Table 1. Univariate analysis revealed significant differences for 13 of 14 water quality variables. Only temperature did not significantly vary among the eight sites examined. Temperatures were comparable to other north Mississippi hill land streams previously reported (Cooper and Knight 1991; Cooper, Knight, and Shields 1997; Lizotte et al. 2002a). Values followed seasonal fluctuations typical of temperate-zone streams and were within the range to support aquatic life (Cole 1988; Allen 1995).

Conductivity measurements and related total dissolved solids (the total concentration of soluble ions) varied by site and showed similar patterns of variation. Upstream sites in both Abiaca and Coila Creeks had lower mean values than successive downstream sites (Table 1). Although differences in these two parameters were evident among sites within the watershed, values were within the range of those previously reported for other north Mississippi hill land watersheds (Cooper and Knight 1991; Cooper, Knight and Shields 1997; Lizotte et al. 2002a) and were well within the limits to support aquatic life (Allen 1995).

Dissolved oxygen is a fundamental environmental requirement for most aquatic life and its availability determines the behavior and distribution of most aquatic organisms (Abel 2000). Oxygen levels within Abiaca watershed rarely dropped below 4 mg/L, a long-term critical concentration considered necessary to support aquatic life (USEPA 1987). Levels followed seasonal fluctuations typical of temperate-zone streams (Fig. 2). Variation in mean dissolved oxygen levels were greatest at downstream sites (1, 2, and 6) and lowest at sites 4 and 8 (Table 1) revealing influences of flood retarding structures and ensuing outflow from reservoirs Y34-8 and Y34-6 (Fig. 1).

Values for pH also varied along stream length with downstream sites typically having greater mean pH than upstream ones (Table 1). Most pH values ranged from 5.5 to 8.0 (Fig. 2). Watersheds within the north Mississippi hill land region typically have acidic stream water (Cooper and Knight 1991; Cooper, Knight and Shields 1997; Lizotte et al. 2002a) due, in part, to runoff of acidic top soils (Switzer and Pettry 1992; Eick, Brady and Lynch 1999) during storm events. However, sites 1 and 2, encompassing that portion of Abiaca Creek flowing through MBNWR, had mean pH values above 7 and ranging from about 6 to 8 (Table 1). Two factors led to more basic pH at sites 1 and 2. The stream flowed through alluvial plain soil that has a higher pH. Also, as water flow slowed from a drastic reduction in slope, it received much additional sunlight. The resulting increase in phytoplankton (increasing chlorophyll concentrations) removed H+ ions and, as is typical in unbuffered waters, shifted pH toward basic.

Particulate materials entering streams and rivers as total solids and its constituent, total suspended solids (TSS) are considered a major contaminant of water bodies in the U.S. (Cooper 1993). Suspended sediments in rivers and streams affect water quality (Angino and O'Brien 1968), and, as a result, aquatic life. Water quality impacts from sediment loading can include obstruction of light penetration and ensuing reduction in photosynthetic activity, increased loading of pesticides and nutrients adsorbed to sediment surfaces, and increases in bacterial contamination (Cooper and Knight 1989; Knight and Cooper 1996). Abiaca Creek watershed is located in a physiographic region with highly erodable soils and accelerated erosion due to agricultural practices, stream channel modification or replacement, and land-use development (Shields, Knight, and Cooper 1998). In the present study, significant differences in TSS were observed across sites. In general, upstream sites in both Abiaca and Coila Creeks had lower mean values than successive downstream sites (Table 1). Mean values ranged from 34 to 107 mg/L with most values between 10-100 mg/L (Fig. 2) and maximum values between 362-1833 mg/L (Table 1). Maximal TSS concentrations considered optimal for warm water fish production is estimated at 80-100 mg/L (Cooper and Knight 1991). Although maximum values observed in Abiaca Creek watershed exceeded this limit, concentrations typically occurred during high flows associated with storm events and were not sustained over long periods of time. Comparisons of TSS values with other watersheds in the same physiographic region were similar (Cooper and Knight 1991; Cooper, Knight and Shields 1997; Lizotte et al. 2002a).

In-stream nutrient concentrations are an integral part of stream ecosystem productivity. Excessive inputs from anthropogenic sources can alter trophic state and lead to significant eutrophication (Dodds 2002). Phosphorus, frequently a limiting factor of primary productivity in nutrient poor freshwater systems (Cole 1988; Allen 1995), can affect periphytic autotrophs that are especially sensitive to fluctuations in soluble reactive phosphorus concentrations and excessive levels can lead to nuisance algal blooms, associated depleted dissolved oxygen concentrations, degradation of habitat, and reduction in fish diversity (Allen 1995; Abel 2000). Within Abiaca Creek, both soluble phosphorus (SP) and total phosphorus (TP) mean concentrations varied significantly along stream length with downstream sites typically having greater phosphorus than upstream sites (Table 1; Fig. 3). Similar spatial patterns in TSS concentrations show the close association of phosphorus and sediment load. Mean SP concentrations ranged from 11 μg/L to 27 μg/L with the highest observed concentration of 329 μg/L occurring at site 6, just upstream of the Coila Creek – Abiaca Creek confluence (Fig. 1). Mean TP concentrations ranged from 63 μg/L to 175 μg/L with the highest observed concentration of 2,463 μg/L occurring at site 8, just downstream of flood control reservoir Y34-6 along Coila Creek (Fig. 1). However, phosphorus concentrations did not attain levels sufficient to cause oxygen depleting algal blooms. Abiaca Creek phosphorus levels were comparable with other north Mississippi hill land streams such as Otoucalofa Creek (Cooper and Knight 1991; Cooper, Knight and Shields 1997), Long Creek (Cooper and Knight 1991), and Toby Tubby Creek (Lizotte et al. 2002a).

Nitrogen, measured as dissolved inorganic nitrogen species ammonium-ion and nitrate, can, to a lesser extent than phosphorus, also be a limiting nutrient in lotic systems. Like phosphorus, neither nitrogen species reached sustained levels that would lead to eutrophication. Ammonium-ion concentrations in Abiaca Creek ranged from 70 μg/L to 149 μg/L and significantly varied by site. Levels were lowest at downstream sites (1, 2, and 6) and highest at sites 4 and 8 (Table 1; Fig. 4). Concentrations revealed influences of flood retarding structures and ensuing outflow from reservoirs Y34-8 and Y34-6 (Fig. 1) and were inverse to dissolved oxygen levels. Mean nitrate concentrations ranged from 150 μg/L (at site 5) to 226 μg/L (at site 7) with the highest observed concentration of 2,934 μg/L occurring at site 6, just upstream of the Coila Creek – Abiaca Creek confluence (Fig. 1). Although mean nitrate concentrations varied by site, no clear spatial trends were evident. Comparable ammonium-ion and nitrate concentrations occurred in other streams within the same physiographic region (Cooper and Knight 1991; Cooper, Knight and Shields 1997; Lizotte et al. 2002a).

Sestonic (suspended) chlorophyll *a*, an indirect measure of stream algal biomass (Jones, Smart and Burroughs 1984; Gregor and Marsalek 2004), can be used in conjunction with nutrient data to assess the trophic state of a lotic system (Dodds, Jones and Welch 1998; Dodds 2002). Excessive stream algal biomass (algal blooms) due to increases in nutrients (eutrophication) can have negative impacts on the lotic ecosystem such as alteration of habitat, depressed dissolved oxygen levels, discoloration of the water, and production of toxins harmful to other aquatic biota (Abel 2000). Abiaca Creek mean chlorophyll *a* concentrations varied significantly along stream length with downstream sites typically having greater chlorophyll *a* levels than upstream sites (Table 1; Fig. 3), in close association with mean total phosphorus (and to a lesser extent soluble phosphorus) suggesting phosphorus is the limiting nutrient in this system. Comparable chlorophyll *a* values occur within similar watersheds throughout the region (Lizotte et al. 2002b; Lizotte et al. 2003a; Lizotte et al. 2003b).

Stream watershed contamination by bacteria has been a continuing concern throughout the United States for several decades (Bohn and Buckhouse 1985; Cooper and Lipe 1992). Sources of bacteriological contamination are difficult to pinpoint due to the various routes through which they can enter a system, including discharge from a wastewater treatment facility, direct runoff from storm events, groundwater flow, resuspension of bottom sediments within the watershed channel by stream flow or animal disturbance, and direct contamination from animal defecation (Bohn and Buckhouse 1985; Cooper and McDowell 1989; George, Anzil and Servais 2004; Muirhead et al. 2004). In general, downstream sites had greater densities than upstream ones (Table 1; Fig.4) with the exception of fecal coliforms at site 3 (4000 colonies/100 ml) and enterococci at site 5 (655 colonies/100 ml). Bacteriological contamination observed in Abiaca Creek was similar to other north Mississippi hill land streams such as Otoucalofa Creek (Cooper and Knight 1991; Cooper, Knight and Shields 1997), Long Creek (Knight and Cooper 1989; Cooper and Knight 1991), Toby Tubby Creek, and Burney Branch Creek (Lizotte et al. 2002a).

Exploratory Principal Component Analysis (PCA), used to elucidate spatial water quality trends in Abiaca Creek, showed component I incorporating 64% of the total water quality variation. The first component had high loadings for 11 of 13 variables examined and revealed spatial trends in conductivity, pH, solids, phosphorus, and biologicals with upstream sites having overall progressively better water quality than downstream ones (Fig 5). The second component accounted for 16.5% of the total variation. Component II had a high positive loading for dissolved oxygen and a high negative loading for ammonium-N. This confirmed our observations on the influences of flood retarding structures and ensuing outflow from reservoirs Y34-8 (site 4) and Y34-6 (site 8) where dissolved oxygen levels were lowest and ammonium-ion levels greatest (Fig. 5). Other studies observed PCA to be very useful in elucidating spatial water quality trends when examining multiple parameters simultaneously (Pardo 1994; Cao, Williams and Williams 1999). Pardo (1994) noted that the use of PCA allowed a better explanation of factors influencing the dynamics of water quality within a watershed.

Temporal Analysis

Complete description of all water quality parameters measured for each year in Abiaca Creek watershed appears in Table 2. Univariate analysis revealed significant differences for 12 of 14 water quality variables. Only temperature and conductivity did not significantly vary among the eleven years examined (1992-2002).

Dissolved oxygen concentrations varied by year with 1994 having significantly greater mean dissolved oxygen levels than all other years. Dissolved oxygen levels below the critical limit of 4 mg/L occurred in only 3 of 11 years (1994, 1996, 1998; Table 2) although only 1996 had mean monthly levels below the critical limit for all sites (Fig. 2). As a result, sustained values below 4 mg/L were not evident throughout the watershed. Cooper and Knight (1991) described 2-year seasonal dissolved oxygen trends in Otoucalofa and Long Creeks that were similar to this study. Long-term (10-year +) trends in Otoucalofa Creek dissolved oxygen concentrations produced similar yearly effects observed in Abiaca Creek (Cooper, Knight and Shields 1997).

Variation in Abiaca Creek mean pH values across years showed a four to five-year cycle in this parameter. Lowest mean pH occurred in 1992 and progressively increased each year until 1995. Values declined again in 1997 and, again, progressively increased until 1998 before progressively declining until 2002 (Table 2). Yearly fluctuations in Otoucalofa Creek (another north Mississippi hill land stream) were evident, however a similar pattern in annual pH variations was not (Cooper, Knight and Shields 1997). Aquatic organisms can be sensitive to even small changes in pH and levels between 5 and 9 generally support a diversity of biota (Allen 1995; Abel 2000). The lowest and highest pH values recorded in Abiaca Creek, 5.3 (2000 and 2002) and 8.37 (1995), are within the critical pH range with fluctuations in mean monthly pH consistently between 6 and 8 (Fig 2).

Total solids and its constituent, total suspended solids (TSS) had significant but limited annual variation with 1993 and 2002 having the lowest mean annual TSS and 1996 the highest (Table 2). Highest TSS concentrations considered optimal for warm water fish diversity is estimated at 80 to 100 mg/L (Cooper and Knight 1991). Mean monthly maximum values observed in Abiaca Creek watershed occasionally exceeded this limit (Fig. 2). These increased concentrations typically occurred during high flows associated with storm events or during gravel mining operations and were not sustained over long periods of time with the exception of site 1 during 1996 when significant levee construction occurred along MBNWR (Cooper and Davis 2000). Long-term TSS concentrations produced no discernable increasing or decreasing trends. Values for the 11-year period appeared relatively stable and were similar to long-term trends observed in Otoucalofa Creek (Lizotte et al. 2003a).

All nutrient species examined in Abiaca Creek watershed showed significant annual variation. Although levels of the two measured phosphorus species fluctuated yearly, no clear trend was evident. Mean SP concentrations in 1994 were greater than all other years whereas mean TP levels in 1999 were lowest for the 11 year period (Table 2). Fluctuations in long-term trends of mean monthly total phosphorus levels in Abiaca Creek (Fig. 3) were similar to another north Mississippi hill land stream, Otoucalofa Creek (Lizotte et al. 2003a). However, higher TP levels were sustained at site 1 during 1996 (Fig. 3) when significant levee construction occurred along MBNWR (Cooper and Davis 2000). As with phosphorus, the two nitrogen species studied, ammonium-N and nitrate-N fluctuated annually, but, again, no clear trend was evident. Levels of ammonium-N in Abiaca Creek during 1999 and 2002 were less than all other years with mean concentrations of 59 and

38 μg/L, respectively (Table 2). Nitrate levels within the watershed significantly increased in 1998, peaked in 1999, and returned to previous levels by 2000 (Table 2; Fig. 4). Seasonal trends in aqueous nitrogen species levels within watersheds in regions of intensive agriculture typically show increases in the fall and winter followed by decreases in spring and summer (Shirmohammadi, Yoon and Magette 1997; Bouraoui, Turpin and Boerlen 1999). Although significant portions of the Yazoo basin are intensively farmed, seasonal trends in ammonium-N and nitrate-N concentrations in Abiaca Creek watershed (Fig. 4) are not indicative of impacts from intensive agricultural practices.

Annual variations in mean chlorophyll *a* concentrations within Abiaca Creek watershed were evident. Mean concentrations were lowest during 1992 (3.87 μg/L) and highest in 1998 (14.84 μg/L) with an overall trend of increasing chlorophyll *a* levels from 1992 to 2002 (Table 2) but not in association with any annual nutrient values. Mean monthly values indicate general seasonal trends with increases during spring and summer followed by decreases during fall and winter (Fig 3). Similar temporal trends in chlorophyll *a* concentrations was observed by Lizotte et al. (2003b) for Otoucalofa Creek in the Yazoo basin. Possible explanations, aside from nutrients, for the overall increase in chlorophyll *a* levels annually include possible reservoir aging and reduction in canopy cover, the influence of flood control structures (i.e. setback levees along MBNWR) altering flows and allowing for more stable habitat, and improved control and mitigation of urban and rural pesticide runoff, specifically herbicides, allowing an increase in primary productivity.

Yearly changes in bacterial contamination were evident within Abiaca Creek watershed. Variation in fecal coliform densities across years showed 1992 had the lowest mean density and 1994 the highest (Table 2). Mean monthly fecal coliform densities failed to produce any seasonal trends (Fig. 4) and suggest the source of contamination could be primarily wildlife. Annual variation in enterococci densities showed 1995 had the lowest mean density and 2001 the highest. Mean densities were generally lower from 1992 to 1996 and increased from 1997 to 2002. While both runoff and increasing discharge levels with associated suspended solids flush regions in and around the watershed where wildlife and livestock may defecate, neither bacterial contaminant measured coincided with suspended solids levels and is similar to results observed in similar watersheds by Cooper and Knight (1991).

Exploratory PCA was conducted to elucidate temporal water quality trends in Abiaca Creek watershed. Analysis showed the first three components incorporating just 66.3% of the total water quality variation. The first principal component accounted for 29.9% of the total water quality variation. It had high positive loadings for 5 of 12 parameters and revealed temporal trends in TS, TSS, TP, ammonium-N, and fecal coliform levels with fluctuations every 1 to 2 years (Fig. 5). Principal component II accounted for 18.5% of the total variation and had high loadings for TS, TSS, and SP with fluctuations cycling every 5 to 6 years (Fig. 5). The third principal component accounted for 17.9% of the total variation in water quality and loaded high for dissolved oxygen and fluctuated every 2 years (Fig. 5).

SUMMARY

Spatial water quality trends in Abiaca Creek watershed changed longitudinally from upstream to downstream with upstream sites having overall better water quality than downstream ones. Dissolved oxygen and ammonium-N levels were influenced by localized flood control structures. Overall water quality was also influenced by local geographic characteristics such as land-use practices, gravel mining operations and flood control structures. Temporal water quality trends were increasingly complex and had varying cyclic fluctuations varying from 1 to 5 years for various water quality parameters. Temporal trends were influenced by climatic conditions and varying localized events such as changes in land-use practices, gravel mining operations, and construction of setback levees along MBNWR.

ACKNOWLEDGMENTS

Appreciation is extended to the many students at the University of Mississippi and personnel at the USDA-ARS National Sedimentation Laboratory for providing technical assistance. The authors wish to thank Sam Testa, Robert Cullum, and Carol Britson for providing helpful comments. This research was funded, in part,

by the United States Army Corps of Engineers, Vicksburg District.

LITERATURE CITED

Abel, P. D. 2000. Water Pollution Biology. Philadelphia: Taylor and Francis Ltd.

Allen, J. David. 1995. Stream Ecology: Structure and Function of Running Waters. New York: Chapman & Hall.

American Public Health Association. 1998. Standard Methods for the Examination of Water and Wastewater. 20th ed. Washington DC: American Public Health Association.

Angino, E. D. and W. J. O'Brien. 1968. Effects of suspended material on water quality. International Association of Scientific Hydrology. 78:120:28.

Berenson, M. L., D. M. Levine, and M. Goldstein. 1983. Intermediate Statistical Methods and Applications: A Computer Package Approach. New Jersey: Prentice-Hall, Inc.

Bohn, C. C. and J. C. Buckhouse. 1985. Coliforms as an indicator of water quality in wildland streams. Journal of Soil and Water Conservation. 32:226:30.

Bouraoui, F., N. Turpin, and P. Boerlen. 1999. Trend analysis of nutrient concentrations and loads in surface water in an intensively fertilized watershed. Journal of Environmental Quality. 28:1878:85.

Cao, C., D. D. Williams, and N. W. Williams. 1999. Data transformation and standardization in the multivariate analysis of river water quality. Ecological Applications. 9:669:77.

Cole, Gerald A. 1988. Textbook of Limnology. Prospect Heights: Waveland Press, Inc.

Cooper, Charles M. 1993. Biological effects of agriculturally derived surface water pollutants on aquatic systems – a review. Journal of Environmental Quality. 22:402:408.

Cooper, C. M. and S. A. Davis. 2000. Vegetation Survey of a Restored Floodplain in Northern Mississippi, USA. Oxford: USDA-ARS NSL Research Report No. 33.

Cooper, C. M. and S. S. Knight. 1989. Bacterial contamination in two agrarian hill land streams in northern Mississippi, USA. International Journal of Ecology and Environmental Science. 15:85:96.

Cooper, C. M. and S. S. Knight. 1991. Water quality cycles in two hill land streams subjected to natural, municipal, and non-point agricultural stresses in the Yazoo Basin of Mississippi, USA (1985-1987). Verhandlungen Internationale Vereinigung Für Theoretische Und Angewandte Limnologie. 24:1654:63.

Cooper, C. M. and W. M. Lipe. 1992. Water quality and agriculture: Mississippi experiences. Journal of Soil and Water Conservation. 47:220:23.

Cooper, C. M. and L. L. McDowell. 1989. Bacterial contamination in streams and lakes of the Mississippi River delta. Environment & Ecology. 7:169:77.

Cooper, C. M., S. S. Knight, and F. D. Shields, Jr. 1997. The demonstration erosion control project: water quality in incised streams. In Proceedings of the Conference on Management of Landscapes Disturbed by Channel Incision, May 19-23, 1997, by the Center for Computational Hydroscience and Engineering: The University of Mississippi, 1025-1028.

Dodds, W. K. 2002. Freshwater Ecology: Concepts and Environmental Applications. San Diego: Academic Press.

Dodds, W. K., J. R. Jones, and E. B. Welch. 1998. Suggested classification of stream trophic state: distributions of temperate stream types by chlorophyll, total nitrogen, and phosphorus. Water Research. 32:1455:62.

Eick, M. J., W. D. Brady, and C. K. Lynch. 1999. Charge properties and nitrate adsorption of some acidic southeastern soils. Journal of Environmental Quality. 28:138:44.

Fowler, J. M. and E. O. Heady. 1981. Suspended sediment production potential on undisturbed forest land. Journal of Soil and Water Conservation. 36:47:9.

George, I., A. Anzil, and P. Servais. 2004. Quantification of fecal coliform inputs to aquatic systems through soil leaching. Water Research. 38:611:18.

Gregor, J. and B. Marsalek. 2004. Freshwater phytoplankton quantification by chlorophyll *a*: a comparative study of in vitro, in vivo and in situ methods. Water Research. 38:517:22.

Jones, J. R., M. M. Smart, and J. N. Burroughs. 1984. Factors related to algal biomass in Missouri Ozark streams. Verhandlungen Internationale Vereinigung Für Theoretische Und Angewandte Limnologie. 22:1867:75.

Knight, S. S. and C. M. Cooper. 1996. Insecticide and metal contamination of a mixed cover agricultural watershed. Water Science Technology. 33:227:34.

Lizotte, R. E., Jr., M. T. Moore, C. M. Cooper, and M. M. Holland. 2002a. Water quality under natural conditions: comparisons of urban, rural, and reference watersheds in north Mississippi. 2002 Proceedings of the Mississippi Water Resources Conference. 2002:107:16.

Lizotte, R. E., Jr., C. M. Cooper, J. T. Hill, M. M. Holland, M. T. Moore, and S. S. Knight. 2002b. Water Quality in Northern Mississippi Hill Land Streams in the Demonstration Erosion Control (DEC) Project: Calendar Year 2000. Oxford: USDA-ARS NSL Research Report No. 27.

Lizotte, R. E., Jr., M. T. Moore, C. M. Cooper, J. T. Hill, M. M. Holland, and S. S. Knight. 2003a. Water Quality in Northern Mississippi Hill Land Streams in the Demonstration Erosion Control (DEC) Project: Calendar Year 2001. Oxford: USDA-ARS NSL Research Report No. 35.

Lizotte, R. E., Jr., C. M. Cooper, A. T. Mikell, Jr., M. T. Moore, S. S. Knight, and J. T. Hill. 2003b. Water Quality in Northern Mississippi Hill Land Streams in the Demonstration Erosion Control (DEC) Project During Calendar Year 2002, With Emphasis on Chlorophyll. Oxford: USDA-ARS NSL Research Report No. 40.

Muirhead, R. W., R. J. Davies-Colley, A. M. Donnison, and J. W. Nagels. 2004. Faecal bacteria yields in artificial flood events: quantifying in-stream stores. Water Research. 38:1215:24.

Pardo, Isabel. 1994. Comparative water quality characterization by PCA of an unperturbed and a polluted stream. Archive Für Hydrobiologie. 132:95:114.

Rohlf, F. J. 1990. NTSYS-pc: Numerical Taxonomy and Multivariate Analysis System. Applied Biostatistics, Inc. v. 1.7.

Shields, F. D., S. S. Knight, and C. M. Cooper. 1998. Rehabilitation of aquatic habitats in warmwater streams damaged by channel incision in Mississippi. Hydrobiologia. 382:63:86.

Shirmohammadi, A., K. S. Yoon, and W. L. Magette. 1997. Water quality in mixed land-use watershed-Piedmont region in Maryland. Transactions of the American Society of Agricultural Engineers. 40:1563:72.

Statistical Package for the Social Sciences (SPSS), Inc. 1997. SigmaStat v. 2.03 for Windows. SPSS, Inc.

Steel, R. G. D., J. H. Torrie, and D. A. Dickey. 1997. Principles and Procedures of Statistics: A Biometric Approach. New York: McGraw-Hill, Inc.

Switzer, R. E. and D. E. Pettry. 1992. Phosphorus distribution in loessial fraguidalfs as affected by relief. Soil Science Society of America Journal. 56:849:56.

U. S. Environmental Protection Agency (USEPA). 1987. Quality Criteria for Water 1986. Washington DC: EPA 440/5-86-001.

Table 1. Descriptive statistics, mean±SD (range), of selected water quality parameters from 8 sites within Abiaca Creek watershed (1992-2002).

Water quality parameter	Abiaca Creek Site							
	1	2	3	4	5	6	7	8
Temperature (C)	18.7±7.4 (4.3-31.3)	18.5±7.1 (4.5-30.7)	18.3±6.1 (5.1-27.9)	18.7±6.1 (5.9-28.9)	18.3±5.9 (6.1-27.5)	19.3±6.3 (6.0-29.4)	18.0±3.5 (9.2-27.3)	19.5±6.7 (6.1-29.9)
Conductivity (μmhos/cm)	92.4±30.0 (20.2-170.0)	90.9±27.8 (18.6-164.0)	78.6±26.3 (16.0-138.0)	74.9±33.6 (15.9-164.5)	58.2±12.9 (5.0-91.0)	76.8±22.3 (14.0-124.0)	50.3±8.2 (9.0-85.0)	66.7±19.8 (16.3-114.0)
Dissolved oxygen (mg/L)	9.20±1.87 (3.45-14.47)	9.17±1.75 (3.79-14.38)	8.91±1.53 (3.06-13.35)	8.07±1.93 (3.82-12.45)	8.88±1.36 (5.66-12.65)	9.18±1.53 (4.80-12.91)	8.95±1.27 (4.35-11.82)	8.74±1.69 (3.30-13.06)
pH	7.34±0.57 (5.96-8.37)	7.22±0.51 (5.92-8.23)	6.93±0.53 (5.90-8.32)	6.64±0.49 (5.60-7.99)	6.95±0.54 (5.80-8.20)	6.93±0.48 (6.00-8.02)	6.50±0.59 (5.30-8.00)	6.77±0.52 (5.70-8.10)
Total solids (mg/L)	176±117 (73-698)	177±141 (74-1344)	135±88 (66-599)	123±77 (43-620)	109±161 (37-1379)	176±232 (58-1929)	88±62 (37-421)	117±72 (53-564)
Dissolved solids (mg/L)	77±22 (11-150)	78±21 (0-148)	70±20 (0-150)	65±19 (0-110)	57±17 (0-96)	69±18 (12-119)	55±21 (5-219)	63±17 (23-134)
Suspended solids (mg/L)	98±122 (0-631)	99±146 (0-1252)	64±97 (0-558)	58±82 (0-531)	53±164 (0-1321)	107±233 (0-1833)	34±55 (0-362)	53±77 (0-503)
Soluble phosphorus (μg/L)	27±21 (0-99)	22±25 (0-239)	17±26 (0-212)	11±16 (0-149)	11±13 (0-73)	18±33 (0-329)	13±19 (0-146)	15±21 (0-170)
Total phosphorus (μg/L)	175±146 (0-876)	166±144 (0-883)	142±120 (6-661)	123±117 (0-731)	94±120 (0-714)	179±248 (0-1475)	63±84 (0-475)	132±225 (7-2463)
Ammonium-N (μg/L)	84±97 (0-579)	88±95 (0-548)	97±115 (0-728)	149±124 (0-851)	90±106 (0-907)	80±81 (0-525)	70±107 (0-1007)	102±114 (0-939)
Nitrate-N (μg/L)	178±180 (0-1590)	164±147 (0-1430)	191±149 (0-1254)	203±212 (0-1656)	150±123 (0-611)	200±276 (0-2934)	226±286 (0-2158)	167±173 (0-1465)
Chlorophyll a (μg/L)	12.85±16.91 (0-91.89)	12.63±21.22 (0-122.39)	10.13±12.00 (0-77.77)	11.47±13.52 (0-73.97)	6.01±8.68 (0-43.50)	12.48±23.21 (0-216.90)	5.75±9.69 (0-77.09)	9.78±11.34 (0-68.26)
Fecal coliform (# colonies/100 ml)	2946±5373 (0-37600)	2610±5319 (0-31600)	4001±19506 (0-210000)	2518±6242 (0-55600)	1951±6121 (0-59000)	2344±6470 (0-64000)	1381±3893 (0-30800)	1130±1729 (0-11600)
Enterococci (# colonies/100 ml)	847±2078 (0-20800)	795±2299 (0-20000)	690±1953 (0-20000)	599±2038 (0-20000)	655±1256 (0-9000)	606±1970 (0-20000)	432±1161 (0-8560)	384±691 (0-4000)

Table 2. Descriptive statistics, mean±SD (range), of selected water quality parameters for 11 years (1992-2002) within Abiaca Creek watershed.

Water quality parameter	Year				
	1992	1993	1994	1995	1996
Temperature (C)	19.4±6.7 (4.3-30.7)	18.0±6.2 (6.5-28.9)	18.8±6.2 (6.6-30.1)	19.1±6.6 (6.6-20.3)	18.5±6.5 (7.2-30.4)
Conductivity (μmhos/cm)	76.5±28.5 (38.0-168.0)	77.4±31.0 (9.0-170.0)	67.9±22.3 (34.0-120.0)	76.5±26.0 (5.0-132.0)	70.9±27.9 (26.0-132.0)
Dissolved oxygen (mg/L)	8.69±1.68 (6.10-13.00)	8.74±1.22 (5.04-10.90)	9.48±1.57 (3.97-13.44)	9.25±1.47 (6.52-12.75)	8.41±2.18 (3.06-11.80)
pH	6.38±0.43 (5.58-7.90)	6.77±0.60 (5.56-8.16)	7.11±0.45 (5.85-8.03)	7.33±0.54 (6.05-8.37)	7.33±0.43 (6.46-8.32)
Total solids (mg/L)	120±56 (67-419)	130±87 (52-599)	135±99 (54-626)	112±108 (43-1037)	211±254 (48-1929)
Dissolved solids (mg/L)	71±18 (22-120)	84±24 (43-219)	65±15 (29-107)	67±20 (0-150)	60±23 (10-101)
Suspended solids (mg/L)	48±57 (0-351)	47±80 (0-524)	73±103 (0-554)	49±113 (0-983)	151±256 (0-1833)
Soluble phosphorus (μg/L)	14±12 (0-42)	20±20 (0-92)	35±18 (5-86)	10±8 (0-41)	12±10 (0-66)
Total phosphorus (μg/L)	143±169 (14-1475)	160±192 (18-1325)	163±155 (5-883)	104±95 (2-661)	175±206 (16-1475)
Ammonium-N (μg/L)	86±51 (1-305)	111±72 (5-441)	151±135 (24-1007)	101±59 (9-251)	112±116 (1-851)
Nitrate-N (μg/L)	119±46 (3-225)	204±187 (25-1430)	154±106 (9-921)	144±60 (5-343)	165±85 (25-616)
Chlorophyll a (μg/L)	3.87±3.87 (0.00-21.25)	5.97±7.17 (0.55-43.89)	6.76±6.33 (0.00-32.71)	10.89±15.02 (0.15-69.22)	4.78±4.21 (0.00-17.44)
Fecal coliform (# colonies/100 ml)	687±1253 (0-6720)	2471±4194 (0-20160)	5633±22782 (120-210000)	2020±2232 (20-11800)	3219±3084 (0-16000)
Enterococci (# colonies/100 ml)	467±1007 0-8560)	768±1302 (0-5760)	282±418 (0-2000)	111±150 (0-660)	268±337 (0-1400)

Table 2. Continued.

Water quality parameter	Year					
	1997	1998	1999	2000	2001	2002
Temperature (C)	18.3±5.6 (5.0-26.5)	19.7±6.1 (8.3-28.9)	18.5±6.3 (4.7-29.6)	19.3±5.6 (6.3-29.9)	18.2±6.1 (5.3-29.3)	17.8±6.9 (4.5-28.0)
Conductivity (µmhos/cm)	69.1±22.4 (35.0-125.0)	73.0±27.2 (30.0-146.1)	73.8±28.4 (20.9-132.0)	79.7±31.7 (19.9-164.5)	71.6±30.0 (15.9-136.1)	74.0±26.2 (34.0-137.1)
Dissolved oxygen (mg/L)	8.65±1.31 (5.30-12.40)	8.47±1.61 (3.82-11.20)	9.22±1.71 (5.19-12.30)	9.10±1.71 (5.52-14.47)	9.00±1.75 (4.44-12.80)	8.76±1.55 (4.63-12.71)
pH	6.64±0.40 (5.60-7.60)	7.04±0.54 (6.00-8.20)	7.18±0.34 (6.50-8.00)	6.87±0.66 (5.30-8.30)	6.79±.61 (5.50-8.30)	6.59±0.53 (5.30-7.60)
Total solids (mg/L)	133±112 (42-996)	126±62 (49-410)	126±74 (47-500)	185±238 (41-1379)	135±98 (37-724)	105±43 (48-337)
Dissolved solids (mg/L)	60±19 (11-104)	64±21 (0-110)	64±22 (12-148)	74±18 (28-115)	55±18 (8-96)	72±16 (34-112)
Suspended solids (mg/L)	73±112 (0-958)	57±60 (0-322)	61±75 (0-434)	111±238 (0-1321)	72±97 (0-646)	34±40 (0-256)
Soluble phosphorus (µg/L)	15±19 (0-97)	21±25 (0-155)	12±11 (0-48)	8±10 (0-56)	23±53 (0-329)	15±18 (0-99)
Total phosphorus (µg/L)	134±126 (0-706)	148±260 (23-2463)	44±37 (2-209)	130±148 (5-714)	143±141 (6-702)	119±116 (0-595)
Ammonium-N (µg/L)	77±62 (0-269)	112±134 (0-907)	59±149 (0-939)	115±109 (0-571)	88±92 (0-548)	38±92 (0-728)
Nitrate-N (µg/L)	227±367 (0-2934)	267±269 (12-1656)	355±364 (0-1961)	143±78 (17-408)	150±104 (1-795)	150±72 (12-437)
Chlorophyll a (µg/L)	13.65±14.74 (0.00-94.12)	14.84±21.34 (0.00-122.39)	11.18±18.07 (0.00-111.47)	14.75±27.65 0.00-216.90)	12.96±15.03 (0.00-119.40)	9.35±9.75 (0.00-53.48)
Fecal coliform (# colonies/100 ml)	972±1245 (0-7659)	2278±4020 (0-26500)	1120±3859 (0-29500)	2097±4949 (0-28000)	4351±13335 (0-64000)	1598±4952 (0-37600)
Enterococci (# colonies/100 ml)	506±584 (0-4000)	913±1714 (0-7200)	866±2650 (0-20800)	629±1130 (0-7600)	1437±4356 (0-20000)	734±883 (0-5100)

Figure 1. Sampling sites for Abiaca Creek watershed, Mississippi.

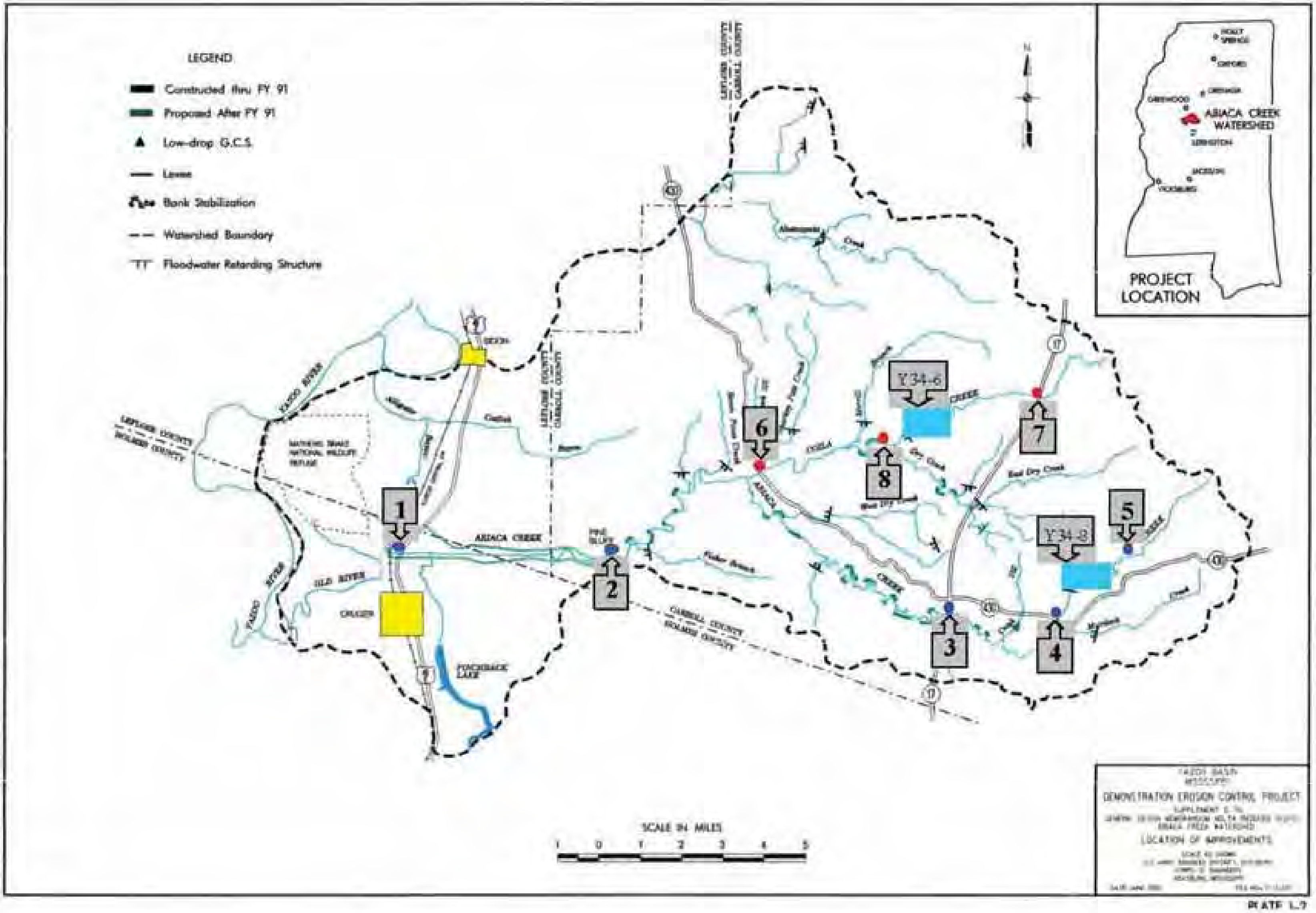


Figure 2. Monthly dissolved oxygen, pH, and suspended solids measurements for sites 1, 5, and all sites (mean) for Abiaca Creek watershed, Mississippi, from 1992-2002.

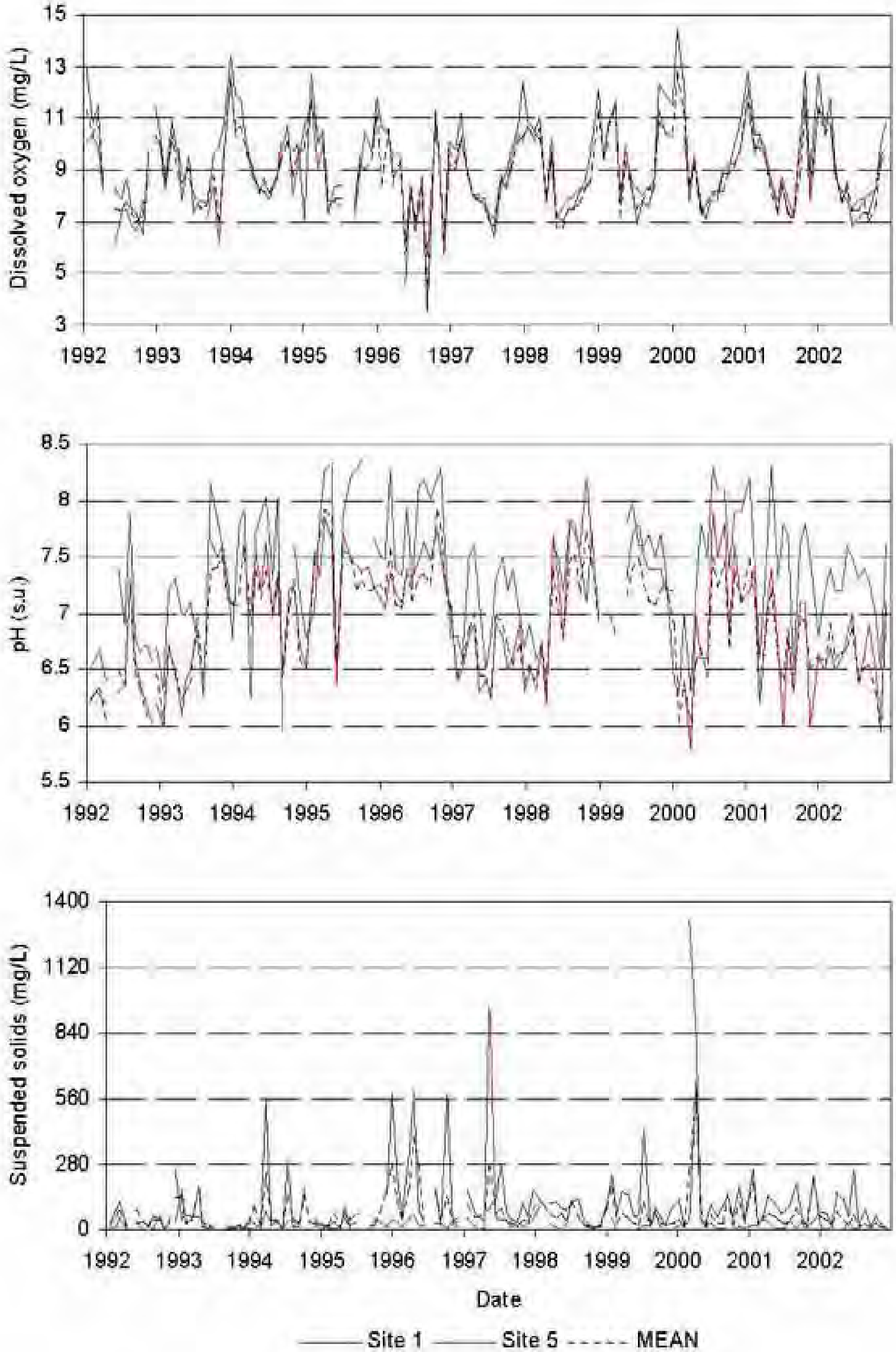


Figure 3. Monthly soluble phosphorus, total phosphorus, and chlorophyll *a* measurements for sites 1, 5, and all sites (mean) for Abiaca Creek watershed, Mississippi, from 1992-2002.

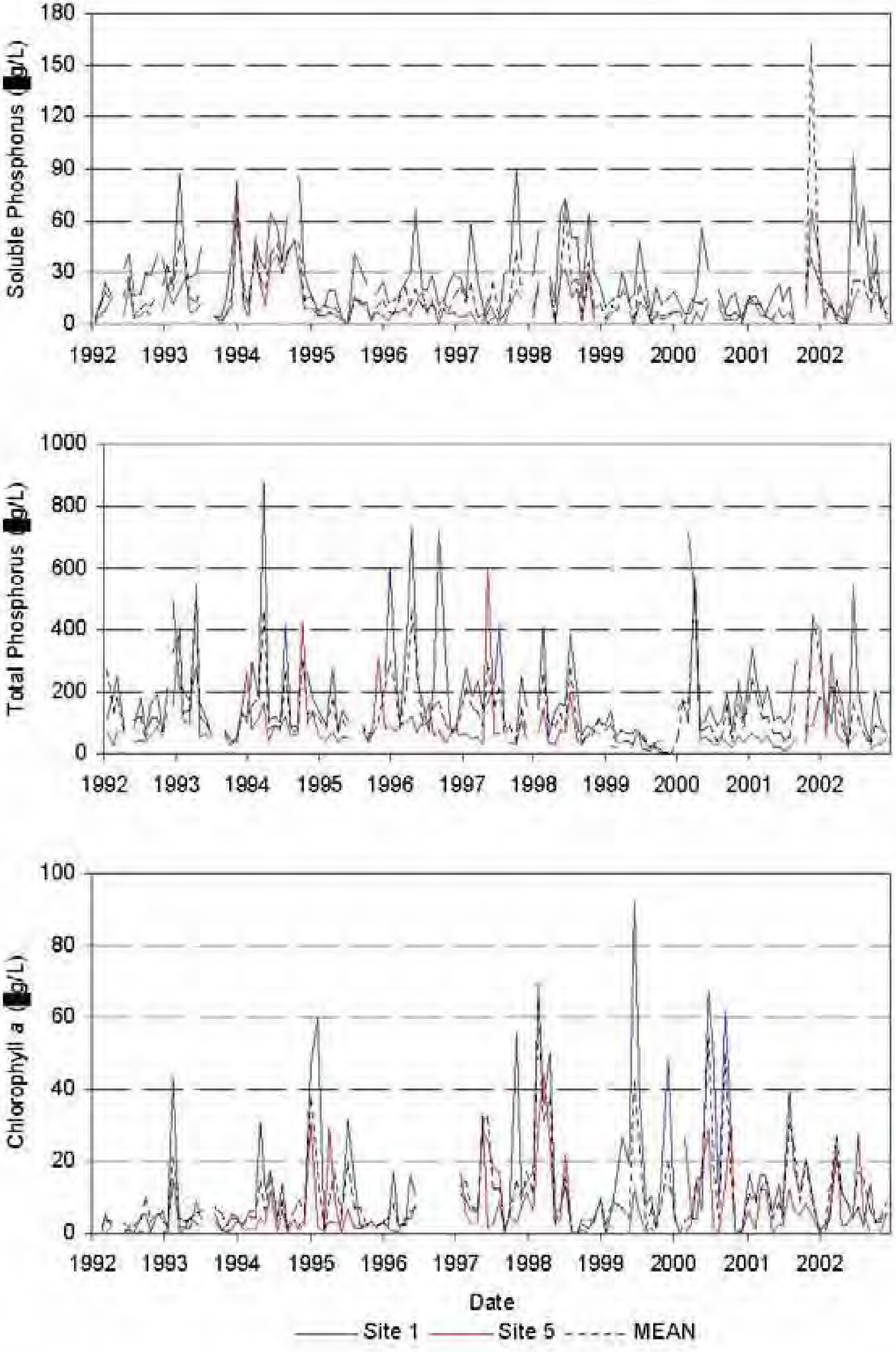


Figure 4. Monthly ammonium-N, nitrate-N, and fecal coliform measurements for sites 1, 5, and all sites (mean) for Abiaca Creek watershed, Mississippi, from 1992-2002.

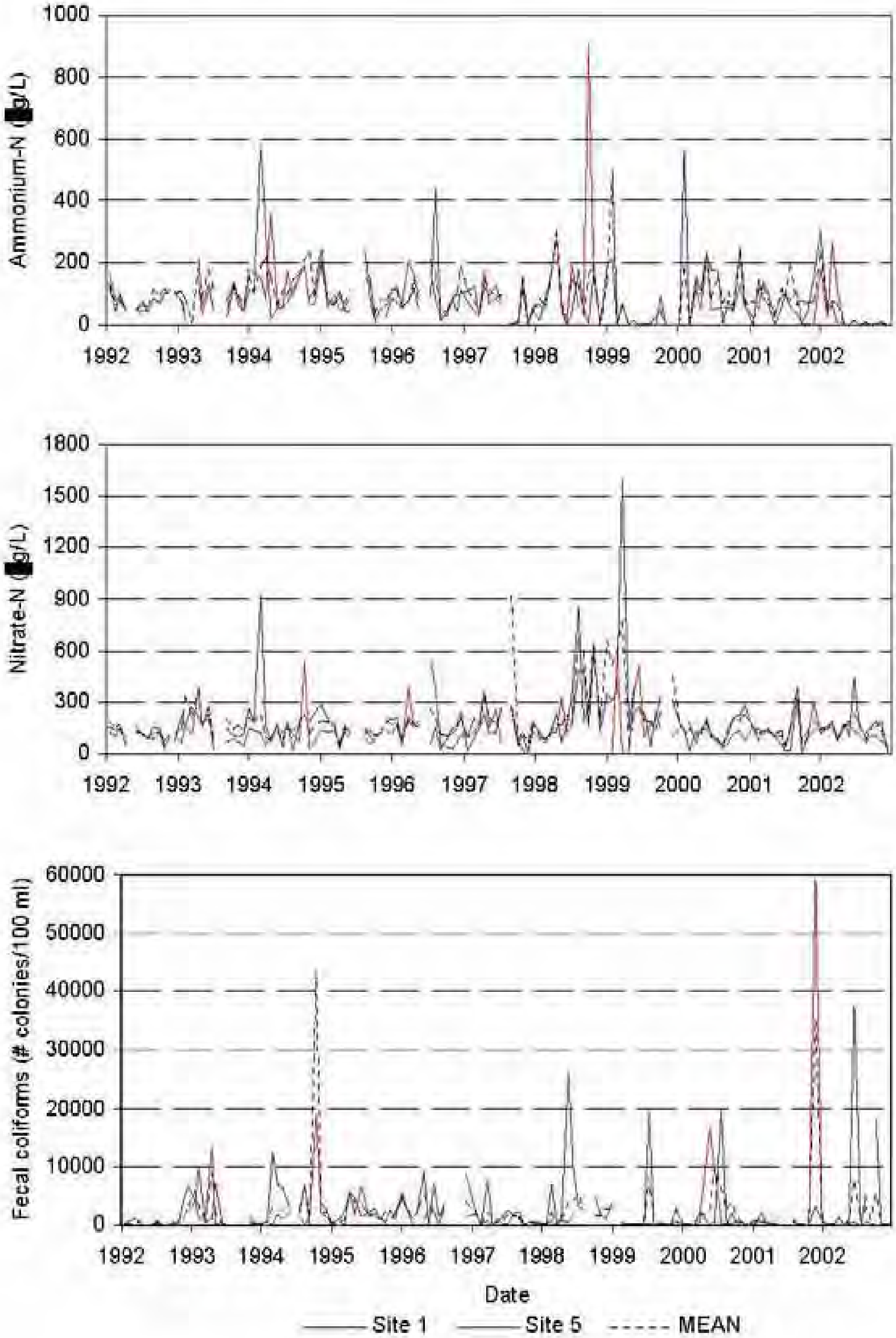
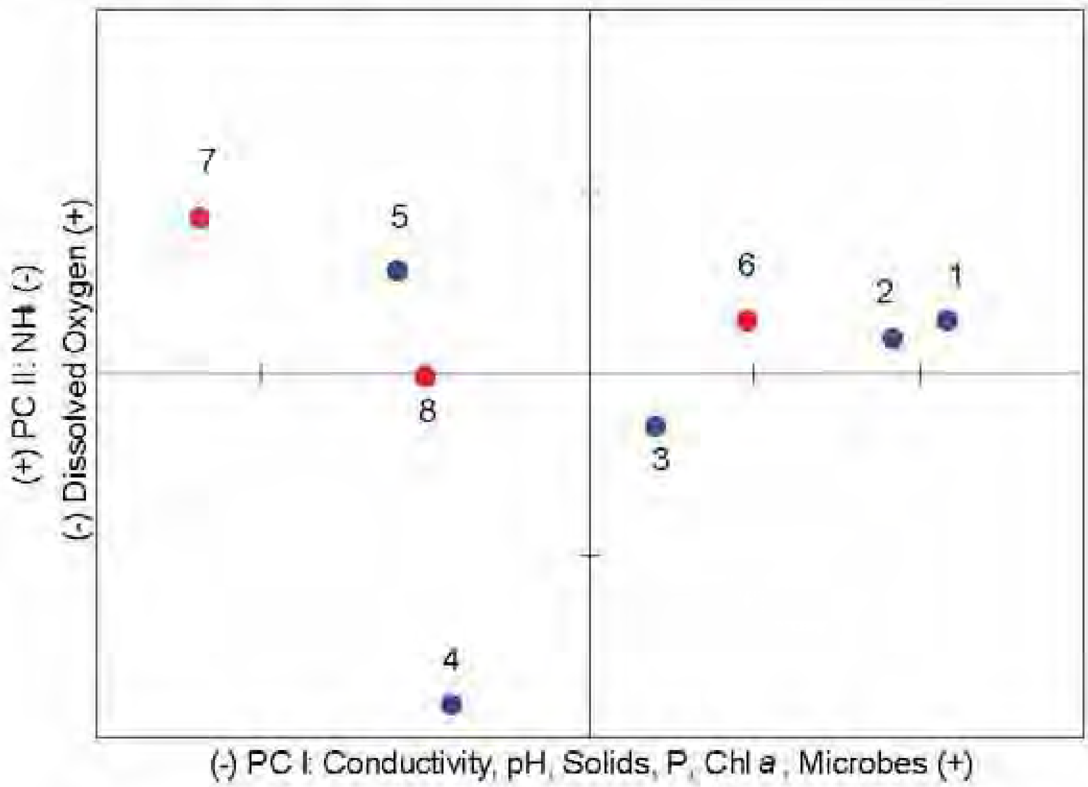
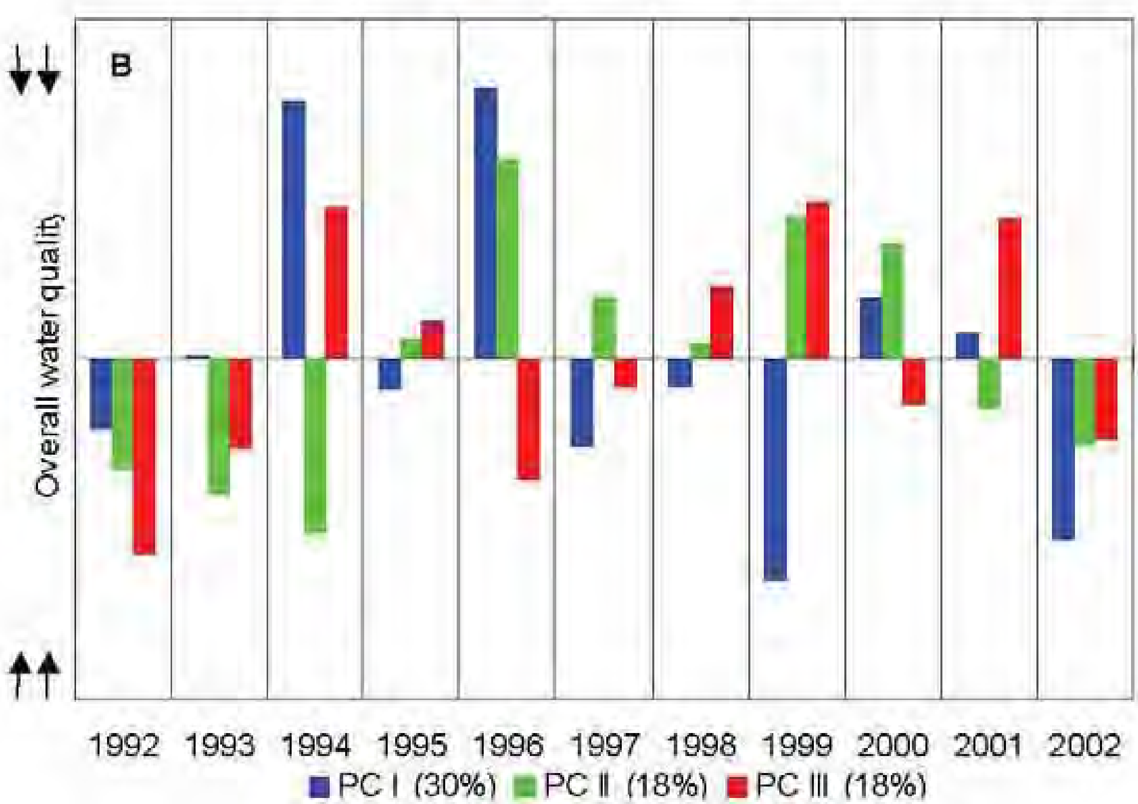


Figure 5. Plot of A) spatial variation of the first two principal components of water quality variation among eight sites and B) temporal variation of the first three principal components of water quality variation among 11 years within Abiaca Creek watershed, Mississippi.





Mississippi Embayment National Water-Quality Assessment – Cycle II: the Second Decade

by J.L. Smoot and R.H. Coupe

In 2001, the second decade of the U.S. Geological Survey's National Water-Quality Assessment (NAWQA) Program began. The program has been redesigned, and the second decade is referred to as Cycle II. The number of study units has been reduced from 60 to 42, and each study unit will be revisited in three groups of 14 on a rotational schedule. In 2004, the Mississippi Embayment NAWQA will begin its second decade of the NAWQA Program. Similar to Cycle I, each group will be intensively studied for three years, followed by six years of low-intensity assessment. The primary emphasis of Cycle II (2001 – 2011) is to assess long-term trends in water quality and to improve our understanding of the factors and processes that govern water quality. An additional emphasis is to fill critical gaps remaining in the status assessment, the main focus of Cycle I (1991 – 2001). This balance of priorities follows the recommendation of the NAWQA Planning Team which concluded:

> " The primary goals of NAWQA during its first decade continue to be appropriate as the program begins Cycle II. These goals are:
>
> - Provide a nationally consistent description of current water-quality conditions for a large part of the nation's water resources. [*status*]
> - Define long-term trends (or lack of trends) in water quality. [*trends*]
> - Identify, describe, and explain, as possible, the major factors that affect observed water-quality conditions and trends. [*understanding*]
>
> To be successful NAWQA must continue to focus on all of these goals. However, there should be a shift in the relative emphasis and resources given to the three goals as the program moves into its second decade. Relative to the first Cycle, the first goal, occurrence and distribution, should receive less emphasis in Cycle II. The third goal, explanation, should receive greater emphasis. The relative emphasis given to trends should increase in Cycle II because low-intensity phase sampling, a key component for trends analysis, was not fully implemented during Cycle I."

Chemical Mixtures (Phase I): Consequences of WNV Eradication on the Amphipod *Hyalella azteca*.

James Weston[1,2] and Marc Slattery[1,3,4]
The University of Mississippi; [1]Environmental Toxicology Research Program, [2]Dept. of Biology, [3]Dept. of Pharmacognosy and [4]The National Center for Natural Products Research; University, MS 38677.

Outbreaks of West Nile Virus (WNV) throughout the United States, and particularly in the Mississippi Valley States, have spurred plans to control the mosquito vector Culex spp. Chemical agents commonly used to control mosquito vectors are non-species specific pesticides that may potentially interact with non-target aquatic organisms. These compounds enter the aquatic environment via direct or indirect routes eventually becoming part of water and sediment matrices. Individually or as mixtures with other co-occurring persistent or transient anthropogenic compounds, such as agricultural pesticides, these mosquitocides can potentially degrade the water quality and aquatic habitat of non-target aquatic organisms.

Our group will present preliminary findings (Phase I) which are part of a multi-year study evaluating the co-occurrence and ecotoxicity of vector eradication compounds individually and in mixtures with agricultural pesticides. Currently, our work has focused on methoprene, the active ingredient of Altosid™, a commonly used mosquito larvicide and its ecotoxicological effects on *Hyalella azteca*, a common freshwater amphipod and an important trophic link in aquatic ecosystems. This preliminary work, and information from the literature, was necessary to establish NOEC values for mixture studies which are under development.

Runoff Quality in Bermudagrass Plots Treated with Poultry Litter

Key Words: Hydrology, Nutrients, Nitrate Contamination, Water Quality
Presentation Type: Oral
Presenter's Name: Alton B. Johnson, Alcorn State University
Presenter's Address: 1000 ASU Drive #852, Alcorn State, MS 39096
Phone: (601) 877-6529; Fax: (601) 877-3743; E-mail: bjohnson@lorman.alcorn.edu
Co-Authors: Mariantonette O. Jordan, University of Wisconsin, Madison
Dennis Rowe, USDA-ARS
Teferi Tsegaye, Alabama A&M University

ABSTRACT

The overall objective of this study was to quantify runoff volumes, concentrations of NO_3-N, PO_4-P, K, Cu, Fe and Zn, and near-surface hydrology of bermudagrass plots treated with poultry litter under simulated rainfall. Poultry litter with application rates of 0, 4.48, 8.96, 17.92 and 35.84 Mg ha^{-1} was applied to micro-plots (1.75 x 2 m) on a 5% slope. The soil used in this study was a loessial Memphis silt loam (fine-silty, mixed, thermic Typic Hapludalf). Rainfall simulator was used to produce two runoff events immediately and 1.55 h after poultry litter application. Soil profile water content increased with rainfall application. Cumulative runoff volumes for the 0, 4.48, 8.96, 17.92 and 35.84 Mg ha^{-1} plots for the first rainfall event were 114.6, 84.3, 102.3, 155.4 and 88.9 L, respectively. During the second rainfall event, cumulative runoff volumes were 116.8, 106.9, 121.1, 167.3, and 130.7 L, respectively. Flow-weighted mean concentrations of NO_3-N, PO_4-P and K increased with litter application rate, however, PO_4-P concentration in the 8.96 Mg ha^{-1} treatment was significantly smaller (19.68 mg L^{-1}) than the 4.48 Mg ha^{-1} treatment (24.12 mg L^{-1}) in the first rainfall event ($p = 0.05$). Nitrate-nitrogen concentrations in the 17.92 and 35.84 Mg ha^{-1} treatments were 55 and 112 times higher than the 4.48 Mg ha^{-1} treatment. Approximately 13, 8.2, 6.6 and 2.6% of soluble P was measured from runoff of the treated plots. Potassium concentration increased hyperbolically with increased poultry litter rates. In all treated plots, copper, iron and zinc concentrations were far below 0.001 mg L^{-1} for the two rainfall events.

Title: Effects of Mississippi Delta Sediment Contaminants on CYP1B-Gene Expression in Channel Catfish

Key Words: Toxic Substances, Sediments, Water Quality

Oral Presentation Preferred

Presenters Contact Information: Kristie Willett, University of Mississippi, Pharmacology and Environmental Toxicology, Box 1848, University MS 38677, 662-915-6691, Fax 662-915-5148

Co-authors: H Butala [1], M Patel [1], S Quiniou [2] and G Waldbieser [2]

[1] Pharmacology and Environmental Toxicology, University of Mississippi University MS; [2] USDA Catfish Genetics Research Unit Stoneville MS

Sediments in some Mississippi rivers and lakes contain significant concentrations of environmental contaminants including pesticides and industrial by-products. Chemical analysis of sediments collected from three Mississippi Delta waterways (Lake Roebuck, Bee Lake and Sunflower River), suggested that polycyclic aromatic hydrocarbon (PAH) and organochlorine pesticides were highest at Lake Roebuck. Our research has been investigating the potential for sediment associated contaminants to cause physiological effects in channel catfish, specifically on CYP1B gene expression. CYP1B is a P450 gene that in mammals is involved in the metabolism of PAHs and estradiol to potentially toxic intermediates. Quantitating induction of CYP1B mRNA or estrogen metabolism in catfish could potentially be a useful biomarker of exposure. The objectives of our study were to characterize *in vivo* CYP1B mRNA expression and estrogen metabolism in laboratory raised and wild-caught channel catfish (*Ictalurus punctatus*) from Lake Roebuck, Bee Lake and Sunflower River. Initial experiments involved cloning the channel catfish CYP1B gene. Preliminary cloning results suggest that the channel catfish sequence contains 510 amino acids and has a 55 and 50% identity with the human and scup CYP1B genes, respectively. Laboratory fish were exposed *i.p.* to corn oil or 20 mg/kg benzo(a)pyrene (BaP) for 4 days. Using quantitative real time RT-PCR, BaP exposure induced CYP1B mRNA in blood, liver and gonad tissues. CYP1B mRNA levels from Delta catfish were not statistically increased relative to control fish, and CYP1B levels from the livers of these animals were significantly lower than laboratory controls. The relative tissue levels of CYP1B mRNA from Lake Roebuck fish were gill >> blood > liver = gonad. Liver microsomes metabolized estradiol to predominately 2-hydroxyestradiol and estrone, however a statistically higher 4:2-hydroxyestradiol ratio was found in BaP exposed animals (0.17) compared to controls (0.04), suggesting that BaP caused induced formation of the genotoxic 4-hydroxyestradiol metabolite. Liver microsomes from the Delta fish produced statistically more 4-hydroxyestradiol compared to control animals but less than the BaP exposed fish. These results will ultimately help characterize the utility of CYP1B as a marker of environmental contamination and the physiological significance of CYP1B in fish.

Optical fiber chemical sensor for water quality monitoring

S. Tao*, J. C. Fanguy, S-F. Gong, L. Xu and K. Soni
Diagnostic Instrumentation and Analysis Laboratory, Mississippi State University
205 Research Blvd., Starkville, MS 39759 (*E-mail: tao@dial.msstate.edu)

1. Principle of optical fiber chemical sensor

An optical fiber chemical sensor (OFCS) can detect and measure the concentration of a compound by sensing the interaction of the compound with the light propagating in an optical fiber.[1] Depending on the location at which the interaction occurs, optical fiber chemical sensors can be divided into two classes: active core fiber optic sensor (ACFOS) and evanescent wave fiber optic sensor (EWFOS). In an ACFOS, the interaction of an analyte compound with light occurs inside an optical fiber core, while in an EWFOS, the interaction of an analyte compound with light occurs in the cladding layer of an optical fiber. A light beam traveling down an optical fiber can be scattered or absorbed by a compound existing inside the fiber core or the cladding as an impurity or as a dopant. The light propagating in an optical fiber can also excite a compound in the fiber to a higher energy level and causes the emission of fluorescence. All these interactions can be used in designing an OFCS. Therefore, analytical spectroscopic techniques, such as ultra violet/visible (UV/Vis) absorption spectrometry, infrared (IR) absorption spectrometry, Raman scattering spectrometry, fluorescence (FL) spectrometry, etc., have been used in OFCS design.[2] The characteristics, including sensitivity, response time, selectivity, etc. of an OFCS are decided by the properties of the compound to be detected, the analyte/light interaction used for the detection, the location of analyte/light interaction, and the micro structure of the optical fiber and the cladding.

1.1 Principle of ACFOS and EWOFS

When a light beam is injected into an optical fiber, the light travels down the fiber through a series of total internal reflection at the interface of optical fiber core and cladding layer. If an analyte exists in the fiber core, the analyte molecules can interact with light propagating inside the fiber core. In this case, the optical fiber core acts as an optical spectroscopic cell for detecting analyte/light interaction. Theories established in conventional analytical spectroscopy can be used to describe the interaction of an analyte with light inside the fiber core. For example, the absorption of light of a specific wavelength by an analyte inside the fiber core can be described by using the Lambert-Beer's law:

$$A = \mathrm{Log}\,(1/T) = \varepsilon CL \qquad (1)$$

In this equation, A is absorbance, T is the transmittance, ε is the absorption coefficient, C is the concentration of the analyte inside the fiber, L is the length of the interaction, which is decided by the following equation:

$$L = l/(1-\sin^2\theta)^{1/2} \qquad (2)$$

where, l is the length of the optical fiber transducer and θ is the incident angle of light beam to the optical fiber. Similarly, optically excited fluorescence of an analyte and optical scattering by an analyte inside an optical fiber core can be described using theories established in conventional analytical spectroscopy. [3]

On the other hand, as a light beam travels down an optical fiber, a standing wave, also known as evanescent wave (EW), forms at each point of total internal reflection along the optical fiber. This EW distributes a small part of the power of the light guided inside the optical fiber into the cladding layer. The quantity of EW power is related to the total power of the light guided inside an optical fiber. An approximate equation describing the optical power flowing in the cladding of a multimode optical fiber has been given by D. Gloge:[4]

$$I_{clad}/I_{total} = \gamma = 4/3 * N^{-1/2} \quad (3)$$

where, N is the number of free space modes transmitted in the optical fiber and can be approximately expressed as:

$$N = 2(\pi a)^2(n_{core}^2 - n_{cladding}^2)/\lambda^2 \quad (4)$$

In this equation, a is the diameter of the multimode optical fiber core, n_{core} and $n_{cladding}$ are the refractive index of fiber core and cladding, respectively, and λ is the wavelength of light guided in the fiber. In a more rigorous description, the light power flowing inside the cladding also depends on the conformation of optical fiber.[5] For designing an EW-based optical fiber sensor it is important to increase the EW power in order to achieve highest sensitivity. This can be accomplished through choosing optical fibers of different material, changing the cladding material, or changing the conformation of the fiber, for example, by bending the fiber.[6]

The distribution of the optical power in the cladding of an optical fiber is not uniform. The power intensity decreases exponentially with the increase of perpendicular distance from the interface of fiber core/cladding. The change of power intensity with distance away from the fiber core/cladding interface can be expressed as follow:[7]

$$I = I_0 \exp(-z/d_p) \quad (5)$$

In this equation, I is the power intensity at distance z from the interface of fiber core/cladding, I_0 is the power intensity at the interface and d_p is defined as the penetrate depth, which is expressed as follow:

$$d_p = \lambda/2n_{core}[\sin^2\theta - (n_{clading}/n_{core})^2]^{1/2} \quad (6)$$

where, θ is the incident angle of the light entering the optical fiber. Equations (5) and (6) indicate that for an EWOFS, an analyte molecule can be sensed only if it exists at a distance from the fiber core/cladding interface comparable with the wavelength of light used for sensing the compound. Therefore, in constructing an EWOFS, the thickness of the reagent-containing polymer cladding should be comparable to the wavelength of light used in sensing.

Almost all of the analytical spectroscopic techniques used in conventional analytical chemistry can be used for detecting the interaction of an analyte with the EW in the cladding layer. Taking optical absorption as an example, the EW absorbance by a compound in the cladding layer can be expressed as follow:

$$A_{EW} = \mathrm{Log}(1/T) = \gamma\varepsilon C(d_p l n_{cladding} \sin\theta / a(n_{core}^2 - n_{cladding}^2 \sin^2\theta)^{1/2}) \qquad (7)$$

In this equation, γ is the ratio of optical power flowing in the cladding over total light power guided through the fiber. ε is the absorption coefficient of the analyte, and $d_p l n_{cladding} \sin\theta / a(n_{core}^2 - n_{cladding}^2 \sin^2\theta)^{1/2}$ is the absorption path length, which is equal to the penetration depth (d_p) times the number of total internal reflections, which is calculated as $l n_{cladding} \sin\theta / a(n_{core}^2 - n_{cladding}^2 \sin^2\theta)^{1/2}$, as light travels in an optical fiber of length l. Similarly, EW excited fluorescence,[8,9] EW Raman spectroscopy,[10] EW scattering,[11] etc, can be used in designing EWOFS to detect the interaction of an analyte in the EW field with the light penetrated into the EW field.

1.2 Comparison of ACFOS and EWOFS

Comparing equation (1) with equation (7), it is clear that the sensitivity of an ACFOS is much higher than that of an EWOFS. Two factors, the light intensity ($I_{cladding} = \gamma I_{total}$, γ value is usually smaller than 0.05) and the interaction path length ($= d_p l n_{cladding} \sin\theta / a(n_{core}^2 - n_{cladding}^2 \sin^2\theta)^{1/2}$, dp is only in μm level), limit the sensitivity of an EWOFS. For example, G. L. Klunder, et al.[12] calculated the absorption path length of an EW based optical sensor with a 12 m optical fiber to be only 3 mm.

However, most of the reported OFCS are based on fiber optic EW spectrometry. An EW based OFCS can use conventional silica optical fiber made for the communication industry for sensor design. This fiber is inexpensive and easy to handle, and is compatible with all kinds of tools and instruments used in the communication industry. Commercially available silica fiber is a solid material. It is almost impossible to introduce an analyte molecule into the fiber core for detecting the interaction of the molecule with light guided in such an optical fiber. Therefore, in order to make an ACFOS, a special optical fiber core has to be developed. This fiber core should be able to guide light and allow introduction of analyte material into the fiber core. Several specially designed optical fibers have been developed and can be used for designing ACFOS. These include hollow waveguide (HW),[13] liquid core waveguide (LCW),[14, 15] porous optical fiber made from polymers.[16-18]

2. The structure of optical fiber chemical sensor

The structure of an OFCS is similar to that of a spectroscopic instrument used in conventional analytical spectroscopy, except that an optical fiber is used as an optical sample cell for detecting the interaction of an analyte with light. An example of OFCS for detecting optical absorption is shown in Fig. 1. In this sensor, the absorption cell is either an optical fiber core or the cladding layer of an optical fiber.

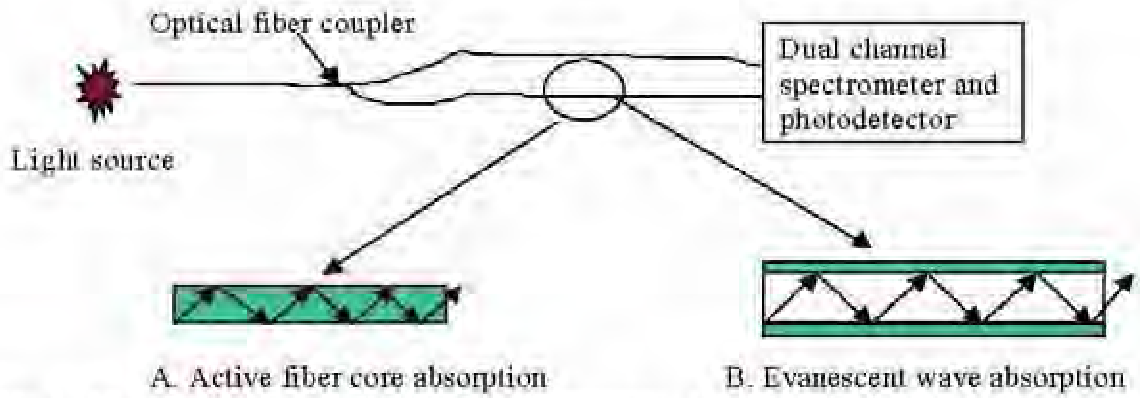


Fig. 1 An OFCS using optical absorption spectrometry. In an ACFOS (A), the light absorbing material exists inside the fiber core, while in an EWOFS (B), the light absorbing material exists in the cladding.

The dual roles of an optical fiber as both a light guiding medium and a sample cell significantly simplifies the optical structure of OFCS and makes the sensor more flexible. This makes OFCS very attractive for field application. In addition, most optical fiber sensors are designed for monitoring a specific analyte using light of specific wavelength. Simple light sources, such as light emitting diode (LED), laser diode (LD), small tungsten bubble, etc. can be used in these sensors. Simple optical dispersing elements or even band pass filters can be used for selecting light of specific wavelength. All these features make an OFCS much simpler, smaller and inexpensive compared with conventional spectroscopic instruments used in analytical laboratories.

3. Advantages of OFCS for field application

Optical spectroscopic techniques are widely used in analytical laboratories for highly sensitive, precise detection of trace analytes in complex samples. It is now widely recognized that most of the analytical spectroscopic detection methods can be reproduced in fiber optic spectroscopy by using appropriately designed optical fiber as a spectroscopic sample cell. OFCS using fiber optic spectroscopic techniques is not as sensitive and precise as laboratory spectroscopic instruments. However, for field applications, OFCS has the following advantages:

1. Small size and low cost.
2. Remote sensing capability.
3. Long term real time monitoring capability.
4. Easy field deployment and continuous monitoring capability.
5. Easy implementation of a sensor network with present optical fiber communication infrastructure.
6. Feasibility of distributed sensing (multi sensors fabricated on a single optical fiber).
7. Feasibility of deployment into small spaces which is unaccessible to conventional instruments.
8. In situ and in vivo sensing capability.
9. Imperviousness to interferences from electromagnetic fields.

4. Development of OFCS for water quality monitoring in DIAL

4.1 Liquid core waveguide ACFOS for monitoring Cr(VI) in water

Chromate compounds have been used as a reagent in pigment production and leather tanning. In the past, since the hazardous characteristic of chromate compounds had not been recognized, chromium-containing waste has been inadequately disposed. At present, the leaches of chromium compounds from the waste dumped site to ground water caused water contamination all around the world.[19-21]

Chromium can exist in nature as a compound in one of its two stable valences. Chromium in Cr(III) compounds is nontoxic and is actually an essential nutrition for human body. Chromium in Cr(VI) compound, the hexachromium, is verified to be cancerogenic.[22,23] Therefore, chromium contamination is actually a problem of Cr(VI) contamination. In water contamination investigation and contamination control, what is important is the concentration of Cr(VI) ions in water.

Present laboratory analytical methods for chromium detection are very sensitive. For example, inductively coupled plasma atomic emission spectrometry can be used to detect chromium in water to part-per-billion (ppb) level.[24] Graphite furnace atomic absorption spectrometry also has the capability of detecting chromium in water to sub-ppb level.[25] However, all these methods can only give information about total chromium concentration in water. A separation procedure, such as extraction, ion chromatography (IC), must be used to separate Cr(VI) from Cr(III) in order to obtain Cr(VI) concentration in a water sample. In addition, the instruments used in these analytical methods are expensive, big in size and susceptible to environmental noises. It is very difficult to deploy these instruments to field. On the other hand, Cr(VI) ions in water is known to absorb UV light with peak absorption at around 373 nm. Cr(VI) ions in water can be detected by using this light absorption phenomenon. However, conventional intrinsic UV absorption technique is not sensitive enough for detecting Cr(VI) in ground water.

A liquid core waveguide (LCW) is an optical fiber with water or an aqueous solution as a light guiding media.[14,15] A tube made from a special amorphous fluoropolymer, which has a refractive index (from 1.29 to 1.31) smaller than that of water (1.33), is used to construct a LCW. When water is filled in this tube light can be guided through water inside the tube via total internal reflection. Trace chemical compounds or ions dissolved in water filled inside the tube can be detected using analytical spectroscopic techniques with the water filled tube as an optical sample cell. The sensitivity of optical spectroscopy using a LCW as a sample cell can be thousands of times higher than that of conventional spectroscopic technique, because the length of a LCW can be hundreds of meters, while the length of a sample cell in a conventional spectroscopic technique can only be in centimeters range.

A simple optical fiber Cr(VI) sensor, consisting from a UV light emitting diode (LED), a 2 meters LCW and a photodiode, has been developed in DIAL.[15] A photograph of the laboratory setup of this sensor is shown in Fig. 2. The LED used in this sensor emits UV light at 375 nm with peak width of 15 nm. The emission profile of this LED fits well with the absorption spectrum of Cr(VI) ions in water (Fig. 3). Therefore, no optical dispersing element is needed in the Cr(VI) sensor when this LED is used as a light source of the sensor. This not only makes the sensor simple in structure, but also robust for field deployment.

Fig. 2 A photograph of a laboratory set-up of the Cr(VI) sensor.

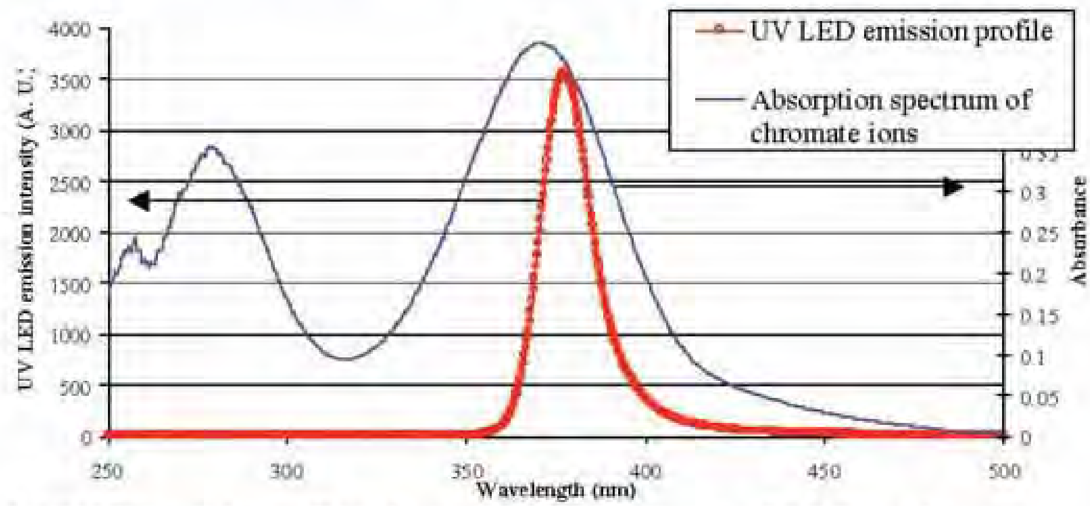


Fig. 3 UV LED emission profile and optical absorption spectrum of Cr(VI) ions in water.

The response of this sensor for monitoring a water sample containing Cr(VI) ions is shown in Fig. 4. The sensor can detect Cr(VI) in water down to 0.1 ppb. Metal ions and organic compounds normally found in ground water do not interfere with the detection of Cr(VI) ions in water with this sensor.

4.2 LCW ACFOS for detecting mercury in water[14]

Mercury is a toxic metal with special properties. The contamination of ground water by mercury emitted from coal-fired power plants and elevated alkylmercury concentration in fishery products are presently serious social concern around the world. Atomic absorption spectrometry (AAS) is a sensitive technique for mercury detection. Conventional AAS instrument needs at least three expensive components. These are a special light source, an atomizer and a high-resolution spectrometer with a sensitive photodetector. The instrument for mercury AAS detection usually has to be installed in an analytical laboratory and operated by well-trained analytical chemist. It is difficult to deploy such an AAS instrument to field for mercury detection.

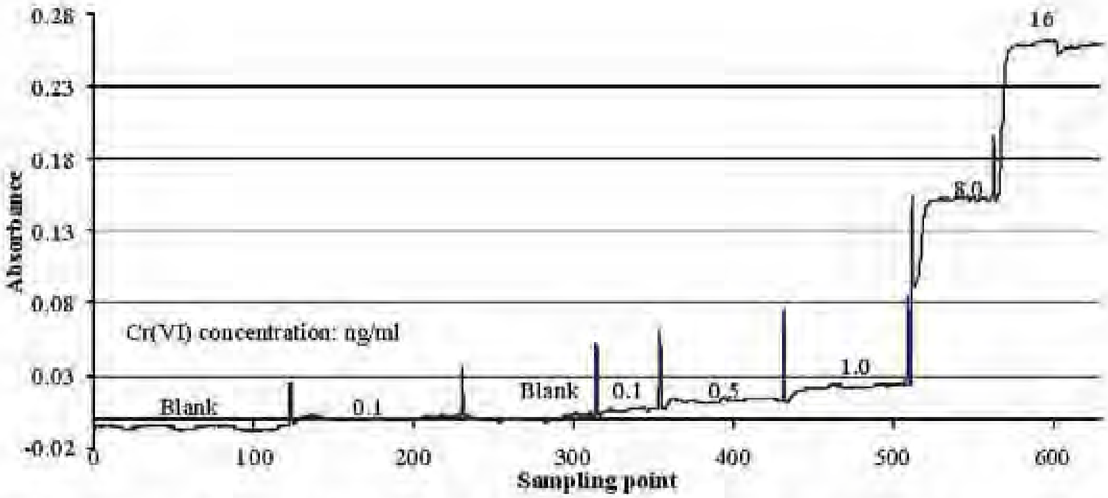


Fig. 4 Response of an ACFOS using an LCW as a transducer to a water sample containing Cr(VI) ions of different concentration.

A simple structured ACFOS for detecting mercury in a water sample has recently been developed in DIAL.[14] This sensor consists from a deuterium lamp as a light source, an 80 cm LCW as an absorption sample cell and an optical fiber compatible UV/Vis spectrometer as a detector. The structure of this mercury sensor is similar to that of the Cr(VI) sensor showing in Fig. 2. Mercury containing water sample is mixed with a $NaBH_4$ solution. Mercury ions in the water sample are reduced to mercury atoms by the reagent. The mercury atoms containing water is then injected or pumped into the LCW. Atomic absorption by mercury atoms in water inside the LCW is monitored. The atomic absorption caused by mercury atoms in water has a broadband spectrum with peak wavelength at 255 nm and bandwidth of 20 nm. The absorption signal of water sample containing different concentration of mercury is shown in Fig. 5. Mercury in water in low ppb level can be detected with this simple sensor. In further development, a band pass filter will be used to replace the spectrometer in order to construct a low cost, simple and robust mercury sensor for field application.

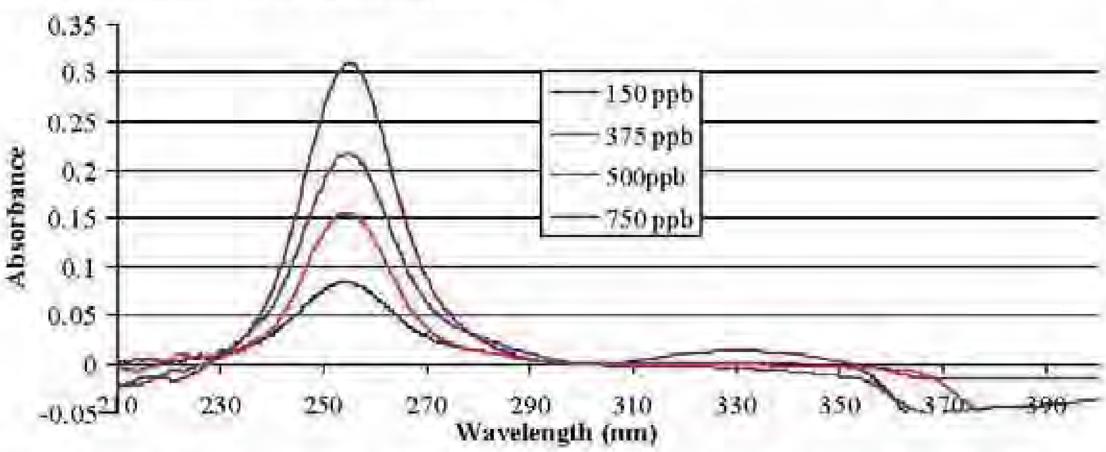


Fig. 5 Absorption spectrum of LCW ACFOS by mercury atoms generated by reduction of mercury ions of different concentration in water

4.3 EWOFS using a flexible tubular waveguide as a transducer

From equation (7), it is clear that when the parameter (diameter, material and incident angle, etc) of an optical fiber is decided, the only way to increase the sensitivity of an EWOFS is to increase the length of the active coating. However, in conventional EWOFS using a silica optical fiber as a transducer, it is very difficult to make a sensor of long active coating because the silica fiber is very fragile once its jacket and polymer cladding have been removed. This is especially true when a fiber of small diameter (for example, a single mode fiber) is used to make the sensor.

DIAL has recently explored the application of a flexible fused silica capillary (FFSC) as a tubular waveguide (TW) for the fabrication of a long path EWOFS. The structure of an FFSC TW is shown in Fig. 6. The outside of the FFSC is cladded with a doped silica. An organic polymer or metal layer is coated on the top of the cladding to mechanically protect the FFSC. This makes the FFSC strong and flexible in operation. The inner surface of the FFSC is fused silica which is the same as that of a silica optical fiber. When a light beam is injected into one end of the capillary, the light is guided inside the wall of the capillary as showing in Fig. 6. The observed image of the light at the distal end of the FFSC is in the shape of a ring as showing in Fig. 7.

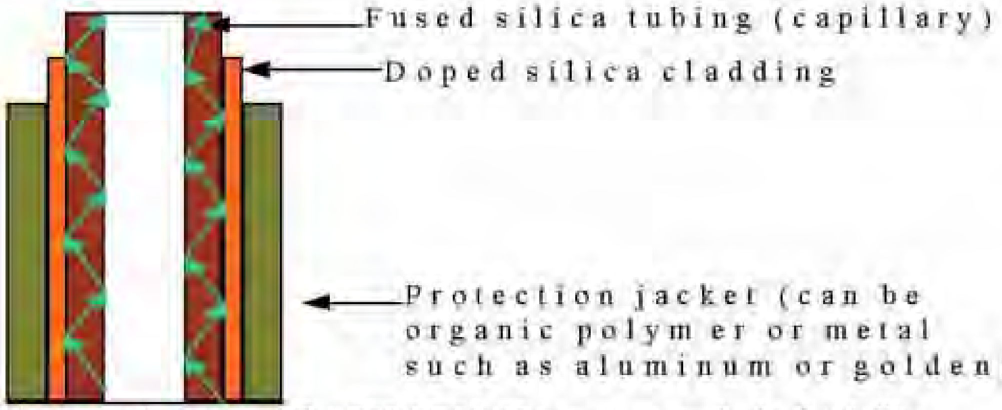


Fig. 6 Diagrammatic structure of an FFSC TW. The green arrows in the fused silica tubing illustrate a light beam traveling through the waveguide

Fig. 7 End view of an FFSC TW under a microscope as a light beam from a green LED guided through the FFSC.

4.3.1 Intrinsic EW absorption sensor with a FFSC as a transducer for sensing Cr(VI) in water

When a light beam is guided through the FFSC, an EW field is formed in the interface of the capillary inner surface and water inside the capillary. This EW field can interact with a species within the field to give out a sensing signal. A chemical species absorbing the light guided through the TW can be detected by using intrinsic EW absorption technique.

One example of this FFSC intrinsic EW absorption technique is a Cr(VI) sensor. This sensor consists from a UV light source (deuterium lamp or a UV LED), two normal silica fibers, an FFSC and a photodetector (with or without an optical dispersing element). Each end of the FFSC is connected to a silica optical fiber through the horizontal ports of a "T" connector. The perpendicular port of the "T" connectors is used for sample inlet and outlet. A light beam from the light source is injected into one of the silica optical fiber and the light guided through the capillary is detected by feeding the light emerged from the second silica fiber into a photodetector. The structure of such a sensor is shown in Fig. 8. A sensor of such structure with a 1 meter FFSC as a transducer has been tested for Cr(VI) detection. Test result is shown in Fig. 9. This sensor can be used to detect/monitor Cr(VI) in an aqueous solution down to 23 ppb.

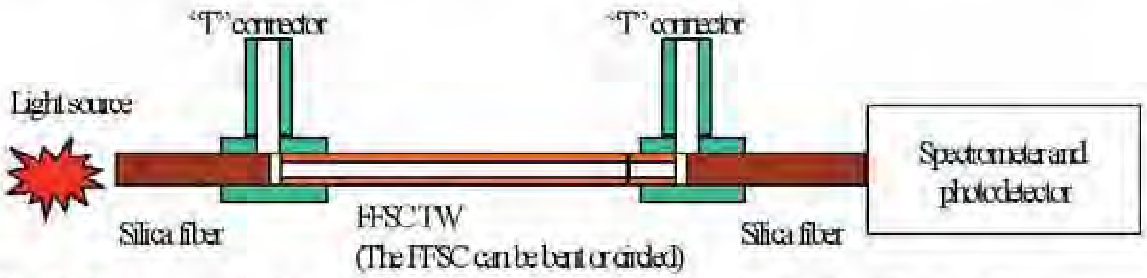


Fig. 8 Diagrammatic structure of an OFCS using an FFSC TW as a transducer. The inner surface of the FFSC can be coated with polymer (with or without reagent doping) to make different sensors. In the Cr(VI) sensor described in this paper, there is no coating on the inner surface.

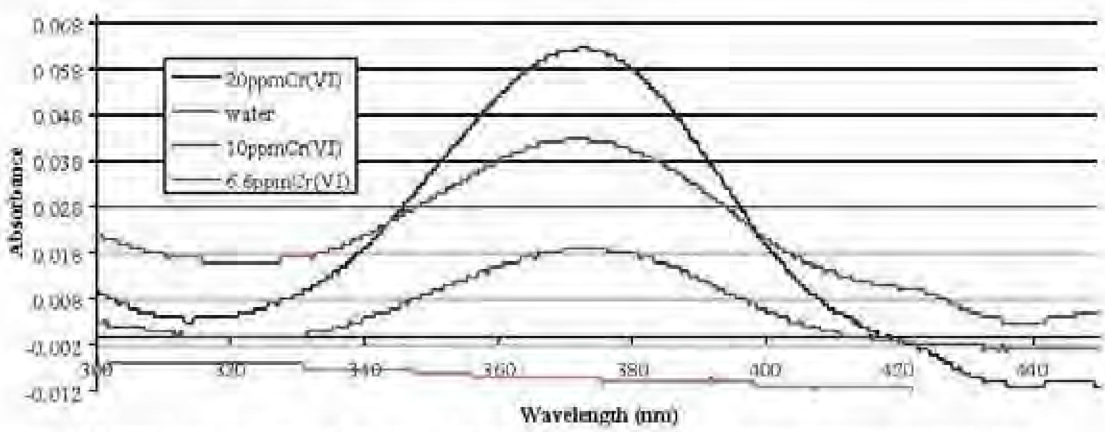


Fig. 9 Absorption spectra of an FFSC EWOFS exposed to a water sample containing Cr(VI) ions of different concentration (length of FFSC = 1 m).

4.3.2 Intrinsic EW absorption sensor using a hydrophobic polymer coated FFSC as a transducer for monitoring aromatic compound in a water sample

A polymer can be coated on the inner surface of the FFSC to extract/concentrate a target species from a water sample in order to increase the sensitivity of the intrinsic EW absorption sensor. This sensor design concept has been used to construct an OFCS for detecting/monitoring hydrophobic aromatic compounds in a water sample. In this sensor, the FFSC is coated on the inner surface with polydimethylsiloxane (PDMS). When a water sample containing aromatic compounds flowing through the coated capillary, the hydrophobic aromatic compounds in the water sample are extracted into the PDMS coating. The extracted aromatic compounds in the coating layer interacts with the EW field and this interaction is monitored in the same way as that in the FFSC intrinsic absorption Cr(VI) sensor. A toluene sensor using a 0.5 meters PDMS coated FFSC has been constructed as an example of the sensors of this class. This sensor monitors the intrinsic EW absorption of the extracted toluene at around 260 nm. Test result of this sensor for monitoring toluene in a water sample is shown in Fig. 10. This sensor can detect toluene in water down to 0.1 ppm. This sensor is reversible. When a water sample contains no toluene flows through the FFSC, the toluene absorbed in the PDMS coating layer can be washed off. This solid phase extraction/intrinsic EW absorption technique can also be used for monitoring other organic compounds in water.

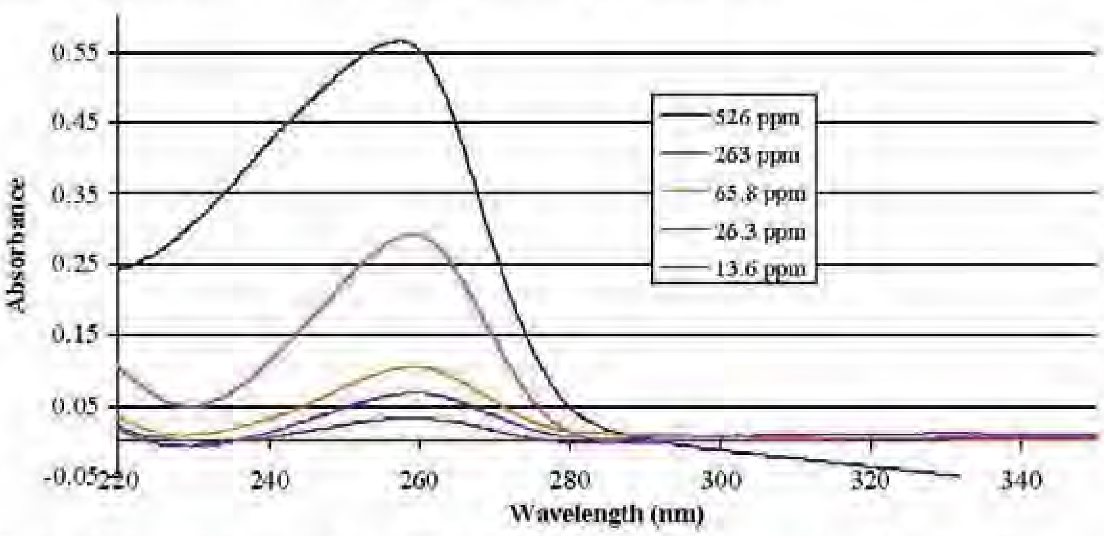


Fig. 10 Absorption spectra of an FFSC EWOFS exposed to a water sample containing toluene of different concentration. The FFSC is coated with PDMS (length of FFSC = 0.5 m).

4.3.3 OFCS using an FFSC coated with a reagent-doped polymer as a transducer for monitoring trace metal ions in a water sample

The polymer coated on the inner surface of an FFSC can also be doped with a chemical/biochemical agent. A species in a water sample can be extracted into the polymer layer and react with the reagent doped inside the polymer layer. This reaction in the coating layer can convert an optically inert species to an optically active species at specific optical wavelength, and thus can be detected with an EW spectroscopic technique. A copper ions sensor has been developed using this structure. In this sensor, a 0.35 meters FFSC coated with an Eriochrome cyanine R doped sol-gel silica is used as a transducer. When a water sample containing copper ions flows through the coated capillary, copper ions in the water sample are extracted into the polymer layer and react with the reagent doped in the sol-gel silica coating. The formed complex of copper ions with the reagent changes the color of the sol-gel silica coating (from orange to purple) and this color change is detected by using fiber optic EW absorption spectrometry. The response of this sensor to copper ions of different concentration in a water sample is shown in Fig. 11. Copper ions in water down to 2.5 ppb can be detected with this sensor. This sensor is also reversible because the complex formation of copper ions with the reagent is in dynamic equilibration with water molecules in the solution.

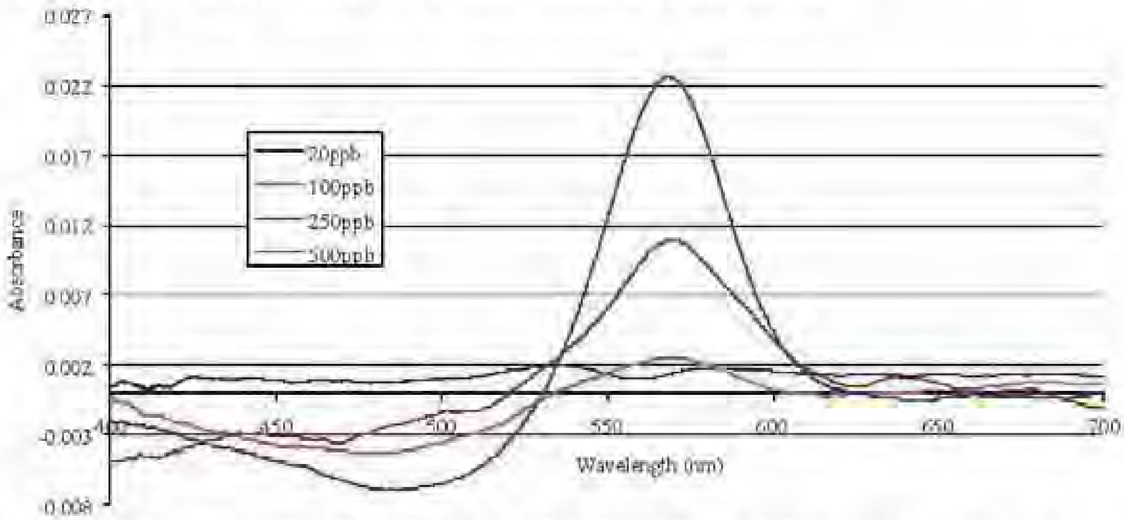


Fig. 11 Absorption spectra of an FFSC EWOFS exposed to a water sample containing copper ions of different concentration. The FFSC is coated with Eriochrome Cyanine R doped sol-gel silica (length of FFSC = 0.35 m).

5. Conclusion

OFCSs with capability of detecting toxic metal ions and organic compounds in water samples down to ppb level have been developed. These sensors are simple in structure, low cost in both fabrication and operation. All the sensors, except the mercury sensor, can be deployed to field for continuous monitoring without personnel presence. In further work, micro communication device will be integrated into the sensors. Sensing signal of individual sensors can be send to a communication/data process center. A sensor network can be formed with this technique for long-term real time monitoring the distribution and movement of contaminants in ground water.

References

1. O. S. Wolfbeis, *Anal. Chem.*, **74**, 2662 (2002).
2. J. P. Dakin, S. J. Mackenzie and J. Hodgkinson, Optical Fiber Sensors, **4**, 1 (1997).
3. J. D. Ingle, ed, "*Spectrochemical Analysis*", Prentice Hall, 1988.
4. D. Gloge, *Appl. Opt.*, 10, 2252 (1971).
5. S. K. Khijwania and B. D. Gupta, *Opt. Quantum Electron.*, **31**, 625 (1999).

6. T. Lee S, N. A. George, P. Sureshkumar, P. Radhakrishnan, C. P. G. Vallabhan and V. P. N. Nampoori, *Opt. Lett.*, **26**, 1541 (2001).
7. A. Messica, A. Greenstein and A. Katzir, *Appl. Opt.*, **35**, 2274 (1996).
8. B. D. MacCrain, C. M. McDonagh, G. O'Keeffe, E. T. Keyes, J. G. Vos, B. O'Kelly and J. F. McGilp, *Analyst*, **118**, 385 (1993).
9. O. S. Wolfbeis and A. Sharma, *Anal. Chim. Acta*, **208**, 53 (1988).
10. J. Baldwin, N. Schuehler, I. S. Butler and M. P. Andrews, *Langmuir*, **12**, 6389 (1996).
11. A. Doicu, Y. Eremin and T. Wriedt, *Opt. Commun.*, **190**, 5 (2001).
12. G. L. Klunder, J. Burck, H. J. Ache, R. J. Silva and R. E. Russo, *Appl. Spectrosc.*, **48**, 387 (1994).
13. R. J. George, J. A.Harrington, *SPIE*, **4204**, 230 (2001).
14. S. Tao, S. Gong, L. Xu and J. C. Fanguy, *Analyst*, in press.
15. S. Tao, C. B. Winstead, H. Xian and K. Soni, *J. Environ. Monit.*, **4**, 815 (2002).
16. S. Tao, C. B. Winstead, J. P. Singh and R. Jindal, *Opt. Lett.*, **27**, 1382 (2002).
17. G. L. Klunder and R. E. Russo, *Appl. Spectrosc.*, **49**, 379 (1995).
18. S. Tao, C. B. Winstead, R. Jindal and J. P. Singh, *IEEE Sensor Journal*, in press.
19. C. Whalley, A. Hursthouse, S. Rowlatt, P. Iqbal-Zahid, H. Vaughan and R. D. Durant, *Water, Air and Soil Pollution*, 1999, **112**, 389-405.
20. http://www.swrcb.ca.gov/rwqcb4/html/water_qty/chromium_81.html.
21. E. C. Thornton and J. E. Amonette, *Environ. Sci. Technol.*, 1999, **33**, 4096.
22. C. T. Dillon, P. A. Lay, A. M. Bonin, M. Cholewa, G. J. F. Legge, T. J. Collins and K. L. Kostka, *Chem. Res. Toxicol.*, 1998, **11**, 119.
23. G. Quievryn, J. Messer and A. Zhitkovich, *Biochem.*, 2002, **41**, 3156.
24. S. Tao and T. Kumamaru, *Anal. Proc.*, 1995, **32**, 371.
25. R. E. Clement and P. W. Yang, *Anal. Chem.*, 1999, **71**, 257R.

HABITAT ASSESSMENT OF SELECTED STREAMS IN THE MISSISSIPPI RIVER ALLUVIAL PLAIN IN NORTHWESTERN MISSISSIPPI AND EASTERN ARKANSAS: WINTER AND SUMMER 2002

By Richard A. Rebich, Heather L. Welch, and Richard H. Coupe
U.S. Geological Survey, Jackson, Mississippi

INTRODUCTION

The U.S. Environmental Protection Agency (EPA) outlines in section 303(d) of the Clean Water Act (CWA) a requirement for each State to design restoration and remediation strategies for impaired water bodies within that State (Mississippi Department of Environmental Quality, 2000). As part of their statewide stream water-quality assessments, the Mississippi Department of Environmental Quality (MDEQ) uses the Index of Biological Integrity (IBI) method to determine impairment for most stream watersheds in Mississippi (Mississippi Department of Environmental Quality, 2000); however, this same IBI method could not be used for streams in the Mississippi River Alluvial Plain (MRAP) in northwestern Mississippi (Matt Hicks, MDEQ, written commun., 2002). MDEQ identified the need for an assessment method to evaluate water bodies for this particular region. Therefore, a workgroup was created to evaluate current methods to assess stream conditions for northwestern Mississippi streams and to define target conditions to serve as endpoints for ecological integrity (Randy Reed, MDEQ, written commun., 2001).

The workgroup, which included representatives from several State and Federal agencies, suggested a pilot study to: (1) collect four types of data – fish, macroinvertebrate, water quality, and habitat; and (2) determine if a particular data type could be used to indicate a range of stream conditions, and ultimately impairment, in northwestern Mississippi streams. For each data-collection effort, sampling protocols were evaluated for their effectiveness in indicating ranges of stream conditions. In some cases, more than one sampling protocol was evaluated.

Purpose and Scope

The U.S. Geological Survey (USGS), in cooperation with MDEQ, collected water samples and assessed stream habitat at 43 MRAP sites in northwestern Mississippi (sites 8-50, fig. 1) during two index periods (winter, January-April 2002, and summer, July-September 2002). Data were also collected at seven MRAP sites in eastern Arkansas (sites 1-7, fig. 1) during the same two index periods. The habitat assessment data are the focus of this report. This report: (1) documents methods of site selection and categorization, data collection, quality assurance/quality control, and statistical analysis; and (2) presents summaries of the habitat assessments and results of statistical analyses to determine if any of the habitat assessments could indicate a range of stream conditions for northwestern Mississippi streams.

Description of the Study Area

The study area is in the part of the MRAP that lies in northwestern Mississippi and eastern Arkansas (fig. 1). The study focused primarily on the part of the MRAP in northwestern Mississippi, an area described briefly in the following paragraphs.

The entire MRAP in Mississippi is drained by the Yazoo River, which is formed by the confluence of the Tallahatchie and Yalobusha Rivers. The Yazoo River flows southward from Greenwood along the eastern edge of the alluvial valley to the Mississippi River at Vicksburg. Four flood-control reservoirs (Arkabutla, Sardis, Enid, and Grenada Lakes) are located in the northeastern part of the Yazoo River basin. These reservoirs control the runoff from more than 4,400 mi^2 of drainage area within the Yazoo River Basin (Coupe, 2000).

Tributary inflow to the Yazoo River downstream of Yazoo City is diverted by a levee along the right bank of the river channel from Yazoo City downstream to the split of the old channel and the Yazoo River Diversion Channel. In the mid-1960's, the U.S. Army Corps of Engineers (USACE) constructed a diversion canal that connected Steele Bayou, Deer Creek, the Little Sunflower River, and the Big Sunflower River. Runoff from the four basins is controlled by two flood-control structures on Steele Bayou and Little Sunflower River. The flood-control structures on Steele Bayou and Little Sunflower River are closed when the stage of the Yazoo River approaches the pool elevation at each structure, thus preventing extensive alluvial flooding by backwater from the Mississippi River. The flood-control structures are opened when the stage in the Yazoo River drops below the pool elevation, allowing water from Steele Bayou and Little Sunflower River to flow into the Yazoo River (Coupe, 2000).

The study area is sparsely populated and contains no major metropolitan areas. Agriculture is the dominant type of land use with cotton, soybean, catfish, rice, and corn being the most economically important crops. Farmers in the MRAP irrigate row crops and flood rice fields with ground water and some surface water, using as much as 7 billion gallons of water per day during the summer months (Kleiss and others, 2000).

METHODS

The methods used for data collection and analysis in this study were as important to the workgroup as the actual data collected. The following sections document the methods used for site selection and categorization, data collection, quality assurance and quality control, and statistical analysis.

Site Selection and Categorization

In order to evaluate stream conditions in diverse water bodies, 50 MRAP sites (fig.1) of varying stream sizes were recommended by the workgroup for study. Initial and alternate sites (discussed later) were treated as one site. Forty-three of the 50 sites were located in the eastern part of the MRAP region in the Yazoo River Basin, hereafter referred to as northwestern Mississippi (NWM) sites. Seven of the 50 sites were located in the western part of the MRAP region in eastern Arkansas, hereafter referred to as eastern Arkansas (EA) sites.

All 43 NWM sites were categorized according to drainage-area size, presence of flood-control structures, and whether the site was perennial or intermittent based on information from the USACE Engineer Research and Development Center (ERDC). The categories were as follows: 1) large, regulated; 2) large, unregulated; 3) medium; 4) small-perennial; and 5) small-intermittent. Fifteen of the 43 NWM sites were further categorized according to subjectively evaluated ("good" or "poor") stream conditions. These 15 NWM sites were considered by ERDC personnel to have good or poor stream conditions based on existing fisheries data that included total number of species, total number of fish, and species diversity (Jan Hoover and Jack Kilgore, ERDC, oral commun., 2001). Eighteen of the 43 NWM sites were randomly selected to increase the number of sites that had small drainage areas. These 18 random sites were selected by Tetra Tech, Inc., using Geographical Information System (GIS) software (James Stribling, Tetra Tech, oral commun., 2003). The random sites were categorized as either small-perennial or small-intermittent, but, because of insufficient data, were not categorized as having good or poor stream conditions. EA sites are on streams sampled as part of the USGS National Water-Quality Assessment (NAWQA) Program (Billy Justus, U.S. Geological Survey, written commun., 2003) and were included to expand the range of available data. These seven sites were chosen to represent good stream conditions. Sites that were sampled and their associated categories are listed in table 1.

About 30 alternate small NWM sites were chosen by using the GIS software that was used to selected the random sites. A list of these sites, in order of sampling preferences, was provided to the field team for use when a site was dry, could not be accessed, or did not fit the proper size classification description. If the primary sites could not be sampled, the top alternate in that size category (perennial or intermittent) was chosen from the alternate list, regardless of location of the primary site.

Data Collection

Data were collected during two index periods: winter (January-April 2002) and summer (July-September 2002). In 2002, the study area received approximately 6 in. greater than normal precipitation causing above average streamflow conditions in the winter index period. The USACE closed some of the flood-control structures in the Yazoo River Basin, which created backwater conditions for several of the NWM sites during the study period. The backwater conditions created access problems (sampling was unsafe, and conditions were unsuitable) during the winter sampling period; consequently, habitat was assessed for only 27 of the 43 NWM sites through mid-March. In addition, habitat was assessed at only one EA site during the winter index period.

A habitat-assessment form (fig. 2) was used to document habitat characteristics in a stream reach. The assessment form was modified by MDEQ to adapt to the low-gradient streams in the MRAP region (Barbour and Stribling, 1994; Florida Department of Environmental Protection, 1996). Stream reaches were selected and measured: 300 ft for small streams or 1,500 ft for medium or large streams. The upstream and downstream limits of the reach were marked on or near the stream bank with orange or pink flagging labeled with the stream name, upstream or downstream end, date, and samplers' initials.

The habitat-assessment form included a general characteristics section: water appearance, water odor, water temperature, stream depth, stream width, and high-water mark. Subsequent sections of the assessment were scored on a scale of 1 to 20 (some were 1-10, fig. 2) according to the Habitat Parameter Assessment Guidelines for Glide Pool Streams (Barbour and Stribling, 1994; Florida Department of Environmental Protection, 1996) with 1 representing the most degraded and 20 representing the most stable habitat. The scored information included: epifaunal substrate/available cover, pool substrate characterization, pool variability, degree and type(s) of channel alteration, sediment deposition, channel sinuosity, channel flow status, bank vegetative protection, bank stability, and riparian vegetation zone width. A total habitat assessment score was determined by summing the individual scores from each of the sections. Upon completion of the assessment form, photographs were taken from the upstream and downstream ends of the reach (Mississippi Department of Environmental Quality, 2002).

Quality Assurance and Quality Control

There were at least three potential sources of error associated with habitat-assessment scores: basin/stream heterogeneity, sample variance, and field-personnel error. Fifteen duplicate habitat-assessment samples (or 20 percent) were collected on adjacent reaches by two different field personnel at each site to determine variability in stream heterogeneity. Habitat-assessment total scores for these duplicates were identical for 13 of the 15 samples. Relative percent differences were 1.2 and 3.5 percent, respectively, for duplicate habitat-assessment total scores determined at White River at Devalls Bluff, AR, and at Big Sunflower River below Bogue Phalia near Darlove, MS (relative percent differences were calculated by subtracting the value of a duplicate sample from the value of its paired sample, then dividing by their average and multiplying by 100). Habitat-assessment duplicates were not collected to assess sample variance and field-personnel error.

Statistical Analysis

Traditional statistical analyses require data sets to be random and independent. The habitat assessment data collected for this study violated these basic rules for two reasons: (1) only 18 sites were randomly selected -- the remaining sites were selected as was previously discussed; and (2) many of the sites were located on the same river, and therefore, are not independent. Although the habitat assessment data violated these basic rules, statistical analyses were completed, and the results were interpreted for exploratory purposes.

The software package SigmaStat (SPSS, Inc., 1997a), was used to perform statistical analyses on the habitat assessment total scores (hereafter referred to as total scores). SigmaStat uses the Kolmogorov-Smirnov test with Lilliefors' correction to determine if the total scores were normally distributed and to select the most appropriate statistical analyses (SPSS, Inc., 1997b, p. 6-29). The total scores data were determined to be normally distributed; therefore, the test statistic for each analysis was the mean of the data set being tested. A p-value, which is the probability of attaining a specified significance level, was calculated for each test (Helsel and Hirsch, 1992). P-values were compared to a significance level, or α, of 0.05 (5 percent), which meant that there was less than a 5-percent chance of errors in test results.

The purpose of the statistical analyses was to determine if the total scores could indicate ranges in stream conditions among and along streams in the study area. To accomplish this purpose, the analyses were designed to determine statistically significant differences for the following comparisons (based on site categories presented in table 1):

1. Sample index period – Habitat was assessed at nearly every NWM site during the winter and summer index periods, which created winter and summer data sets (or paired data sets) with an equal number of values for each constituent. The paired t-test was the most appropriate test to determine statistically significant differences in two data sets of equal sizes (Helsel and Hirsch, 1992); in this case, differences in the paired winter and summer data sets. If the associated p-value for a particular test was higher than 0.05, then the paired data were not statistically different. If the p-value was equal to or less than 0.05, then the tests indicated that the paired data were statistically different.
2. Site location – Because there were fewer EA sites sampled than NWM sites, statistical analyses would require comparing two data sets of unequal sizes. The t-test was determined to be the most appropriate statistical test to determine if total scores collected from the two regions were statistically different (Helsel and Hirsch, 1992). Since habitat was not assessed at the EA sites during the winter index period (except for one site), total scores from the EA and NWM sites were only compared for the summer index period.
3. Drainage-area size – Analysis of variance (ANOVA) was used to compare water-quality data at the 43 NWM sites categorized as large, medium, or small (table 1). ANOVA is used to compare multiple data sets of unequal sizes (Helsel and Hirsch, 1992); for this study, this test was used to determine if data from the individual size categories were statistically different from data from all size categories combined. If statistically significant differences were detected, then all pair-wise comparisons were analyzed separately: for example, data from small sites compared to data from medium sites.
4. Subjectively evaluated stream conditions – The t-test was used to compare total scores from the 15 NWM sites categorized as good or poor (table 1). The t-test is used to compare two data sets of unequal sizes.

HABITAT-ASSESSMENT TOTAL SCORE DATA AND STATISTICAL RESULTS

All of the habitat assessment data are presented in table 2 including scores for individual sections and the total scores for all sections. Distributions, by category, for total scores are presented as boxplots in figure 3. These types of plots allow for the side-by-side comparison of data distributions (Helsel and Hirsch, 1992). Results of all the statistical analyses are presented in the following paragraphs, and a discussion of the results is presented at the end of this section. For statistically significant results, mean total scores are presented in parentheses in the text as a means to compare the data in original units.

Statistical results

The result of a paired t-test indicated a statistically significant difference when comparing total scores collected at NWM sites during the winter index period to total scores collected during the summer index period (the p-value of the test was 0.044). The mean total score for the winter index period (78) was lower than the mean total score for the summer index period (88). In evaluating the individual sections of the habitat assessments (table 2), it appears that scores were likely influenced by higher than average flows during the summer index period at some of the sites. For example, higher individual scores were obtained for bottom substrate, pool substrate, pool variability, sediment deposition, and channel flow status at Big Sunflower River at Hopson Spur and Quiver River near Rome for the summer index period than for the winter index period.

Habitat assessments for six EA sites were available for the summer index period. The result of a t-test indicated a statistically significant difference when total scores at the EA sites were compared to total scores at NWM sites for the summer index period (the p-value of the test was <0.001). The mean total score at EA sites (151) was nearly double the mean total score at NWM sites (81) for the summer index period.

ANOVA tests were run separately for the two index periods when total scores at the NWM sites were compared based on drainage-area size (small, medium, and large). Statistically significant differences were detected for both index periods (p-value = 0.009, winter; p-value= 0.03, summer). In looking at all pair-wise comparisons for the winter index period, the mean total score for large sites (102) was higher the mean total score for medium sites (59) and for small sites (77). Although statistically significant differences were detected in the total scores for the summer period, none of the pair-wise comparisons were statistically significant.

Results of a t-test indicated no statistically significant differences when total scores from five NWM sites categorized as good were compared to total scores from the ten NWM poor sites. Statistically significant differences were also not detected when total scores from the 18 randomly selected NWM sites were included in an ANOVA analyses with the total scores from the good and poor NWM sites. However, statistically significant differences were detected (p-value = 0.001, ANOVA test) when total scores from EA sites were considered in the analyses. This last ANOVA test was run only for the summer index period because habitat was assessed at EA sites for the summer index period only. In considering all pair-wise comparisons, the mean total score from EA sites (151) was higher than the mean total scores from all NWM site categories (good, 106; poor, 100; random, 81).

Discussion

Statistically significant differences were observed in the total scores for all four comparisons, and therefore, total scores were considered practical in indicating ranges in stream conditions among the sites sampled. Statistical results were also evaluated to determine the value of data analysis by category. For NWM sites, sample index period was considered a weak comparison due to the influence of higher than normal flows during the summer index period. The comparison of total scores from the NWM sites categorized according to drainage area size proved to be a fairly strong comparison during the winter index period with higher scores for the large sites as compared to the medium and small sites. Similar results may have been realized for the summer index period had summer flows not been higher than average. Total scores for EA sites greatly influenced test results and were always significantly higher than total scores from NWM sites whether comparing all scores or comparing total scores from the EA sites scores from good, poor, or random NWM sites. The weakest statistical results were for the comparison of total scores from NWM sites categorized as having good or poor stream conditions.

SUMMARY

Habitat was assessed at 50 MRAP sites by personnel of the USGS and MDEQ during the winter and summer for 2002. Forty-three of the 50 sites were located in northwestern Mississippi; seven sites were located in eastern Arkansas. These seven sites were subjectively chosen for this study because they were representative of good stream conditions for the study area.

MDEQ protocols were followed for habitat assessments. There were at least three potential sources of error associated with habitat assessment: basin/stream heterogeneity, sample variance, and field personnel error. Fifteen duplicate habitat-assessment samples (or 20 percent) were collected on adjacent reaches from ten sites to determine variability in stream heterogeneity. Habitat-assessment total scores for these replicates were identical for 13 of the 15 samples, and relative percent differences were less than 4 percent for the other two replicates. Habitat-assessment replicates were not collected to assess sample variance and field personnel error.

Statistical analyses were performed to determine if habitat-assessment total scores could be used to detect ranges in stream conditions for sites sampled in the MRAP region. Statistical analyses compared the total scores based on sample-index period, site location, drainage-area size, and subjectively evaluated stream conditions (sites that were categorized as good or poor).

Statistically significant differences were observed in the total scores for all four comparisons, and therefore, total scores were considered practical in indicating ranges in stream conditions among the sites sampled. Statistical results were also evaluated to determine the value of data analysis by category. For NWM sites, sample index period was considered a weak comparison due to the influence of higher than normal flows during the summer index period. The comparison of total scores from the NWM sites categorized according to drainage area size proved to be a fairly strong comparison during the winter index period with higher scores for the large sites as compared to the medium and small sites. Similar results may have been realized for the summer index period had summer flows not been higher than average. Total scores for EA sites greatly influenced test results and were always significantly higher than total scores from NWM sites whether comparing all scores or comparing total scores from the EA sites scores from good, poor, or random NWM sites. The weakest statistical results were for the comparison of total scores from NWM sites categorized as having good or poor stream conditions.

REFERENCES

Barbour, M.T., and Stribling, J.B., 1994, A technique for assessing stream habitat structure, *in* Riparian ecosystems in the humid U.S.: Functions, values and management, 1993, Proceedings: Washington D.C., National Association of Conservation Districts, p. 156-178.

Coupe, R.H., 2000, Occurrence of pesticides in five rivers of the Mississippi Embayment study unit, 1996-98: U.S. Geological Survey Water-Resources Investigations Report 99-4159, 55 p.

Florida Department of Environmental Protection, 1996, Standard operating procedures for biological assessment: variously paginated.

Helsel, D.R., and Hirsch, R.M., 1992, Statistical methods in water resources: Elsevier Publishing, NY, 522 p.

Kleiss, B.A., Coupe, R.H., Gonthier, G.A., and Justus, B.G., 2000, Water quality in the Mississippi Embayment – Mississippi, Louisiana, Arkansas, Missouri, Tennessee, and Kentucky, 1995-98: U.S. Geological Survey Circular 1208, 36 p.

Mississippi Department of Environmental Quality, 2000, State of Mississippi water quality assessment 2000 section 305 (b) report: Mississippi Department of Environmental Quality, 105 p.

Mississippi Department of Environmental Quality, 2002, Standard operating procedures for Mississippi Delta pilot study phase I: 82 p.

SPSS, Inc., 1997a, SigmaStat for Windows version 2.03: SPSS, Inc., copyright 1992-1997.

SPSS, Inc., 1997b, SigmaStat statistical software user's manual – Version 2.0 for Windows 95, NT, and 3.1: SPSS, Inc., variously paginated.

Table 1. List of site names, locations, sizes, types, and sampling dates

[USGS, U.S. Geological Survey; MDEQ, Mississippi Department of Environmental Quality; AR, Arkansas; M, medium; N.A., not applicable; S-P, small-perennial; L-R, large-regulated; MS, Mississippi; S-I, small-intermittent; L-U, large-unregulated; w, winter; s, summer]

Site number (fig. 1)	Station number	Station name	MDEQ number	Latitude	Longitude	Size	Station type[1]	Winter sample date[2]	Summer sample date[2]
1	07074700	Village Creek near Newport, AR	212	35° 35' 33"	91° 14' 31"	M	Good	N.A.	7/30/02
2	07074883	Glaise Creek at Hwy 64 near Augusta, AR	213	35° 17' 30"	91° 28' 26"	M	Good	N.A.	7/30/02
3	07077527	Cache River near Cotton Plant, AR	210	35° 05' 07"	91° 17' 54"	M	Good	N.A.	7/31/02
4	07077720	Bayou DeView at Hwy 38 near Cotton Plant, AR	211	35° 00' 17"	91° 12' 28"	M	Good	N.A.	7/29/02
5	07047947	Second Creek near Palestine, AR	216	35° 02' 21"	90° 54' 40"	S-P	Good	N.A.	7/31/02
6	07077000	White River at Devalls Bluff, AR	208	34° 47' 25"	91° 26' 45"	L-R	Good	1/22/02	N.A.
7	07078040	Lagrue Bayou near DeWitt, AR	209	34° 19' 00"	91° 16' 57"	M	Good	N.A.	7/29/02
8	344529090115500	Unnamed Tributary to Coldwater River near Prichard, MS	317	34° 45' 29"	90° 11' 55"	S-I	Random	1/31/02	7/15/02
9	344402090230100	Unnamed Tributary to White Oak Bayou near Tunica, MS	316	34° 44' 02"	90° 23' 01"	S-I	Random	1/31/02	N.A.
10	342815090195500	Unnamed Tributary to Twelvemile Bayou near Tibbs, MS	315	34° 28' 15"	90° 19' 55"	S-I	Random	2/1/02	7/15/02
11	342630090142600	Yellow Lake Bayou at Sledge, MS	411	34° 26' 30"	90° 14' 26"	S-P	Random	3/5/02	7/15/02
12	342510090183500	Unnamed Tributary to White Oak Bayou near Sledge, MS	314	34° 25' 09"	90° 18' 36"	S-I	Random	2/5/02	7/16/02
13	341640090055100	Unnamed Tributary to Tallahatchie River near Locke Station, MS	306	34° 16' 39"	90° 05' 52"	S-P	Random	2/5/02	7/16/02
14	07288010	Big Sunflower River at Hopson Spur, MS	28	34° 09' 23"	90° 32' 59"	M	Poor	2/13/02	7/23/02
15	340657090080900	Unnamed Tributary to Tallahatchie River near Crowder, MS	313	34° 06' 57"	90° 08' 09"	S-I	Random	N.A.	7/16/02
16	335915090423900	Hushpuckena River near Hushpuckena, MS	218	33° 59' 15"	90° 42' 39"	S-P	N.A.	2/13/02	7/22/02
17	335632090291000	Bear Bayou near Minot, MS	402	33° 56' 32"	90° 29' 10"	S-P	Random	2/25/02	7/17/02
18	335737090270100	Quiver River near Rome, MS	305	33° 57' 39"	90° 26' 54"	S-P	Random	2/25/02	7/17/02
19	07280900	Cassidy Bayou at Webb, MS	217	33° 57' 01"	90° 20' 27"	S-P	Poor	N.A.	8/13/02
20	335919090133600	Opposum Bayou near Webb, MS	33	33° 59' 19"	90° 13' 36"	S-P	Good	N.A.	8/12/02
21	335946090121100	Tallahatchie River near Webb, MS	201	33° 59' 46"	90° 12' 11"	L-R	N.A.	N.A.	8/12/02
22	340120090113300	Tallahatchie River near Charleston, MS	200	34° 01' 20"	90° 11' 33"	L-R	N.A.	N.A.	8/13/02
23	340203090073000	Panola Quitman Floodway near Charleston, MS	202	34° 02' 03"	90° 07' 30"	L-R	N.A.	N.A.	8/13/02
24	335250090454700	Unnamed Tributary to Jones Bayou near Mound Bayou, MS	511	33° 52' 50"	90° 45' 47"	S-I	Random	3/5/02	7/23/02
25	07288280	Big Sunflower River near Merigold, MS	54	33° 49' 57"	90° 40' 12"	M	Poor	2/14/02	7/23/02

Table 1. List of site names, locations, sizes, types, and sampling dates…*continued*

Site number (fig. 1)	Station number	Station name	MDEQ number	Latitude	Longitude	Size	Station type[1]	Winter sample date[2]	Summer sample date[2]
26	335200090094500	South Lake Bayou near Tippo, MS	303	33° 52' 00"	90° 09' 45"	S-P	Random	N.A.	7/16/02
27	334303090060100	Yalobusha River near Leflore, MS	203	33° 43' 03"	90° 06' 01"	L-R	N.A.	N.A.	8/14/02
28	07288643	Bogue Phalia near Shaw, MS	59	33° 36' 10"	90° 51' 10"	M	Poor	2/14/02	7/23/02
29	334030090482200	East Bogue Hasty near Skene, MS	513	33° 40' 30"	90° 48' 22"	S-I	Random	2/25/02	7/24/02
30	334402090395400	Unnamed Tributary to Darr Bayou near Cleveland, MS	311	33° 44' 06"	90° 39' 57"	S-I	Random	2/12/02	7/24/02
31	333940090370900	Jones Bayou at Linn, MS	58	33° 39' 34"	90° 37' 07"	S-P	Poor	2/26/02	8/2/02
32	334248090311000	Quiver River Southeast of Ruleville, MS	215	33° 42' 48"	90° 31' 10"	M	Poor	N.A.	7/23/02
33	334251090181900	Unnamed Tributary to Tallahatchie River near Minter City, MS	310	33° 42' 51"	90° 18' 19"	S-I	Random	2/20/02	7/17/02
34	07286200	Yalobusha River at Whaley, MS	204	33° 37' 54"	90° 06' 38"	L-R	N.A.	N.A.	8/14/02
35	333600090281000	McGregory Bayou near Blaine, MS	415	33° 36' 00"	90° 28' 10"	S-P	Random	2/12/02	7/25/02
36	07288500	Big Sunflower River at Sunflower, MS	214	33° 32' 50"	90° 32' 35"	M	Poor	2/27/02	8/5/02
37	07281610	Tallahatchie River above Pemberton Cut near Greenwood, MS	205	33° 31' 58"	90° 14' 17"	L-R	N.A.	N.A.	8/15/02
38	332749090103400	Pelucia Creek near Rising Sun, MS	301	33° 27' 51"	90° 10' 25"	S-P	Random	2/19/02	7/18/02
39	07288600	Quiver River near Moorhead, MS	69	33° 29' 16"	90° 31' 06"	M	Good	N.A.	8/6/02
40w	07288530	Big Sunflower River above Quiver River near Indianola, MS	67	33° 28' 23"	90° 34' 30"	L-U	Poor	2/28/02	N.A.
40s	07288610	Big Sunflower River near Moorehead, MS	67	33° 27' 44"	90° 33' 45"	L-U	Poor	N.A.	8/6/02
41	07288620	Big Sunflower River at Baird, MS	66	33° 25' 38"	90° 35' 30"	L-U	Good	3/7/02	8/6/02
42	07288621	Big Sunflower River at Indianola, MS	71	33° 25' 06"	90° 38' 01"	L-U	Poor	3/7/02	8/6/02
43	332501090405800	Sheperds Bayou near Indianola, MS	300	33° 25' 01"	90° 40' 57"	S-P	Random	2/15/02	8/5/02
44	07288624	Big Sunflower River at Kinlock, MS	85	33° 18' 34"	90° 42' 23"	L-U	Good	3/8/02	8/7/02
45	331432090435300	Big Sunflower River below Bogue Phalia near Darlove, MS	87	33° 14' 15"	90° 43' 55"	L-U	Good	3/8/02	8/7/02
46	330730090431300	Murphy Bayou at Murphy, MS	506	33° 07' 30"	90° 43' 13"	S-I	Random	2/28/02	8/7/02
47	07287500	Yazoo River at Yazoo City, MS	206	32° 55' 41"	90° 24' 46"	L-R	N.A.	N.A.	8/28/02
48	07288800	Yazoo River at Redwood, MS	207	32° 29' 14"	90° 49' 02"	L-R	N.A.	N.A.	8/27/02
49	07288720	Big Sunflower River at Holly Bluff, MS	106	32° 48' 49"	90° 43' 08"	L-U	Poor	N.A.	8/28/02
50	322804090533900	Steele Bayou above Little Sunflower Connect Channel, MS	110	32° 28' 04"	90° 53' 39"	L-U	N.A.	N.A.	8/27/02

[1] "Good" and "poor" refer to subjectively evaluated water quality (see text). "N.A." in this column means "not categorized as having good or poor water quality." Sites categorized as "random" were also not categorized as having good or poor water quality.
[2] "N.A." refers to sites sampled for only one index period. For site "40", these were separate sites in close proximity to each other that were considered the same location for statistical analyses.

Table 2. Habitat-assessment data collected during the winter and summer 2002 index periods

[MDEQ, Mississippi Department of Environmental Quality; LB, left bank; RB, right bank; AR, Arkansas; BD, biological duplicate; MS, Mississippi; s, summer; w, winter]
[The ten habitat parameters were scored on a scale of 1 to 20, with 1 representing the most degraded and 20 representing the most stable habitat]

Site number (fig. 1)	Station number	Station name	MDEQ number	Date	Habitat-assessment scores: Bottom substrate / available cover	Pool substrate characterization	Pool variability	Channel alteration	Sediment deposition	Channel sinuosity	Channel flow status	Bank vegetative protection LB	Bank vegetative protection RB	Bank stability LB	Bank stability RB	Riparian vegetation width LB	Riparian vegetation width RB	Total
1	07074720	Village Creek near Newport, AR	212	7/30/02	18	13	10	20	18	15	20	10	10	10	9	10	5	168
2	07074853	Glaise Creek at Hwy 64 near Augusta, AR	213	7/30/02	5	6	6	15	3	12	11	8	8	9	9	10	7	109
			213-BD	7/30/02	5	6	6	15	3	12	11	8	8	9	9	10	7	109
3	07077527	Cache River near Cotton Plant, AR	210	7/31/02	7	11	13	18	11	18	20	10	10	10	10	10	10	158
			210-BD	7/31/02	7	11	13	18	11	18	20	10	10	10	10	10	10	158
4	07077720	Bayou DeView at Hwy 38 near Cotton Plant, AR	211	7/29/02	18	13	18	15	14	16	20	10	10	10	10	9	10	173
5	07047947	Second Creek near Palestine, AR	215	7/31/02	13	17	11	15	14	18	20	10	10	10	10	10	10	168
			215-BD	7/31/02	13	17	11	15	14	18	20	10	10	10	10	10	10	168
6	07077000	White River at Devalls Bluff, AR	208	1/23/02	6	6	3	12	6	7	18	1	3	3	5	9	9	88
			208-BD	1/23/02	6	7	7	10	6	7	18	1	3	3	1	9	9	86
7	07078040	Lagrue Bayou near De Witt, AR	209	7/29/02	18	11	6	15	9	18	10	5	8	8	8	10	10	136
			209-BD	7/29/02	18	11	6	15	9	18	10	5	8	8	8	10	10	136
8	344520090115500	Unnamed Tributary to Coldwater River near Prichard, MS	317	1/31/02	3	8	3	3	0	0	13	3	3	3	3	0	0	36
				7/15/02	4	6	0	1	0	0	18	1	8	3	3	0	0	44
9	344402090230100	Unnamed Tributary to White Oak Bayou near Tunica, MS	316	1/31/02	4	11	2	3	3	2	18	2	3	5	5	0	0	57
10	342813090195500	Unnamed Tributary to Twelvemile Bayou near Tibbs, MS	315	2/1/02	3	6	2	11	17	0	9	9	9	10	10	1	1	88
				7/15/02	6	8	3	1	12	0	11	9	9	9	9	2	2	81
11	342630090142600	Yellow Lake Bayou at Sledge, MS	411	2/5/02	0	6	0	5	1	6	15	4	4	5	5	4	4	59
				7/15/02	5	6	6	3	3	7	18	7	7	9	9	6	6	92
12	342530090183500	Unnamed Tributary to White Oak Bayou near Sledge, MS	318	2/5/02	3	6	0	3	6	0	20	9	9	4	4	0	0	64
				7/16/02	2	1	0	1	20	0	7	8	8	7	7	0	0	61
13	341640090335100	Unnamed Tributary to Tallahatchie River near Locke Station, MS	306	2/5/02	6	6	8	16	6	10	7	5	5	6	6	6	6	93
				7/16/02	6	11	8	11	6	6	5	6	6	8	8	5	5	91
14	07288010	Big Sunflower River at Hopson Spur, MS	28	2/13/02	3	6	2	11	1	6	3	4	4	6	6	4	4	60
				7/22/02	6	6	8	15	6	13	5	5	5	6	6	9	9	99
15	340657090080900	Unnamed Tributary to Tallahatchie River near Crowder, MS	313	7/16/02	6	9	2	1	1	0	15	7	6	6	6	2	1	63
16	335913090823900	Hushpuckena River near Hushpuckena, MS	218	2/13/02	3	9	11	11	9	9	18	3	3	6	6	8	8	104
			218-BD	2/13/02	3	9	11	11	9	9	18	3	3	6	6	8	8	104
			218	7/22/02	13	8	12	14	9	10	18	9	9	7	7	9	9	133
			218-BD	7/22/02	12	8	12	14	9	10	18	9	9	7	7	9	9	133
17	335632090291000	Bear Bayou near [illegible], MS	402	2/25/02	3	6	2	15	3	15	15	5	6	6	6	7	6	95
			402-BD	2/25/02	4	6	3	15	3	15	15	5	6	6	6	7	6	96
			402	7/17/02	6	11	3	3	3	4	11	7	7	9	9	2	2	77
			402-BD	7/17/02	6	11	3	3	3	4	11	7	7	9	9	2	2	77
18	335737090270100	Quiver River near Rome, MS	305	2/25/02	6	6	6	15	3	15	5	8	9	8	7	9	9	106
				7/17/02	19	13	10	15	9	16	20	9	9	9	9	9	9	156
19	07280900	Cassidy Bayou at Webb, MS	217	8/13/02	5	6	6	15	3	4	11	5	5	9	9	0	4	82
20	335919090133500	Opossum Bayou near Webb, MS	33	8/12/02	6	11	7	11	9	7	16	9	9	6	6	10	10	117
			33-BD	8/12/02	6	11	7	11	9	7	16	9	9	6	6	10	10	117
21	335946090131100	Tallahatchie River near Webb, MS	201	8/12/02	6	8	7	3	11	4	18	2	6	2	5	2	7	81
22	340120090113300	Tallahatchie River near Charleston, MS	200	8/13/02	7	12	6	11	11	12	18	7	7	7	7	4	7	116
23	340203090073000	Panola Quitman Floodway near Charleston, MS	202	8/13/02	5	4	0	3	20	4	20	7	7	5	5	2	5	87
24	335250090854700	Unnamed Tributary to Jones Bayou near Mound Bayou, MS	511	2/5/02	3	4	0	3	11	4	18	5	5	5	5	0	0	63
				7/23/02	7	8	7	3	11	0	15	8	8	7	7	2	2	85
25	07288280	Big Sunflower River near Merigold, MS	54	2/14/02	3	6	2	6	3	6	16	2	3	1	1	5	7	60
				7/23/02	7	8	6	11	14	7	18	6	6	6	6	7	4	106
26	335200090094500	South Lake Bayou near Tippo, MS	308	7/16/02	11	11	6	16	11	6	9	9	9	7	7	5	5	112
27	334303090060100	Yalobusha River near Leflore, MS	203	8/14/02	13	12	7	12	18	15	18	9	9	5	5	10	10	142
28	07288643	Bogue Phalia near Shaw, MS	59	2/14/02	3	7	3	3	1	2	16	1	1	1	1	1	0	40
				7/23/02	6	11	8	3	11	4	11	6	7	6	7	7	7	94
29	334030090082200	East Bogue Hasty near Shaw, MS	513	2/25/02	2	6	3	3	2	2	15	2	3	3	5	1	1	48
				7/24/02	5	6	9	3	6	4	15	6	5	7	7	1	1	75
30	334412090095400	Unnamed Tributary to Dean Bayou near Cleveland, MS	311	2/12/02	5	9	5	3	6	2	10	6	6	6	6	2	2	68
				7/24/02	6	6	3	3	6	4	13	7	7	8	8	4	3	78
31	333940090370000	Jones Bayou at Linn, MS	58	2/26/02	7	9	5	15	6	12	15	8	10	9	9	7	10	122
				8/2/02	3	6	0	5	3	4	18	5	8	5	5	3	8	73

Table 2. Habitat-assessment data collected during the winter and summer 2002 index periods...*continued*

Site number (fig. 1)	Station number	Station name	MDEQ number	Date	Habitat-assessment scores: Bottom substrate / available cover	Pool substrate characterization	Pool variability	Channel alteration	Sediment deposition	Channel sinuosity	Channel flow status	Bank vegetative protection		Bank stability		Riparian vegetation width		Total
												LB	RB	LB	RB	LB	RB	
32	334248090311000	Quiver River Southeast of Ruleville, MS	215	7/03/02	6	6	6	13	14	13	13	9	9	8	8	8	8	121
			215-ED	7/04/02	6	6	6	13	14	13	13	9	9	8	8	8	8	121
33	334131090181900	Unnamed Tributary to Tallahatchie River near Minter City, MS	330	2/20/02	1	6	0	1	12	0	20	3	3	5	5	0	0	56
				7/17/02	5	5	3	4	2	4	20	7	6	8	9	2	2	77
34	07286200	Yalobusha River at Whaley, MS	204	8/14/02	6	12	3	10	14	8	18	7	7	4	4	9	9	111
35	333600090281000	McGregory Bayou near Blaine, MS	415	2/12/02	3	6	2	3	1	0	18	4	4	3	3	1	1	49
				7/15/02	2	6	0	3	0	0	5	4	4	7	7	1	2	41
36	07288500	Big Sunflower River at Sunflower, MS	214	2/07/02	5	6	6	3	9	9	15	3	3	3	3	7	5	77
				8/5/02	12	12	7	11	11	12	13	4	5	3	4	4	8	106
37	07281510	Tallahatchie River above Pemberton Cut near Greenwood, MS	203	8/15/02	6	6	3	5	11	5	18	6	6	6	6	9	4	92
38	332749090103400	Pelucia Creek near Rising Sun, MS	301	2/19/02	5	8	6	6	6	4	16	6	6	6	6	5	5	85
			301-ED	2/19/02	5	8	6	6	6	4	16	6	6	6	6	5	5	85
			301	7/18/02	5	7	2	3	17	0	9	5	5	7	7	6	6	79
			301-ED	7/18/02	5	7	2	3	17	0	9	5	5	7	7	6	6	79
39	07288000	Quiver River near Moorhead, MS	59	8/6/02	5	6	6	16	11	13	13	5	5	6	6	7	7	106
40w	07288530	Big Sunflower River above Quiver River near Indianola, MS	67	2/08/02	5	6	6	15	12	9	16	2	2	2	2	7	7	91
40e	07288610	Big Sunflower River near Moorhead, MS		8/6/02	6	6	7	11	11	13	13	6	6	5	5	4	3	96
41	07288520	Big Sunflower River at Baird, MS	56	3/7/02	5	11	7	13	11	11	18	6	6	5	4	6	6	109
				8/6/02	5	6	7	16	3	10	15	9	9	7	7	6	6	106
42	07288521	Big Sunflower River at Indianola, MS	71	3/7/02	7	11	7	15	3	11	20	7	7	5	5	9	8	115
				8/6/02	7	9	3	15	6	10	15	7	8	7	7	9	9	113
43	332501090405800	[illegible] Bayou near Indianola, MS	300	2/15/02	3	8	8	3	3	0	10	3	3	4	4	1	2	52
				8/5/02	5	8	3	3	9	0	11	8	8	5	8	2	2	72
44	07288524	Big Sunflower River at Kinlock, MS	65	3/8/02	3	6	7	13	6	7	18	7	3	6	7	9	7	99
				8/7/02	6	6	6	3	3	11	15	9	9	6	6	7	7	94
45	331432090435300	Big Sunflower River below Bogue Phalia near Darlove, MS	87	3/8/02	3	11	7	11	11	7	18	3	4	4	3	7	7	96
			87-ED	3/8/02	3	6	7	11	6	7	19	7	7	7	7	10	6	103
			87	8/7/02	7	6	9	3	6	11	15	8	8	6	6	5	5	95
			87-ED	8/7/02	7	6	9	3	6	11	15	8	8	6	6	5	5	95
46	330730090431300	Murphy Bayou at Murphy, MS	506	2/08/02	6	11	8	10	11	2	15	4	4	6	6	2	2	87
				8/7/02	6	11	2	8	11	0	11	8	8	7	7	0	0	79
47	07287500	Yazoo River at Yazoo City, MS	206	8/08/02	5	8	7	11	14	11	7	7	7	7	7	9	7	107
48	07288800	Yazoo River at Redwood, MS	207	8/27/02	5	6	8	6	3	7	13	6	6	7	7	9	9	92
49	07288720	Big Sunflower River at Holly Bluff, MS	156	8/08/02	6	6	7	16	6	12	11	9	9	6	6	9	9	112
50	322904090533900	[illegible] Bayou above Little Sunflower Connect Channel, MS	110	8/27/02	7	6	3	6	3	4	13	8	8	7	7	9	9	90

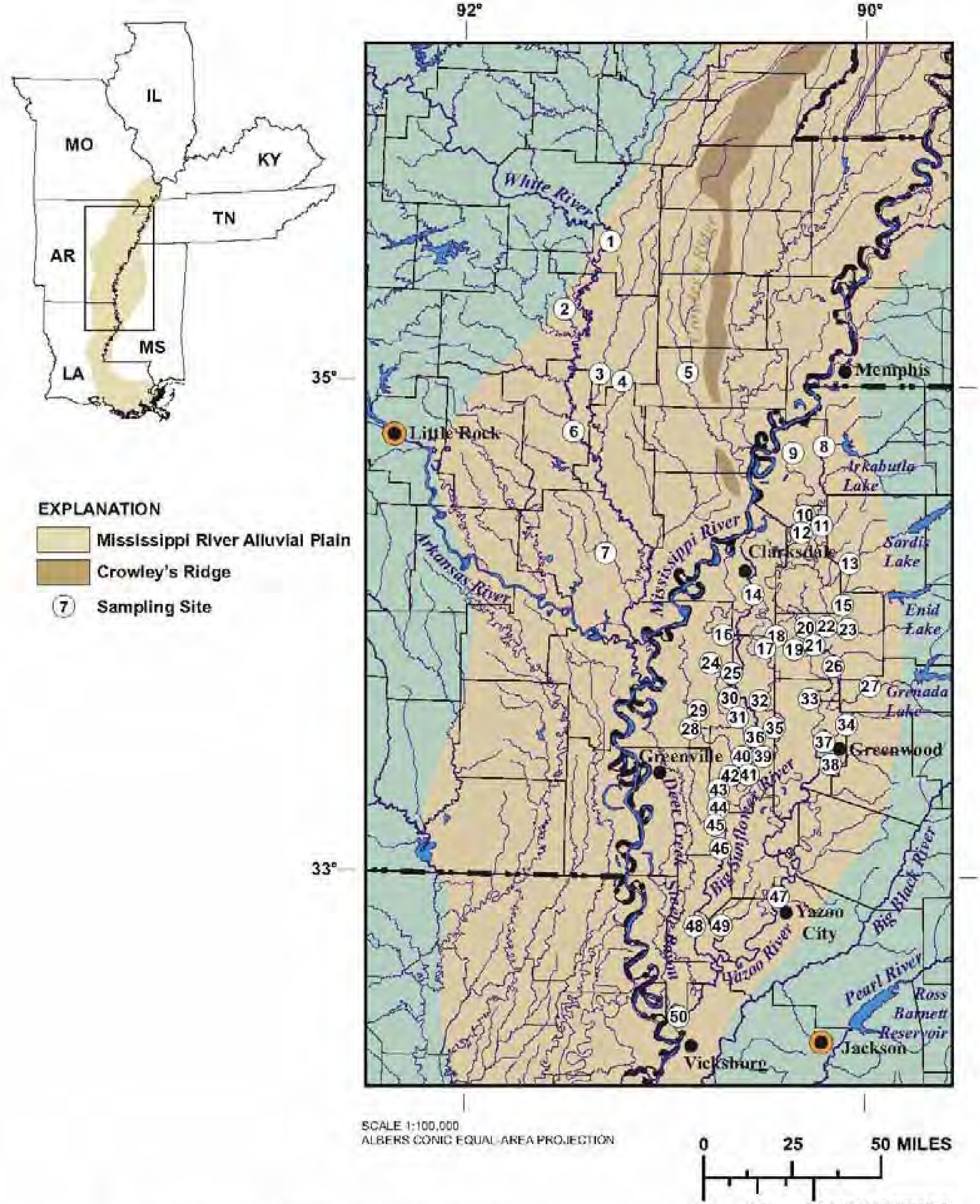


Figure 1. Location of study area and sampling sites.

Mississippi Department of Environmental Quality

SURFACE WATER HABITAT ASSESSMENT FIELD DATA SHEET

Benthos Survey ☐
Fish Survey ☐

Station Name:	Station Location:	
Station Number:	Station Type:	Project Name:
Date/Time:	Lattitude:	Longitude:
County:	Basin:	Ecoregion:
Investigator(s):	Completed by:	Photo ID:
Weather Conditions:		
Comments/Observations (Directions to station/describe important features):		

SECTION I – PHYSICAL CHARATERIZATION

RIPARIAN ZONE/INSTREAM FEATURES

Surrounding Land Use Percent (%): Forest____ Field/Pasture____ Agricultural____ Residential____ Commercial____ Industrial____ Other________

Local Watershed Erosion: None__ Moderate__ Heavy__ Dam Present: Yes__ No__ Channelized: Yes__ No__

Local Watershed NPS Pollution: No Evidence__ Some Potential Sources__ Obvious Sources__ Describe________

Estimated Stream Width (m):____ Bank Width (m):____ High Water Mark (m):____ Average Stream Depth (m):____

Canopy Cover: Open (0-25%)____ Partly Open (25-50%)____ Partly Shaded (50-75%)____ Shaded (75-100%)____

SEDIMENT SUBSTRATE

Sediment Odors: Normal__ Sewage__ Petroleum__ Chemical__ Anaerobic__ Other________

Sediment Oils: Absent__ Slight__ Moderate__ Profuse__

Sediment Deposits: Sludge__ Sawdust__ Paper Fiber__ Sand__ Relict Shells__ Silt__ Other________

Are the undersides of stones which are not deeply embedded black? Yes__ No__

Inorganic Substrate Type	Diameter	Percent Composition	Organic Substrate Type	Characteristics	Percent Composition
Cobble	64-256 mm (2.5-10")		Detritus	Sticks, wood, coarse plant materials (CPOM)	
Gravel	2-64 mm (0.1-2.5")				
Sand	0.06-2 mm (gritty)		Muck/Mud	Black, very fine organic (FPOM)	
Silt	0.004-0.06 mm				
Clay	<0.004 mm (slick)		Marl	Gray shell fragments	
Hard-Pan Clay			Other:		

SECTION II – WATER QUALITY

Air Temp:____°C pH:____ Water Temp:____°C Dissolved Oxygen:____mg/L Conductivity:____µmhos/cm

Salinity:____ppt TDS:____mg/L Dissolved Oxygen (% Sat):____ Other________ Instruments________

Water Odors: Normal__ Sewage__ Petroleum__ Chemical__ Other________ % of Reach Affected:____

Water Surface Oils: None__ Flecks__ Globs__ Sheen__ Slick__ Photograph ID:____ % of Reach Affected:____

Turbidity: Clear__ Slightly Turbid__ Turbid__ Opaque__ NTU:________ Water Color:________

SECTION III – HABITAT TYPES SAMPLED

Indicate number of jabs allocated / habitat type (allocate jabs in proportion to their frequency within reach - EXCEPTION: standard 5 jabs in sand/silt for *all* stations)

COBBLE/GRAVEL - HARD SUBSTRATES IN FAST-FLOWING RIFFLE/RUN WATERS	
SNAGS - DEBRIS ACCUMULATIONS OF LEAVES AND STICKS	
VEGETATED BANKS - UNDERCUT BANKS / ROOT MATS	
SUBMERGED MACROPHYTES - AQUATIC PLANTS THAT ARE ROOTED ON THE STREAM BOTTOM	
SAND/SILT - SOFT, BOTTOM SUBSTRATES	5
TOTAL NUMBER OF JABS *MUST* EQUAL 20	

Figure 2. Surface-water habitat-assessment field-data sheet.

SECTION IV – HABITAT ASSESSMENT

HABITAT PARAMETER		HABITAT SCORE
1. Bottom Substrate/Available Cover		
____ Fallen trees/large woody debris ____ Deep pools ____ Shallow pools ____ Overhanging shrubbery in water ____ Large rocks	____ Undercut banks ____ Thick root mats ____ Dense macrophyte beds ____ Deep riffles/runs with turbulence	
2. Pool Substrate Characterization		
3. Pool Variability		
4. Channel Alteration		
5. Sediment Disposition		
6. Channel Sinuosity		
7. Channel Flow Status		
8. Bank Vegetative Protection	--Left Bank*	
	--Right Bank*	
9. Bank Stability	--Left Bank*	
	--Right Bank*	
10. Riparian Vegetation Zone Width	--Left Bank*	
	--Right Bank*	
	Total Score:	

Are the undersides of stones which are not deeply embedded black?

Figure 2. Surface-water habitat-assessment field-data sheet - - Continued.

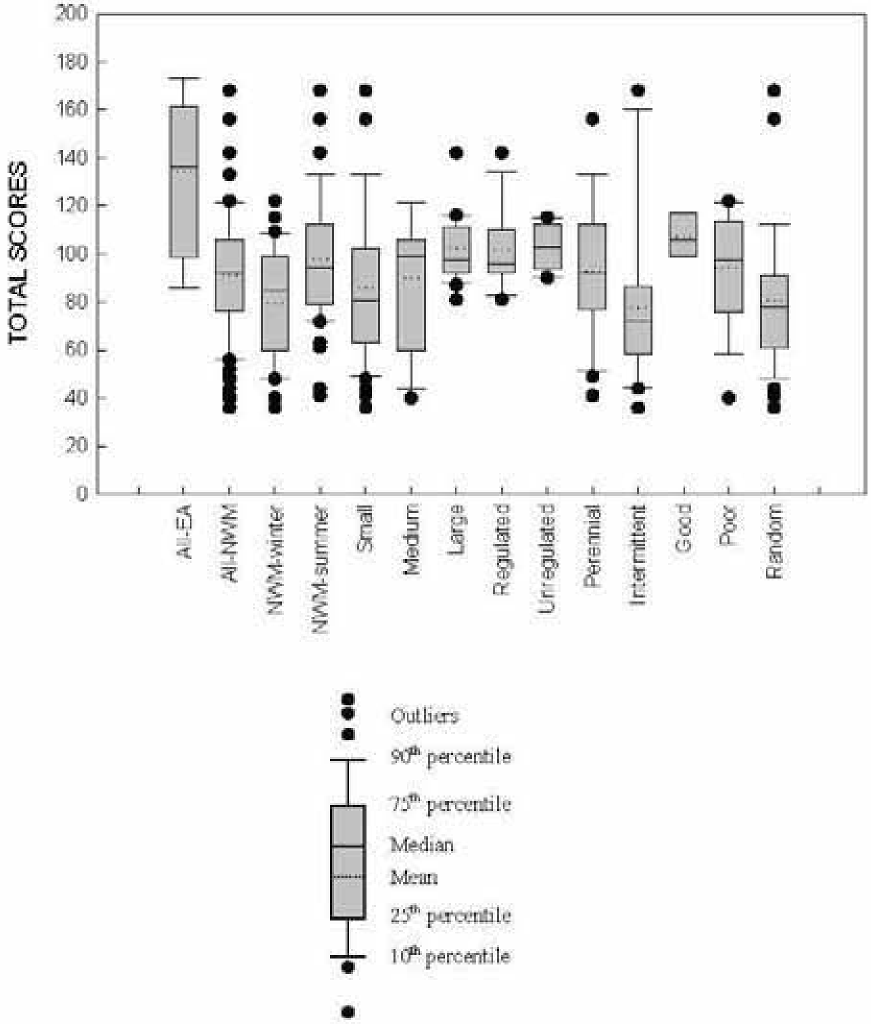


Figure 3. – Distributions for habitat assessment total scores collected at northwestern Mississippi (NWM) and eastern Arkansas (EA) sites.

Invasive Aquatic Plants: A Threat to Mississippi Water Resources

John D. Madsen. Mississippi State University, Mississippi State, MS 39762-9652

Abstract

Invasive aquatic plants are an ever-growing nuisance to water resources in Mississippi and the rest of the United States. These plants are generally introduced from other parts of the world, some for beneficial or horticultural uses. Once introduced, they can interfere with navigation, impede water flow, increase flood risk, reduce hydropower generation, and increase evapotranspirational losses from surface waters. Invasive species also pose direct threats to ecosystems processes and biodiversity. Although there are at least twenty different species of nonnative plants currently in Mississippi, with another eight perched on our doorstep, four species cause the bulk of nuisance problems in large surface waters: Eurasian watermilfoil (*Myriophyllum spicatum*), hydrilla (*Hydrilla verticillata*), waterhyacinth (*Eichhornia crassipes*), and water primrose (*Ludwigia hexapetala*). One additional species (giant salvinia (*Salvinia molesta*)) is a source of significant national concern. I will discuss general modes of introduction to the United States, dispersal to water resources, spread throughout a water resource once a plant is introduced to the system, and effects of large stands on water resource quality. General management approaches include prevention of infestation, and biological, chemical, mechanical, and physical control techniques of plant infestations. While many regulatory agencies oppose management for fear of potential adverse effects of the management techniques, in general the failure to prevent widespread growth of these species causes more harm to the resource than effective management.

Keywords: Ecology, Management & Planning, Recreation, Wetlands

Introduction

Aquatic plants are a key component to aquatic ecosystems and the services they provide. Aquatic plants stabilize sediments and shorelines, reduce turbidity, provide habitat for aquatic organisms, and food for waterfowl (Madsen 1997). In most instances, extensive nuisance growths of aquatic plants are not caused by cultural eutrophication, but by the introduction of invasive plants species. Invasive species are typically introduced from other continents through horticultural or aquaria trade, but have become a widespread problem in the United States (Huber et al. 2002, Mullin et al. 2000). Invasive species impact both human uses and ecological attributes of water resources.

Invasive species directly impact human uses of water resources through obstructing commercial and recreational boat traffic, clogging hydropower generation turbines, and increasing flood risk (Madsen 1997). Invasive plants have also impacted societal values of water resources indirectly through increasing the spread of insect-borne disease and decreasing property values (Madsen 1997). The economic cost of invasive aquatic plant management is considerable, and estimated at over $100M per year in the United States

(Pimentel et al. 2000). Despite these high costs, the benefits are generally considered to be substantially more than the cost (Rockwell 2003).

Invasive species also affect the ecological value of water resources through degradation of water quality under dense mats of vegetation, which decreases oxygen concentrations and increases internal loading of nutrients (Madsen 1997). Dense mats of invasive plants also reduce species diversity, suppress native plant species, and cause localized extinction of native plants (Madsen et al. 1991, Madsen 1994). Invasive species are considered a leading cause of species extinction worldwide (Pimentel et al. 2000).

In this review, I will discuss the methods by which invasive species are introduced and spread within the United States, the invasive aquatic plants found in Mississippi and those on the verge of introduction, the five highest-profile invasive aquatic plants in Mississippi, and lastly provide an overview of how these species can be managed.

Introduction and Dispersal of Invasive Aquatic Plants

As with other invasive species, the introduction and spread of invasive aquatic plants has been largely the result of human activity, both intentional and accidental. The initial introduction of species from one continent to the next has been overwhelmingly at the hands of humans (Figure 1). Typical examples of this type of introduction are through importation of aquaculture, ornamental horticultural, and aquaria specimens (Huber et al. 2002, Kay and Hoyle 2001). Even interstate introductions have been largely due to human activity, though some examples of interstate transport of invasive aquatic plants have been observed. In addition to the above modes of human transport, incidental trailering on boats and accidental or intentional shipping in horticultural specimens may be added (Johnstone et al. 1985, Madeira et al. 2000). At the local scale of within a lake or between adjacent lakes of a given watershed, the natural dispersal processes are typically more important than human carriers. Natural dispersal mechanisms include plant movement by wind or water movement and animal carriers (Madsen and Smith 1997, 1999, Madsen et al. 1988, Owens et al. 2001).

Logically, the best way to avoid a problem is to prevent the introduction of invasive aquatic plants, and to do this through modifying those human activities that introduce and spread invasive plants. For instance, educational efforts in numerous states has been successful in reducing the rate of Eurasian watermilfoil spread through boat inspections, signage at boat launches, media awareness, and traffic inspections (Exotic Species Program, 2004).

Invasive Species In or Near Mississippi

Twenty-one invasive aquatic and wetland species have been sighted in Mississippi, while another seven are in states adjacent to Mississippi (Table 1). Water resource management professionals should be alert to the presence of these species in their area. While I will highlight only a few of the more widespread of these species, that is not meant to diminish the potential for invasiveness and deleterious impact of any of the species on this list, or not mentioned. So, in no particular order, I will highlight five species of concern: Eurasian watermilfoil, giant salvinia, hydrilla, waterhyacinth, and water primrose.

Eurasian watermilfoil (*Myriophyllum spicatum* L.) is a submersed plant native to Europe and Asia, growing completely underwater but often forming a dense canopy near the water's surface (Madsen 1997). It is an evergreen perennial, with green shoots to be found throughout the year. Eurasian watermilfoil spreads through the prolific formation of stem fragments, as well as by runners, stolons, and rhizomes (Madsen et al. 1988). The impact of Eurasian watermilfoil on native plant communities has been documented, as well as the natural regeneration of native plant communities after management of Eurasian watermilfoil populations (Madsen et al. 1991, Getsinger et al. 1997). Eurasian watermilfoil is currently found throughout almost all the continental United States (Jacono and Richerson 2003).

Giant salvinia (*Salvinia molesta* D.S. Mitchell) is a perennial floating fern from South America, which has become a severe nuisance in tropical regions of Africa, Australia, and some portions of the United States (Oliver 1993, Nelson et al. 2001). Giant salvinia is very difficult to control, and is resistant to drying and short freezing events (Oliver 1993). In the United States, it is found in isolated areas of California, Arizona, Texas, Louisiana, Alabama, Georgia, Florida, and North and South Carolina. A small population was found in Mississippi, but was successfully controlled. If observed, it should be vigorously eradicated before it can spread to more waters in Mississippi. Giant salvinia is easily confused with the common salvinia (*Salvinia minima* Baker), which is a widespread invasive species in the southeastern United States.

Hydrilla (*Hydrilla verticillata* (L.f.) Michx.) is a submersed herbaceous perennial plant that has become the most severe nuisance submersed species in the southeastern states, in many instances outcompeting Eurasian watermilfoil (AERF 2004). It is spread by tubers, turions, and stem fragments (Madsen and Smith 1999). Hydrilla is found in numerous states from Maine along the coast to Texas, and in Washington State, California, and Arizona. While not as widespread in Mississippi, significant populations do occur in the Tennessee-Tombigbee waterway and in southwestern Mississippi.

Waterhyacinth (*Eichhornia crassipes* (Mart.) Solms) is a perennial plant composed of floating rosettes that reproduces vigorously by growth from stolons (Madsen 1993, Madsen et al. 1993). A native of Central and South America, it remains the most common nuisance aquatic plant in tropical regions. In the United States, it occurs in the southern Atlantic and Gulf Coast states and in California (Mullin et al. 2000). Waterhyacinth is widespread in Mississippi in wetlands and permanent lakes, regardless of water quality.

Water primrose (formerly *Ludwigia uruguayensis* (Camb.) Hara; now separated into *Ludwigia hexapetala* (Hook & Arn) Zardini, Gu & Raven and *Ludwigia grandiflora* (M. Micheli) Greuter & Burdet) is an herbaceous perennial plant that grows as either an emergent or floating-stem growth forms. Native to South America, this species is a common nuisance in shallow wetlands, ponds, and ditches (Crow and Hellquist 2000). Little is known about their biology and ecology. These species grow throughout the southern United States (Crow and Hellquist 2000).

Seven invasive aquatic plants of potential concern to Mississippi grow in adjacent states (Table 1). Of these, I will specifically mention two: Roundleaf toothcup and wetland nightshade.

Roundleaf toothcup (*Rotala rotundifolia*) is an emergent herbaceous perennial currently found in southern Florida and an isolated population near Tuscaloosa, Alabama (USGS, 2003). Although little is known concerning its biology or potential for spread, it is related to the widespread wetland nuisance purple loosestrife (*Lythrum salicaria* L.), which alone is cause for concern.

Wetland nightshade (*Solanum tampicense* Dunal) is an emergent herbaceous perennial plant currently found in south and central Florida (Richerson and Jacono 2003). Wetland nightshade forms dense stands that suppress native species, and have prickly stems and leaves (Fox and Bryson 1998, Fox and Wigginton 1996).

Management Techniques for Invasive Aquatic Plants

Four categories of management techniques will be discussed for aquatic plants: Biological, chemical, mechanical, and physical control techniques (Madsen 2000).

Biological Control. Biological control techniques include herbivorous insects, grass carp, and pathogens. Biological control agents can either be found using the classical approach, through surveys of the native range of invasive plants; or through examining naturalized populations of the plant and searching for naturalized insects or pathogens. The latter approach often discovers generalist feeders or pathogens, so the naturalized populations tend to be less selective. While research has been conducted on biological control for four of our five major weed concerns, none of the weeds have consistent insect or pathogen controls (Table 2, Madsen 2000). Grass carp are effective for controlling hydrilla, but have other environmental concerns regarding their use.

Chemical Control. A total of eight active ingredients are approved for use on invasive aquatic plants by the US Environmental Protection Agency (Table 3). Aquatic herbicides can be divided into contact herbicides, which are more rapid in their effect but are not moved throughout the plant and thus tend to allow plants to regrow, and systemic herbicides, which are moved throughout the plant but tend to have a slower response. In general, systemic herbicides are preferred for use over contact herbicides for managing invasive species. For the safety of applicators, human users of water resources, and the environment, it is imperative that the label instructions be followed. Herbicides are safe for use in the environment when used according to label instructions.

Aquatic herbicides are not sold with surfactants in the formulation, so surfactants safe for use in aquatic environments should be added to the spray tank when used to control emergent and floating plants. Generally, adjuvants are not needed for submersed plant control.

The broadleaf herbicide 2,4-D is widely used for control of Eurasian watermilfoil, waterhyacinth, and water primrose. Since it is selective for broadleaf plants and systemic, it is a particularly good choice when it is desirable to allow native narrowleaf species to grow.

Complexed copper solutions are widely used for control of algal problems and, while labeled for use on vascular plants, copper rarely works well when used by alone on weeds. It has been used with other herbicides to enhance their effectiveness, or with other herbicides to control simultaneous problems with algae.

Diquat is a widely used broad-spectrum contact herbicide for invasive weeds, both emergent and submersed. While it works well on most species for initial kill, plants generally grow back within four to six weeks. For some instances, however, it is the only herbicide feasible for environmental and species effectiveness considerations.

Endothall is a broad-spectrum contact herbicide used for submersed invasive weeds and algae. Endothall is often used in more turbid water, since it does not have the tendency to absorb on silt particles.

Fluridone is a broad-spectrum systemic herbicide widely used for control of submersed species, and in some instances is effective on floating plants such as giant salvinia and duckweed. Fluridone is applied to the water, and absorbed by leaves or roots of the plants.

Glyphosate is a broad-spectrum systemic herbicide used for control of emergent or floating plants, but is not effective on submersed vegetation since it is readily absorbed by particles in the water. Glyphosate should be applied to the vegetation above the water.

Imazapyr is a newly labeled herbicide for aquatic use, though it has been used extensively in rights of way and forestry. A broad-spectrum systemic herbicide, it is slow acting but effective on large perennial and woody plants. Imazapyr should be applied to emergent or floating leaves or stems.

Triclopyr has a relatively new aquatic use label, though it also has been widely used for woody vegetation control in the past. Triclopyr is a broadleaf selective systemic herbicide, for use on both submerged and emergent species. It is a good choice for Eurasian watermilfoil, waterhyacinth, and water primrose.

Mechanical Control. Mechanical control techniques involve operations that remove plant material, either by hand or through the use of tools, as a means of control (Table 4). Generally, these techniques result in immediate nuisance relief, but tend to allow plants to regrow quickly.

Hand pulling is the most widely used technique in the world, and is surprisingly common for use on very small infestations in the United States. It is generally inefficient and expensive, but may work if only individual plants occur that have not formed a dense root mass.

Cutting involves the use of boats or other equipment with an emersed or submersible cutting bar. Generally, cutting alone is discouraged in that it leaves a large amount of biomass in the water to decompose, but in some situations it can be appropriate.

Harvesting goes beyond cutting in that the equipment collects the plant material that is cut, allowing on-land disposal. While this removes the nuisance problem, it can create a solid waste problem. Aquatic plants, being approximately 92% water, are not fit for food or compost, resulting in a waste that is slow to dry.

Diver-operated suction harvesting (or diver operated suction dredging) refers to a process in which SCUBA divers use a portable suction nozzle to remove rooted submersed plant material. While this results in fairly long-term and selective control of nuisance plants, it is very slow and expensive (Eichler et al. 1993).

Rotovating involves the use of a submersible rototilling head on the end of a mechanical arm to till plants in waters up to ten feet deep. Used predominantly for Eurasian watermilfoil control, it can be effective in controlling plants for several years, but creates a large number of fragments and increases water turbidity.

Physical Control. Physical control refers specifically to those techniques that alter the environment to prevent the growth of plants. Growth prevention is usually achieved by reducing light availability, increasing water depth, or changing the substrate to prevent plant growth (Table 5).

Dredging is effective only when it increases the water depth beyond that at which plants can grow, so is most effective for submersed plant management. Given the expense of dredging, it is best used in a larger restoration effort where plant control is a secondary benefit.

Drawdown is one of the least expensive and, for some species, most effective management techniques – if a water control structure is already present on a water body. Drawdown involves dewatering a lake or pond, exposing plants to the air. When combined with winter cold or freezing, it can be particularly effective. Drawdown works well for Eurasian watermilfoil and, to a lesser extent, waterhyacinth; but is ineffective against the other species.

Benthic barrier involves the placement of an impermeable layer on the bottom, to prevent plants from rooting in the sediment. Generally, the barrier is a plastic mat or sheet, but a number of other materials have been used. Benthic barriers are effective for submersed plants, but ineffective for the floating species like giant salvinia, waterhyacinth, and water primrose.

Shading is a widely used technique that can be implemented using either synthetic dyes or additives to the water, in the case of submersed plants, or through encouraging tree growth along ponds or canals for control of all species. The application of this technique is somewhat limited in larger lakes.

Nutrient inactivation is a widely used practice for control of free-floating algae, usually involving the use of alum to bind phosphorus in the water (Welch and Cooke 1999). Nutrient inactivation has not been demonstrated to be effective for management of rooted plants, though the use of alum or other chemicals to bind water column nutrients to control free-floating invasive plants like waterhyacinth and giant salvinia is at least a theoretical possibility. Currently, it would still be considered experimental, and not recommended for operational management of invasive plants.

All four types of techniques should be used to manage invasive plants in the most economical and environmentally compatible manner possible.

Literature Cited

Aquatic Ecosystem Restoration Foundation (AERF). 2004. Best Management Practices Handbook for Aquatic Plant Management in Support of Fish and Wildlife Habitat. Aquatic Ecosystem Restoration Foundation, Lansing, MI. 47pp. http://www.aquatics.org/aquatic_bmp.pdf.

Crow, G.E. and C.B. Hellquist. 2000. Aquatic and Wetland Plants of Northeastern North America, Vol. I: Pteridophytes, Gymnosperms, and Angiosperms: Dicotyledons. University of Wisconsin Press, Madison, WI. 480pp.

Eichler, L.W., R.T. Bombard, J.W. Sutherland, and C.W. Boylen. 1993. Suction harvesting of Eurasian watermilfoil and its effect on native plant communities. J. Aquat. Plant Manage. 31:144-148.

Exotic Species Program. 2004. Harmful Exotic Species of Aquatic Plants and Wild Animals in Minnesota: Annual Report for 2003. Minnesota Department of Natural Resources, St. Paul, MN. 115pp. http://files.dnr.state.mn.us/ecological_services/exotics/annualreport.pdf

Fox, A. M. and C. T. Bryson. 1998. Wetland nightshade (*Solanum tampicense*): A threat to wetlands in the United States. *Weed Technology* 12: 410-413.

Fox, A. M. and A. Wigginton. 1996. Biology and control of aquatic soda apple (*Solanum tampicense* Dunal), pp. 23-28. *In* Mullahey, J. J. (ed.). *Proceedings of the Tropical Soda Apple Symposium*, January 9-10, 1996, Bartow, Florida. Institute of Food and Agricultural Sciences, University of Florida, Gainesville, Florida, United States.

Huber, D.M., M.E. Hugh-Jones, M.K. Rust, S.R. Sheffield, D. Simberloff, and C.R. Taylor. 2002. Invasive Pest Species: Impacts on Agricultural Production, Natural Resources, and the Environment. Issue Paper Number 20, Council for Agricultural Science and Technology, Washington, DC. March 2002. 18pp.

Jacono, C.C. and M.M. Richerson. 2003. Nonindigenous Aquatic Species Accounts: *Myriophyllum spicatum* L. Center for Aquatic Resource Studies, US Geological Survey, Gainesville, FL. December 2003. http://nas.er.usgs.gov/plants/docs/my_spica.html

Johnstone, I.M., B.T. Coffey, and C. Howard-Williams. 1985. The role of recreational boat traffic in interlake dispersal of macrophytes: A New Zealand case study. J. Environ. Manage. 20:263-279.

Kay, S.H. and S.T. Hoyle. 2001. Mail order, the Internet, and invasive aquatic weeds. J. Aquat. Plant Manage. 39:88-91.

Madeira, P.T., C.C. Jacono, and T.K. Van. 2000. Monitoring hydrilla using two RAPD procedures and the Nonindigenous Aquatic Species Database. J. Aquat. Plant Manage. 38:33-40.

Madsen, J.D. 1993. Growth and biomass allocation patterns during waterhyacinth mat development. J. Aquat. Plant Manage. 31:134-137.

Madsen, J.D. 1994. Invasions and declines of submersed macrophytes in Lake George and other Adirondack lakes. Lake Reserv. Manage. 10:19-23.

Madsen, J.D. 1997. Chapter 12. Methods for Management of Nonindigenous Aquatic Plants, pp. 145-171. In: J.O. Luken and J.W. Thieret, eds. Assessment and Management of Plant Invasions. Springer, New York. 324pp.

Madsen, J.D. 2000. Advantages and disadvantages of aquatic plant management techniques. ERDC/EL MP-00-1, U.S. Army Engineer Research and Development Center, Vicksburg, MS. http://www.wes.army.mil/el/elpubs/pdf/mpel00-1.pdf

Madsen, J.D., L.W. Eichler, and C.W. Boylen. 1988. Vegetative spread of Eurasian watermilfoil in Lake George, New York. J. Aquat. Plant Manage. 26:47-50.

Madsen, J.D., K.T. Luu, and K.D. Getsinger. 1993. Allocation of biomass and carbohydrates in waterhyacinth (Eichhornia crassipes): Pond-scale verification. Technical Report A-93-3, U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS. 39pp.

Madsen, J.D. and D.H. Smith. 1997. Vegetative spread of Eurasian watermilfoil colonies. J. Aquat. Plant Manage. 35:63-68.

Madsen, J.D. and D.H. Smith. 1999. Vegetative spread of dioecious hydrilla colonies in experimental ponds. J. Aquat. Plant Manage. 37:25-29.

Madsen, J.D., J.W. Sutherland, J.A. Bloomfield, L.W. Eichler, and C.W. Boylen. 1991. The decline of native vegetation under dense Eurasian watermilfoil canopies. J. Aquat. Plant Manage. 29:94-99.

Mullin, B.H., L.W.J. Anderson, J.M. DiTomaso, R.E. Eplee, and K.D. Getsinger. 2000. Invasive Plant Species. Issue Paper Number 13, Council for Agricultural Science and Technology, Washington, D.C. February 2000. 18pp.

Nelson, L.S., J.G. Skogerboe and K.D. Getsinger. 2001. Herbicide evaluation against giant salvinia. J. Aquat. Plant Manage. 39:48-53.

Oliver, J.D. 1993. A review of the biology of giant salvinia (*Salvinia molesta* Mitchell). J. Aquat. Plant Manage. 31:227-231.

Owens, C.H., J.D. Madsen, R.M. Smart, and R.M. Stewart. 2001. Dispersal of native and nonnative aquatic plant species in the San Marcos River, Texas. J. Aquat. Plant Manage. 39:75-79.

Pimentel, D., L. Lach, R. Zuniga, and D. Morrison. 2000. Environmental and economic costs of nonindigenous species in the United States. BioScience 50:53-65.

Richerson, M.M. and C.C. Jacono. 2003. Nonindigenous Aquatic Species Accounts: *Solanum tampicense* Dunal. Center for Aquatic Resource Studies, US Geological Survey, Gainesville, FL. April 2003.
http://nas.er.usgs.gov/plants/docs/so_tampicense.html

Rockwell, H.W., Jr. 2003. Summary of a Survey of the Literature on the Economic Impact of Aquatic Weeds. Aquatic Ecosystem Restoration Foundation, Flint, MI. 18pp. http://www.aquatics.org/pubs/economics.htm.

U.S. Geological Survey (USGS). 2003. Nonindigenous Aquatic Species Accounts: Rotala rotundifolia. Florida Integrated Science Center, U.S. Geological Survey, Gainesville, FL.
http://cars.er.usgs.gov/Nonindigenous_Species/Rotala_rotundifolia/rotala_rotundifolia.html.

Welch, E.B. and G.D. Cooke. 1999. Effectiveness and longevity of phosphorus inactivation with alum. Lake Reserv. Manage. 15:5-27.

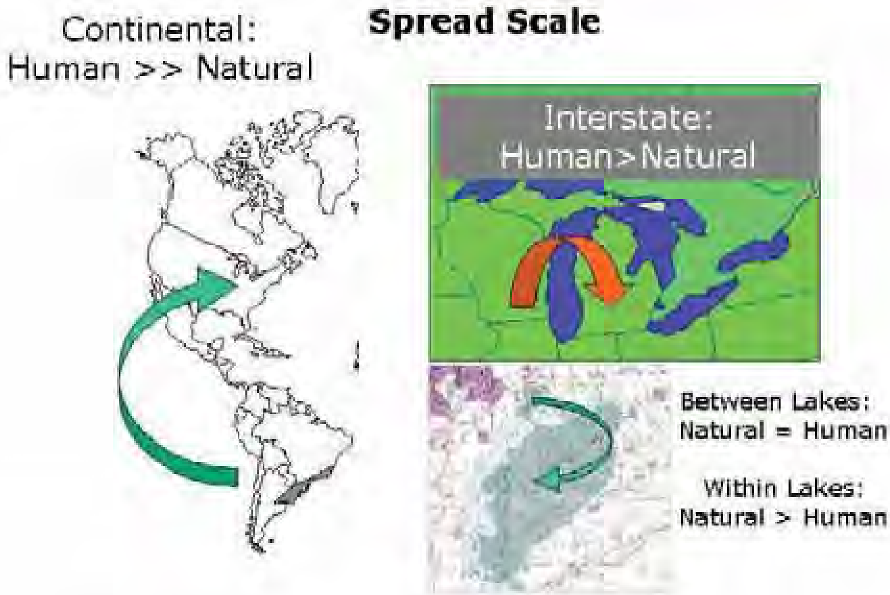


Figure 1. Importance of human versus natural spread mechanisms at the continental, interstate, and local scales.

Table 1. Exotic Invasive Aquatic and Wetland Plants sighted in Mississippi, and those found near Mississippi.

Species sighted in Mississippi

Alligatorweed (*Alternanthera philoxeroides* (Mart.) Griseb.)
Brittle naiad (*Najas minor* Allioni)
Chinese tallow tree (*Sapium sebiferum* (L.) Roxb.)
Common salvinia (*Salvinia minima* Baker)
Curlyleaf pondweed (*Potamogeton crispus* L.)
Deeprooted sedge (*Cyperus entrerianus* Boeck.)
Egeria (*Egeria densa* Planch.)
Eurasian watermilfoil (*Myriophyllum spicatum* L.)
Giant salvinia (*Salvinia molesta* Mitchell)
Hydrilla (*Hydrilla verticillata* Royle)
Marsh dewflower (*Murdannia keisak* (Hassk.) Hand.-Maz.)
Parrotfeather (*Myriophyllum aquaticum* (Vell.) Verde)
Phragmites (*Phragmites australis* (Cav.) Trin.)
Purple loosestrife (*Lythrum salicaria* L.)
Sacred lotus (*Nelumbo nucifera* Gaertn.)
Torpedograss (*Panicum repens* L.)
Waterlettuce (*Pistia stratoites* L.)
Waterhyacinth (*Eichhornia crassipes* (Mart.) Solms)
Water primrose (*Ludwigia hexapetala* (Hook. & Arn.) Zardini, Gu & Raven)
Wild taro (*Colocasia esculenta* (L.) Schott)
Yellow floating heart (*Nymphoides peltata* (Gmel.) Kuntze)

"Watch List" of Species Near Mississippi

Asian marshweed (*Limnophila sessiliflora* (Vahl) Blume)
Indian hygrophila (*Hygrophila polysperma* (Roxb.) T. Anders.)
Melaleuca (*Melaleuca quinquenervia* (Cav.) Blake)
Roundleaf toothcup (*Rotala rotundifolia*)
Wetland nightshade (*Solanum tampicense* Dunal)
White Egyptian lotus (*Nymphaea lotus* L.)
Yellow iris (*Iris pseudacorus* L.)

Table 2. Biological control agents for Mississippi invasive aquatic plants.

Control Technique	Eurasian watermilfoil	Giant salvinia	Hydrilla	Waterhyacinth	Water primrose
Insect	Experimental	Experimental	Poor	Poor	None
Grass Carp	Poor	Poor	Excellent	Poor	Poor
Pathogens	Experimental	None	Experimental	None	None

Table 3. Herbicides for management of Mississippi invasive aquatic plants.

Herbicide	Contact or Systemic	Eurasian watermilfoil	Giant salvinia	Hydrilla	Waterhyacinth	Water primrose
2,4-D	Systemic	Excellent	No	Poor	Excellent	Excellent
Complexed Copper	Contact	Poor	No	Fair	No	No
Diquat	Contact	Good	Excellent	Good	Good	Good
Endothall	Contact	Good	No	Good	No	No
Fluridone	Systemic	Excellent	Good	Excellent	Poor	Poor
Glyphosate	Systemic	No	Excellent	No	Excellent	Excellent
Imazapyr	Systemic	No	Poor	No	Excellent	Excellent
Triclopyr	Systemic	Excellent	No	Poor	Excellent	Excellent

Table 4. Mechanical techniques for Mississippi invasive aquatic plants.

Control Technique	Eurasian watermilfoil	Giant salvinia	Hydrilla	Waterhyacinth	Water primrose
Hand-pulling	Limited	Limited	Limited	Limited	Limited
Cutting	Fair	Poor	Fair	Poor	Fair
Harvesting	Good	Good	Good	Good	Good
Diver-operated Suction Harvesting	Excellent	Poor	Fair	Poor	Poor
Rotovating	Good	Poor	Fair	Poor	Poor

Table 5. Physical control techniques for Mississippi invasive aquatic plants.

Control Technique	Eurasian watermilfoil	Giant salvinia	Hydrilla	Waterhyacinth	Water primrose
Dredging	Excellent	Poor	Excellent	Poor	Poor
Drawdown	Excellent	Poor	Poor	Poor	Poor
Benthic Barrier	Excellent	Poor	Excellent	Poor	Poor
Shading	Good	Good	Good	Good	Good
Nutrient inactivation	Experimental	Experimental	Experimental	Experimental	Experimental

ANALYSIS OF FRESHWATER SAND-DWELLING CHIRONOMID LARVAE IN DISTURBED AND RELATIVELY UNDISTURBED BLACKWATER STREAMS

Robert C. Fitch and David C. Beckett
Department of Biological Sciences
University of Southern Mississippi
P.O. Box 5018 Southern Station
Hattiesburg MS, 39406-5018
Phone: (601) 296-0973
E-mail: Robert.Fitch@usm.edu

Freshwater sand-dwelling chironomid larvae were studied in the summer of 2002 in six blackwater streams in Southern Mississippi. Three of the streams were in relatively undisturbed habitats and the other three streams were in disturbed habitats affected by either non-point source pollution, point source pollution, or both. Sand core samples were taken randomly within three sites per stream (five samples per site; fifteen samples total per stream), and chironomid larvae were identified to the lowest possible taxon. *Rheosmitia* sp. composed 20 - 80% of the larval chironomid population in the undisturbed streams, whereas the three disturbed streams had three different dominant taxa (i.e., *Polypedilum scalaenum* group, *Tanytarsus* sp. P, and *Dicrotendipes* sp.) and low percentages of *Rheosmittia* sp. Taxon richness, total number of chironomids, and species diversities were variable among the streams. However, polar ordination based on percentage similarity showed that the three disturbed streams clustered together, whereas the three relatively undisturbed streams formed a cluster distant from that of the disturbed streams. This study indicates that *Rheosmittia* dominates sandy substrates in blackwater streams that are relatively unpolluted. Furthermore, freshwater sand-dwelling chironomids can serve as indicators of ecological disturbance.

A Survey of Lotic Tardigrades from the Pascagoula drainage

Allen Niven
Department of Biological Sciences
University of Southern Mississippi
P.O. Box 5018 Southern Station
Hattiesburg MS, 39406-5018
Phone: (601) 296-0973
E-mail: Allen.Niven@usm.edu

There are approximately 800 described species of tardigrades. These microscopic metazoans are commonly known as "water bears" because of their lumbering gait. The focus of this research is to identify and describe the association of tardigrades found in the Pascagoula drainage basin. Few studies of tardigrades from around the world are known from river systems and none from streams in Mississippi. Beyond this study, the community of tardigrades associated with this drainage is unknown. Samples were collected from stream substrate in several locations within the Pascagoula drainage basin from March to September 2002. Tardigrades were separated from the substrate, sorted and mounted for identification. Hypsibideae dominated the tardigrade community in all streams surveyed. While seasonality appears to influence the makeup of the communities, the greatest number of specimens was collected in the late spring and the most commonly observed genera was *Hypsibius*. Other commonly observed specimens in included *Isohybsibius* and *Ramazottius*. *Dactylobiotus* was observed in many streams in low occurrence but independent of seasonality.

Port Sedimentation Solutions

William H. McAnally[1] and Julia F. Haydel

ABSTRACT

The cost of sedimentation problems in North America is estimated to be $16B, of which a significant portion is attributed to excessive sedimentation in waterways. Excessive sediment deposition in ports and channels reduces their depth, forcing vessel operators either to time transits to high water periods, to light-load so as to reduce draft, or to limit passage to unsafe narrow passages, or preventing access altogether. The traditional solution to these problems was dredging and disposal of excess sediment, but the cost of dredging and potential environmental effects have made reducing dredging frequency and quantity a necessity. Environmentally friendly alternatives are needed, and such solutions are available.

The purpose of this paper is to present some engineering alternatives to dredging and illustrate their application by examples from the literature and a current example from Lowndes County Port on the Tennessee-Tombigbee Waterway.

Engineering solutions to waterway sedimentation can be classified as those that keep sediment out, keep sediment moving, and remove deposited sediment, and numerous solutions are available within each category. Application of these principles to Lowndes County Port show that training structures constricting waterway width at the port can substantially reduce sedimentation within the port while providing both cost and environmental benefits. A sediment trap offers some of the port shoaling benefits, but at greater cost and without the environmental enhancement possibilities. These same principles can be applied to deep water ports and channels with similar benefits.

INTRODUCTION

The cost of sedimentation problems in North America is estimated to be $16B (*1*), of which a significant portion is attributed to sedimentation in ports and waterways. Sediment deposition reduces depth available for vessels, forcing them to light-load or limiting their access. Dredging, the traditional solution to sedimentation, and disposal of the dredged material have become increasingly expensive and difficult, and less expensive, environmentally friendly alternatives are needed.

The purpose of this paper is to describe some engineering alternatives to dredging and illustrate their application by examples from the literature and a recent analysis of proposed solutions in the Port of Lowndes County on the Tennessee-Tombigbee Waterway.

WATERWAY SEDIMENTATION SOLUTIONS

The International Navigation Association calls dredged material … a valuable renewable resource … (*2*). That may seem to be a contradictory statement when dredging costs more than $700 million annually in the United States (*3*); yet eroding shorelines and incised streams are costly manifestations of too little sediment. A decline of sediment supply in the Mississippi River is responsible for a large part of massive wetlands loss in Louisiana (*4*), prompting proposals for a multi-billion dollar remedial action plan (*5*). Likewise, adverse environmental effects of too much sediment, such as smothering of salmon eggs and

[1] Research Professor, Civil Engineering Department, James Worth Bagley College of Engineering, Mississippi State University, mcanally@engr.msstate.edu.

larvae, are widely acknowledged, yet some species, such as the endangered pallid sturgeon, prefer muddy water habitats and are adversely affected by water with low turbidity (*6*). From these examples it is clear that either too much or too little sediment can be a problem, just as too much water (flooding) or too little water (drought) can be a problem. The key is that sediment is a resource that can be managed for the benefit of human society and environmental quality.

Few port or waterway operators see too little sediment as a problem. Excessive sediment deposition in ports and channels reduces their depth, forcing vessel operators either to time transits to high water periods, to light-load so as to reduce draft, or to limit passage to unsafe narrow passages, or preventing access altogether. The traditional solution to these problems was dredging and disposal of excess sediment. More recently, beneficial use of dredged sediment has recognized the value of the resource by using it for shoreline restoration, marsh creation, and construction material, but usually at increased cost to those performing the dredging (*2*). Disposal other than beneficial uses has become constrained, with in-water placement often prohibited and on-land placement options diminishing.

Despite these difficulties, dredging and disposal of excess sediment was the most economical solution to excessive deposition. However, the cost of dredging has risen sharply and limitations on when to dredge and how to dispose have grown more stringent, decreasing the viability of dredging as the only solution to waterway maintenance. Perhaps related to these changes, consolidation among dredging companies has reduced the number of companies bidding on projects, and smaller projects may draw few, if any, bidders. Many waterways and ports are finding it increasingly difficult or even impossible dredge and they need other options. The options are: use only ports and waterways that are naturally deep enough to allow navigation, use vessels small enough to navigate natural waterway depths, or employ engineering alternatives to traditional dredging. This paper is concerned with the latter alternative.

Numerous engineering alternatives are available. Successful and unsuccessful examples of each are reported in the literature (e.g., *7*) but are not widely appreciated. Design of engineering solutions tends to be unique to each site's characteristics – the size and layout of facilities, hydrography of the waterway, flows, and sediment supply and characteristics, but solutions have much in common if they are classified as those that:

- Keep sediment out
- Keep sediment moving
- Remove deposited sediment

Keeping sediment out solutions include stabilizing erosional areas, erecting barriers, diverting sediment-laden flows, and trapping sediment. Examples include diverting freshwater flow out of Charleston Harbor, SC which reduced port and channel sedimentation by more than 70 percent (*8*), and a sediment trap and tide gate combination in Savannah Harbor, GA that reduced port and waterway dredging by more than 50 percent (*9*). In the Savannah case, locating the sediment trap out of the port area also reduced interference between dredging equipment and vessel traffic, placed the dredging closer to the disposal area, and reduced the unit cost. However, the project was alleged to cause salinity increases upstream, and was taken out of service. Sediment traps can be environmentally beneficial compared with conventional dredging, for example, if fine sediments are allowed to consolidate so that low turbidity, low water volume methods such as clamshell dredging can be employed.

Keeping sediment moving solutions include structural elements that train flow, devices that increase tractive forces on the bed, and designs that reduce cohesive sediment flocculation. Structural elements include lateral training (spur) dikes that are used in many locations to train flow and prevent local deposition of sediment, as in the Red River, LA (*10*), and specialized training structures such as the Current Deflector Wall, a curved training structure that reduced sedimentation in Hamburg Harbor's Kohlfleet basin by 40 percent (*11*). Lateral dikes have been found to be most effective when submerged during high flow events (7). Devices to increase bed tractive forces, including submerged wings (*12*) and water jet manifolds (*13*) were tested in the Navy berths of Mare Island Strait, CA and found to be effective in reducing sediment deposition locally. Cohesive sediment flocculation can be reduced by designs that reduce turbulence, such as solid wharf walls instead of piling supported wharfs.

Removing sediment includes traditional dredging but also includes sediment agitation methods of intentional overflow, dragging, and propwash erosion. Anchorage Harbor, AK was dredged with a combination of agitation and dredge-and-haul in 2000 (*14*). Dragging a rake behind a vessel to suspend sediment so that it can be carried away by currents has been practiced for centuries in China (*15*) and propeller wash is used in the same way in some ports, either intentionally or incidental to normal port operations (*16*).

Each approach described above has implications for water quality or biota impacts that may be either positive or negative. No solution, conventional dredging and disposal or their alternatives, can be exercised without careful consideration of the environmental effects. For example, agitation dredging is prohibited in some locations because it increases turbidity, at least locally. However, non-dredging solutions have been shown to be to benefit environmental quality, such as training dikes providing good fish habitat, especially when notched to pass small quantities of flow. Stone training dikes provide a variety of spatial scale habitats, from small interstial voids to large scour holes, and varied flow conditions that promote aquatic diversity and abundance and are considered to provide environmental quality enhancement (*17, 18, 19, 20, 21, 22*). The potential positive environmental effects of dredging from a sediment trap instead of an active waterway are described above.

THE TENN-TOM WATERWAY

The Tennessee-Tombigbee Waterway is a 234-mile-long inland waterway providing a navigation connection between the Tennessee River and the Gulf of Mexico via the Black Warrior-Tombigbee Waterway and Mobile Bay. Constructed by the U. S. Army Corps of Engineers, it was completed in 1984. The Waterway consists of three distinct sections — River, Canal, and Divide Cut – in Mississippi and Alabama. The River portion generally follows the course of the Tombigbee River from its confluence with the Black Warrior River in Alabama upstream to near Amory Lock and Dam, Mississippi. The Canal section departs from the Tombigbee River course to trend generally northward to Jamie Whitten (Bay Springs) Lock and Dam. The Divide Cut section connects the Canal section to the Tennessee River at Pickwick Lake near the Mississippi-Tennessee boundary. The 149-mile-long River section lies within the Tombigbee River flood plain and a number of river meanders have been cut off, leaving 71 miles of meander loops still connected to the Waterway. Four lock and dam structures raise the water level a total of 117 ft and create pools conducive to sedimentation. Numerous tributaries drain into the River section, bringing significant quantities of sediment. The 46-mile-long Canal section is located near the eastern edge of the Tombigbee River floodplain and was formed by constructing a levee to serve as the western boundary of the section while natural high ground serves as the eastern boundary. Five pools create a chain-of-lakes configuration to provide navigable depths. Inflow to the Canal section is limited to discharges from Whitten Lock and Dam and small tributaries on the eastern edge of the floodplain. The Divide Cut section connects the separate river basins by an excavated cut through the basin divide and extends 39 miles from Bay Springs Lake to Pickwick Lake. Inflows to the section consist of minor local inflows and flow from Pickwick Lake to replace water released downstream at Whitten Lock.

Sediment supply to the Divide Cut and Canal sections is low, but the Waterway bed continues to be a source for resuspension and movement, which cause port sedimentation problems. Sediment supply to the River section is sufficient to cause port and waterway sedimentation problems at any location where the capacity to transport sediment is smaller than the depositable sediment supply.

Five of the six public ports on the Waterway have experienced sedimentation problems and increasing costs of dredging. Field data were collected and analyzed to determine the dominant sediment sources and mechanisms for transport and deposition in three ports that represent the various processes. Analyses (*23*) of those data indicate that sedimentation sources and mechanisms acting in the Waterway ports can be categorized as:

- Surge- and vessel-resuspended fine bed sediment from the waterway bed moves into the port as a density underflow and deposits.

- Sediment (both fine and coarse) transported from upstream during high flow events deposits.

- Other mechanisms contribute sediment (slumping, soil piping, etc.).

The primary mechanism varies among the ports, with vessel resuspension dominating in the Canal and Divide Cut section ports, and transport from upstream dominating in the River section ports.

LOWNDES COUNTY PORT

Lowndes County Port is located in Columbus, Mississippi at about Waterway Mile 330. The port is on a former bendway of the Tombigbee River which has been cut off by the Waterway channel. It lies in the River Section, in the Aliceville Pool formed by Tom Bevill Lock and Dam. A 100-ft wide Federal channel connects the port to the waterway (see Figure 1). Two public berths parallel with the channel can serve two 600 ft barges at 9 ft draft. The port has a 200 ft by 120 ft turning basin at the upstream end of the Federal channel. Table 1 gives the dimensions of the port, the bendway above the port, and the waterway cutoff channel. Port officials report that shoaling occurs principally during the high water season of January-April, and that dryer years produce less shoaling. During high flows on the Waterway, strong currents are observed in the bendway river channel.

Grab samples from the bed of the port area in October 2002 (low flow season) consisted of very soft organic black mud with a small fraction of fine sand. Samples collected in March 2003, 10 days after a high flow event, had median grain sizes ranging from 0.16 to 0.26 mm and the fraction of silts and clays ranging from 2 to 16 percent.

The port has been dredged several times:

- Combined new work and maintenance dredging in 1993 of about 8000 yd^3 did not provide a complete harbor prism, but was halted when the maximum allowable funding was exhausted. Unexpected trees and debris in the new work area were cited as the cause of delays.
- In 1999 required dredging was estimated at 17,000 yd^3, but funding limited the actual dredging quantity at only 7,867 yd^3 at a net cost of more than \$10 per yd^3.
- In 2003 the turning basin at the upstream end of the port was shoaled in to about 5 ft depth and some barges reported bumping high spots lower in the port.

Corps of Engineers' dredging records show maintenance dredging of the waterway above and below the port channel in 1991 and 1993, and 26,304 yd^3 were dredged from the access channel in 1993 at costs ranging from \$2 to \$4 per cubic yard, substantially less per unit than the \$10 per cubic yard experienced by the port for relatively small quantity contracts. On average, the port has accumulated about 5,000 yd^3 of sediment per year since 1991, which would cost between \$20,000 and \$50,000 per year using the port's on-site confined dredged material placement area. When that site is filled, there are no other near-by disposal areas available for use, so disposal costs are expected to increase. (*23*)

The location of the port and its sedimentation history suggest that the primary source of sediment depositing in the port is transport through the bendway channel. That channel has a maximum depths of about 15 ft, but is shallow (less than 5 ft) at its upstream junction with the waterway. During high flow events, sand moves through the bendway, depositing when it reaches the enlarged cross-section of the port area. At other times vessel- or flow-resuspended fine sediments can move into the port area from either upstream or downstream.

There are no known sediment-related environmental issues for Lowndes County Port. A 1998 letter from the Mississippi Department of Environmental Quality stipulated that there were no water quality problems associated with proposed dredging.

DESIGN FOR SEDIMENT REDUCTION

Several engineered solutions to the sedimentation problem are possible. Keeping sediment out solutions include a barrier at the upstream end of the bendway that seals it off from high flow events, and a sediment trap in the bendway above the port. A barrier is inadvisable, since it would restrict recreational boat access and could degrade water quality and habitat conditions in the bendway. A sediment trap just upstream from the port could trap a significant fraction of the sand-sized sediment before it enters the port. That sediment will eventually have to be dredged, but the trap offers the advantages that sediment infilling and dredging operations will not impede navigation and low impact dredging methods such as clamshell removal can be used. It does not resolve the problem of future disposal.

Training structures are the most obvious approach to keep sediment moving through the port. By constricting the channel, they can focus currents and increase the transport rate, albeit at the risk of increasing navigation hazards. Removal of deposited sediment can include continuing traditional dredging, but can also be accomplished by using tug propwash to resuspend fine sediment so that natural currents can flush it from the port area, if the permitting agencies will allow it.

Design of solutions requires an estimate of sediment transport rates. For that purpose the 1.5 year flow event was selected as representative of the flows causing the most sediment deposition. That event approximates bank-full flow, above which flooding occurs. At Stennis Lock and Dam, 5 miles upstream of the port, the 1.5 year event has a flow of 52,000 cfs (*24*). By simple application of Manning's equation to the waterway between Stennis Lock and Dam and Bevill Lock and Dam and the two loops – the bendway and the cutoff channel – the water surface elevation at the site was estimated to be 159 ft, the discharge in the bendway was calculated to be 19,990 cfs, and the friction slope of the bendway flow was estimated to be about $5x10^{-5}$ ft/ft. Application of five non-cohesive sediment transport formulae that have some applicability to conditions at the Stennis Dam site, using the SAM software package (*25*) produced results ranging from 33,000 to 51,000 tons per day of bed material load. The lower end of the computed range, using the Laursen-Copeland transport formula, was selected for use in the design, for it was closest to the transport rate predicted by watershed methods (*23*). According to the Laursen-Copeland formula, the sediment transport rate in the bendway is 1630 tons per day; whereas, in the port it is only 1200 tons per day. The 430 tons per day difference, or 26 percent of the load, represents what will deposit in the port.

Design to keep sediment moving was accomplished by iterative solutions as described above until the sediment discharge in the port reach equaled or exceeded that in the bendway reach above the port. They showed that a port channel with a normal pool top width of 220 ft (instead of the current 300 ft) will either be stable or erode slightly under the 1.5-year flow event. Narrowing the channel by 80 ft can be accomplished by transverse training dikes with top elevation of about 146 ft and average length of about 100 ft. Figure 2 shows how a typical cross-section will be changed by a dike. Transverse dikes with notches will provide the needed constriction, reducing deposition and extending the life of the existing disposal area, without significantly raising flood levels upstream. Two dikes may be sufficient to reduce port sedimentation by 90 percent. If more are needed, using a rule of thumb that dikes should be spaced at 3 to 8 times their length, up to 8 transverse dikes along the east side of the channel will suffice for the roughly 3600 ft of active port use as shown in Figure 3. The solution allows for progressive implementation – constructing one or two dikes and observing the results before proceeding with others. Costs of constructing soil-filled dikes with a geotextile and riprap cover are estimated to be $14,000 to $20,000 per dike (*23*).

Keeping the presently depositing part of the sediment load moving will increase the sediment load of the waterway itself by less than 2 percent at the design flow, so the potential increase in waterway dredging will be small. Additional shoaling may occur in the Federal channel between the port and waterway, which can be remedied by extending the training structure field downstream to the junction of the channels, albeit at additional cost.

Flow speeds at the berths under the bank-full flow are expected to increase only from about 2.1 ft/sec to about 2.6 ft/sec, so mooring loads on barges will not be unduly increased. Discussions with recreational boaters and a towing industry representative have indicated that both can deal with the presence of training dikes if they resolve the deposition problem. (*23*).

Additional measures will further contribute to keeping sediment moving through the port. For example, reducing side and bottom slopes at the upstream end of the port will reduce eddy formation and associated sediment deposition, and using tug propwash to regularly agitate soft sediment deposits next to port structures will reduce accumulation of slack-water-deposited sediment, if allowed.

A trap for the excess sediment was designed using a simple method formulated by Sarikaya (*26*) that considers the settling trajectory of sediment particles entering the trap. Calculation of trapping efficiency for each grain size and then summing the results across all existing grain sizes showed that a trap 10 ft deep, 500 ft long, and as wide as the channel will trap 15 percent of the sediment bed material load, and extending it to 1000 ft long will cause it to trap about 35 percent of the load. Since the excess sediment load is about 26 percent of the total, a trap on this order will capture the excess and prevent its deposition in the port. The size and location of the trap is illustrated in Figure 3. This solution neither reduces the required dredging amount (it could increase it) nor saves disposal area space; however, it can reduce the cost of dredging by decreasing the required frequency (saving mobilization costs) and placing the dredging activity outside the active port area. It will also increase port efficiency by permitting full depth access even when dredging is needed in the trap. However, at an estimated construction cost of $100,000 to $200,000, it exceeds the cost of training structures and offers no offsetting advantages.

Both of these approaches offer substantial reductions in port sediment deposition. They probably will not eliminate the problem, since some material will escape the trap and some will deposit during low flows when the dikes are less effective; however, they both offer efficiency advantages over conventional dredging. The dike solution appears to be effective, will cause no significant environmental adverse effects and will confer positive habitat benefits based on studies by multiple agencies (*17, 18, 19, 20, 21, 22*). If two dikes provide the needed sedimentation reduction at a construction cost of $28,000 to $40,000, they are cost effective compared with a continued dredging cost of $20,000 to $50,000 per year. If 8 dikes are constructed over four years at $40,000 per year, it will still be cost effective over the long term. Final selection of a solution awaits a detailed design, economic analysis, and possibly numerical model testing to ensure a safe, effective, and environmentally friendly project, but these simple calculations demonstrate the possibility of a viable alternative to traditional dredging.

CONCLUSIONS

The cost of dredging and dredged material disposal and need for environmentally sensitive practices makes excessive sediment deposition in ports and waterways a growing burden. Engineering solutions other than conventional dredging offer an effective and, in some cases, environmentally friendly way to reduce the burden, using the principles of keep sediment out, keep sediment moving, and remove deposited sediment.

Lowndes County Port on the Tenn-Tom Waterway offers an example of how sediment control principles can be applied to significantly reduce the need for maintenance dredging in a shallow draft inland port. Examples cited from the literature show that deep draft coastal ports and other inland ports can also benefit from application of these concepts.

ACKNOWLEDGEMENTS

The work described here was funded by the Mississippi Department of Transportation through the Transportation Research Center at Mississippi State University. The Lowndes County Port and U. S. Army Corps of Engineers Mobile District provided valuable data and insights.

REFERENCES

1. Osterkamp, W. R., P. Heilman, and L. J. Lane, Economic Considerations of Continental Sediment Monitoring Program, *International Journal of Sediment Research*, (4) December 12-24, 1998.

2. PIANC, Beneficial Uses of Dredged Material, Report of PIANC Working Group 19, International Navigation Association, Brussels, 1992.
3. U. S. Army Corps of Engineers, Regional Sediment Management Program Description, http://www.wes.army.mil/rsm/RSM-R&D/pdfs/factsheet.pdf. Accessed 24 July 2003.
4. Boesch, D. F., M. N. Josselyn, A. J. Mehta, J. T. Morris, W. K. Nuttle, C. A. Simenstad, and D. J. P. Swift, Scientific Assessment of Coastal Wetland Loss, Restoration, and Management in Louisiana, *Journal of Coastal Research*, Special Issue 20, 1994.
5. Coast 2050, Louisiana Comprehensive Coastwide Ecosystem Restoration Study, http://www.coast2050.gov/, accessed 20 October 2003
6. Dryer, M. P., and A. J. Sandvol, Recovery Plan for the Pallid Sturgeon (Scaphirhynchus albus), US Fish and Wildlife Service, http://ecos.fws.gov/docs/recovery_plans/1993/931107.pdf . Accessed 23 July 2003.
7. Parchure, T. M. and A. M. Teeter, Potential Methods of Reducing Shoaling in Harbors and Navigation Channels, CHETN-XIV-6, Engineer Research and Development Center, Vicksburg, MS, June 2002.
8. Teeter, A. M. *Effects of Cooper River Rediversion flows on shoaling Conditions at Charleston Harbor, Charleston, South Carolina*, Technical Report HL-89-3, U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS, 1989.
9. Committee on Tidal Hydraulics, *Reviews of Problems in Tidal Waterways Considered by the Committee on Tidal Hydraulics*, Headquarters, U.S. Army Corps of Engineers, June 1995.
10. Pinkard, C. Fred, Red River Waterway: A Sedimentation Challenge, *Proceedings of the 1st International Conference on Water Resources*, Part 1, American Society of Civil Engineers, Washington, DC, 1995.
11. Smith, T. J., R. Kirby, and H. Christiansen, Entrance flow control to reduce siltation in tidal basins, in *Coastal and Estuarine Fine Sediment Processes*, W. H. McAnally and A. J. Mehta, Eds., Elsevier, Amsterdam, 2001.
12. Jenkins, S. A., Passive Remedial Sedimentation Control in Parallel Berths and Channels, in *Sedimentation Control to Reduce Maintenance Dredging of Navigational Facilities in Estuaries*, Marine Board, National Research Council, 1987, 153-176.
13. Bailard, J. A., Controlling Sedimentation in Harbor Berthing Areas Using Scour Jet Array Systems, in *Sedimentation Control to Reduce Maintenance Dredging of Navigational Facilities in Estuaries*, Marine Board, National Research Council, 1987, 141-152
14. Hilton, James D., U.S. Army Corps of Engineers Dredging Program, *Sea Technology*, Vol 41, No. 3, March 2000, 21-24.
15. Luo, Zhaosen, and Gu Peiyu, Sedimentation Associated with Tidal Barriers in Chinas Estuaries and Measures for its Reduction, in *Estuarine Comparisons*, Victor Kennedy, ed., Academy Press, New York, 1982. pp 611-622.
16. Richardson, T. W. *Agitation Dredging: Lessons and Guidelines from Past Projects*, Technical Report HL-84-6, US Army Engineer Waterways Experiment Station, Vicksburg, MS, 1984.
17. U. S. Army Corps of Engineers, Environmental Engineering on the Mississippi River, The Solutions, St. Louis District, http://www.mvs.usace.army.mil/engr/river/EnvironEng/en12.htm. Accessed 25 July 2003.
18. Byars, Morgan. S., Lyle W. Zevenbergen, and Peter F. Lagasse. Hydraulic Design for Channel restoration on the Santa Ana Reach of the Rio Grande, Building Partnerships, *Joint conference on Water Resources Engineering and Water Resources Planning and Management*, 91/4, American Society of Civil Engineers, Washington, DC, 2000.
19. Lower Mississippi River Conservation Committee, Habitat, http://lmrcc.org/Recreation/Fishing/habitat.htm, Accessed 20 October 2003.
20. Kuhnle, Roger A., Carlos V. Alonzo, and Fletcher D. Shields, Jr. Local Scour Associated with Angled Spur Dikes: Implications for Bank Stability and Aquatic Habitat, U.S. Agricultural Research Service TEKTRAN, March 2003.
21. Stauffer, K. W. *Habitat Use and Growth of Juvenile Catfish in the Missouri River and a Tributary, the Lamine River*, M.S. Thesis, University of Missouri-Columbia, 1991.
22. Shields, F. D., S. S. Knight, and C. M. Cooper, Streambank Protection and Habitat Restoration, *Proceedings of the 1st International Conference on Water Resources*, Part 1, American Society of Civil Engineers, Washington, DC, 1995.

23. McAnally, W. H., J. F. Haydel, and G. Savant, *Port Sedimentation Solutions for the Tennessee-Tombigbee Waterway in Mississippi, Report 2: Engineering Solutions*, Civil Engineering Department, Mississippi State University, MS, 2003.
24. U. S. Army Corps of Engineers, *Tennessee-Tombigbee Waterway, Columbus Lock and Dam, Design Memorandum No. 18, Sedimentation Program*, Mobile District, 1978.
25. Copeland, Ronald R., Dinah N. McComas, Nolan K. Raphelt, and William A. Thomas, *User's Manual For The Sam Hydraulic Design Package For Channels*, Waterways Experiment Station, U.S. Army Corps of Engineers, Vicksburg, MS, 1998.
26. Sarikaya, H. Z. Numerical Model for Discrete Settling, *Journal of the Hydraulics Division*, American Society of Civil Engineers, 103, HY8, Aug 1977, 866-876.

TABLE 1 Geometric Data for Lowndes County Port

Channel Reach	Top Width at Normal Pool ft	Bottom Width ft	Length ft	Depth at Normal Pool ft
Columbus Cutoff	500	300	10,500	9
Tombigbee River Bendway Above Port	250	150	9,800	12
Port	300	200	3,590	9

Sources: Reference *5* and measurements by authors.

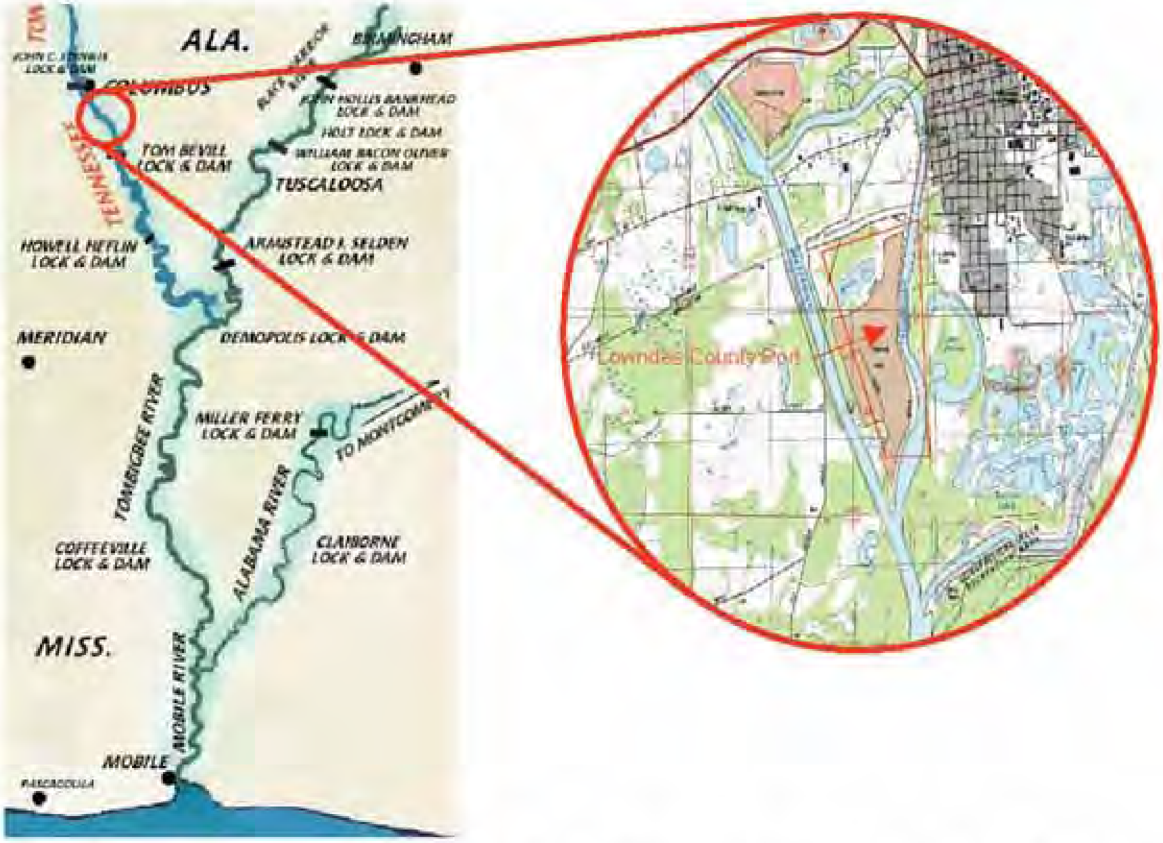


FIGURE 1 Area map (courtesy of the Tennessee-Tombigbee Waterway Development Authority) and Lowndes County Port detail. (Maptech® USGS Topographic Series™, ©Maptech®, Inc., www.maptech.com/topo).

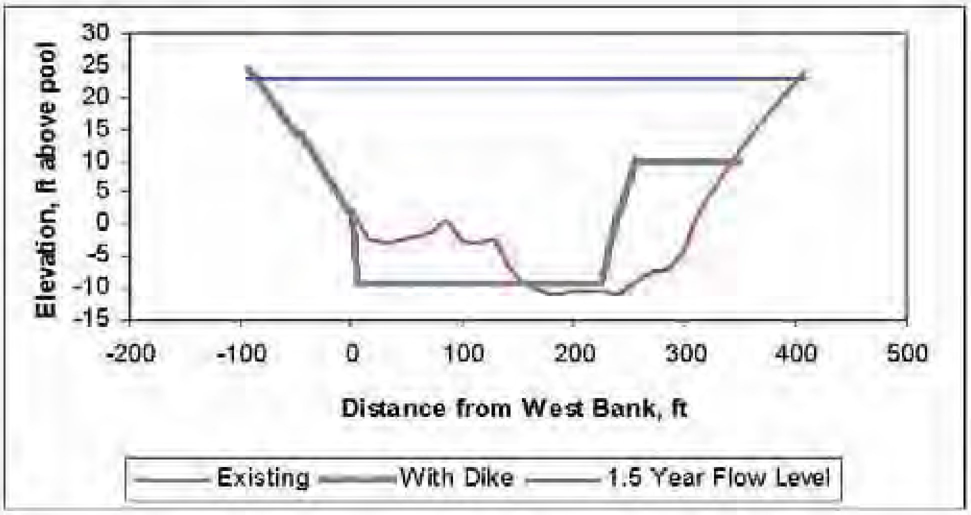


Figure 2 Lowndes County Port cross-section with and without dike in place.

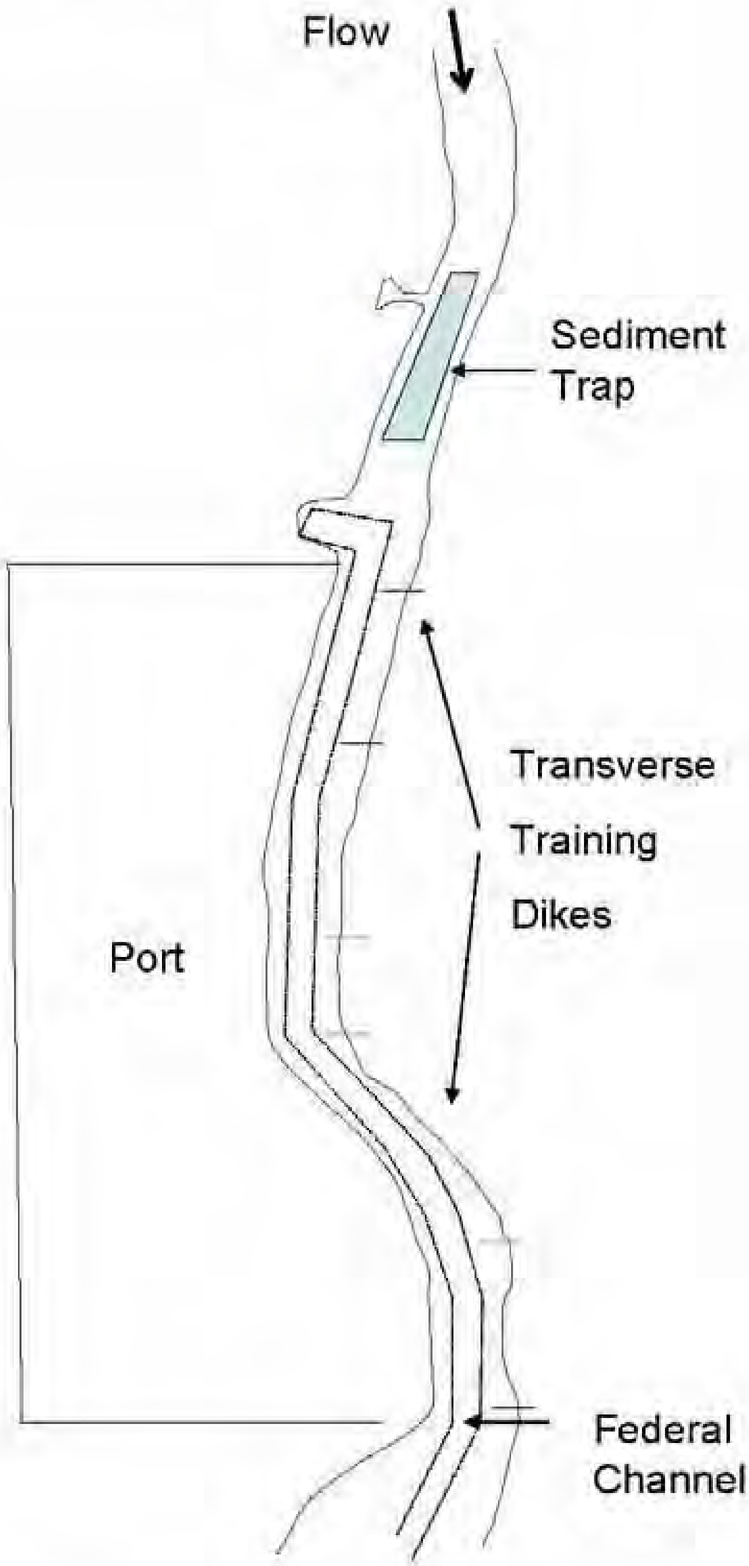


Figure 3 Lowndes County Port layout with sedimentation solutions shown schematically

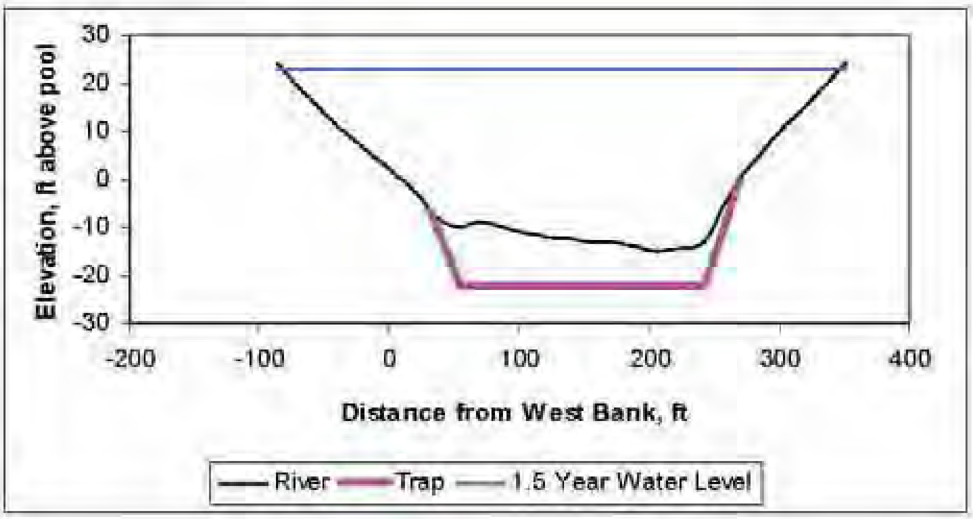


Figure 4 Cross-section of Tombigbee River bendway above Lowndes County Port with sediment trap in place.

2004 Conference Attendees

Keith Allen	MS Department of Health
Peter Ampin	MS State University – Plant and Soil Sciences
Ashley Andrews	MS State University – Plant and Soil Sciences
Kerry Arthur	US Geological Survey
Brent Bailey	MS Farm Bureau
Trent Baldwin	US Geological Survey
Jeff Ballweber	MS State University – GeoResources Institute
David Barnes	MS Department of Environmental Quality
Claiborne Barnwell	MS Department of Transportation
Michelle Barret	MS Department of Environmental Quality
Phil Bass	MS Department of Environmental Quality
Jason Beadle	University of MS – Biology
Laura Beiser	US Geological Survey
Jimmy Bonner	MS State University – Extension Service
Hamid Borazjani	MS State University – Forest Products
Bryant Boswell	Lewis & Clark Presentation
Shirley Bounds	Public Service Commission
Chris Bowen	Pat Harrison Waterway District
Bill Branch	Louisiana State University Ag Center
Debi Brewington	MS State University - GeoResources Institute
Sarah Bryan	Public Service Commission
Richard Bryant	Tombigbee River Valley Water Supply District
Michelle Burns	MS Department of Environmental Quality
Tony Caldwell	MS Department of Environmental Quality
Michael Caples	Butler Snow
Antonio Luiz Cerdeira	Embrapa, Ministry of Brazilian Agriculture, Brazil
Charles Cooper	USDA – ARS – National Sedimentation Laboratory
Emily Cotton	MS Department of Environmental Quality
Richard Coupe	US Geological Survey
Jamie Crawford	MS Department of Environmental Quality
Bobby Cullum	USDA – ARS – National Sedimentation Laboratory
Gregg Davidson	University of MS – Geology & Geological Engineering
Amanda Davis	US Geological Survey
Mike Davis	Pearl River Basin
Fred Deegen	MS Department of Marine Resources
Ann Marie Denman	MS Department of Environmental Quality
Scott Dennis	US Geological Survey
Susan Diehl	MS State University – Forest Products
Alice Dossett	MS Department of Environmental Quality
Karen Dove-Jackson	USACE, Vicksburg District
Daniel Drennen	US Fish & Wildlife Service
Ray Eaton, Jr.	MS Department of Environmental Quality
R.D. Ellender	Univ. of Southern Mississippi – Biological Sciences
Jeremiah Estes	Univ. of Southern Mississippi – Biological Sciences
Robert Fitch	Univ. of Southern Mississippi – Biological Sciences

Rob Fowler	Balch & Bingham, LLC
Jamie Franks	State Representative, District 19
Julia Giller	US Geological Survey, Gulf Coast Liaison
Will Green	MS Department of Environmental Quality
Ken Griffin	Pearl River Valley Water Supply District
Frank Gwin, Jr.	MS Delta Management Systems Evaluation Area
Rick Hagar	MS Soil & Water Conservation
Paul Hartfield	US Fish & Wildlife Service
Vernon Hartley	MS Department of Environmental Quality
Frank Henry	US Geological Survey, HIF Stennis Space Center
Chuck Hill	MS State University – GeoResources Institute
Pete Howard	MS Department of Environmental Quality
Fred Howell	Univ. of Southern Mississippi – Biological Sciences
Russ Howell	US Geological Sciences
Rita Jackson	MS State University – GeoResources Institute
Alton Johnson	Alcorn State University
David Johnson	USACE, Vicksburg District
Randy Jones	MS Department of Environmental Quality
Joyce Kellum	US Geological Sciences
Scott Knight	USDA – ARS – National Sedimentation Laboratory
Robert Kroger	Univ. of Mississippi
Brian Laine	Univ. of Mississippi – Geology & Geological Engineering
P. Patrick Leahy	US Geological Sciences
Richard Lizotte, Jr.	USDA – ARS – National Sedimentation Laboratory
Martin Locke	USDA – ARS – National Sedimentation Laboratory
John Madsen	MS State University – GeoResources Institute
Melanie Magee	EPA – Gulf of Mexico Program
Richard Maiers	MS State University – Forestry
Sitaram Makena	MS Department of Environmental Quality
Joe Massey	MS State University – Plant and Soil Sciences
David Massingill	US Geological Sciences
Mary Matheny	Public Service Commission
William McAnally	MS State University – Civil Engineering
Deirdre McGowan	MS Water Resources Association
James Moak	MS Department of Transportation
Tommy Moffatt	State Senator, District 52
Matt Moore	USDA – ARS – National Sedimentation Laboratory
Steve Moore	Bureau of Plant Industries
Fred Morris, III	US Geological Survey
Carol Moss	US Geological Survey
Karen Myers	USACE
Danny Nelson	Pat Harrison Waterway District
Alan Niven	Univ. of Southern Mississippi – Biological Sciences
Larry Oldham	MS State University – Extension Service
Angela Pell	US Geological Sciences
Dean Pennington	YMD Joint Water Management District
Diane Peranich	State Representative, District 121
Harriet Perry	Univ. of Southern Mississippi – Gulf Coast Laboratory

Mickey Plunkett	US Geological Survey
Jonathan Pote	MS State University – Office of Research
Sam Qarqish	MS Department of Environmental Quality
Richard Rebich	US Geological Sciences
Bill Reid	Pat Harrison Waterway District
Kenneth Reinecke	US Geological Sciences
Randy Reed	MS Department of Environmental Quality
Bo Robinson	Public Service Commission
Michael Runner	US Geological Survey
Jessie Schmidt	MS State University – GeoResources Institute
David Shaw	MS State University – GeoResources Institute
Larry Slack	US Geological Survey
Cade Smith	MS State University – Plant and Soil Sciences
Jonathan Sobley	MS State University – Landscape Architecture
Libba Stanford	YMD Joint Water Management District
Hugh Stevens	Public Service Commission
Mark Stiles	YMD Joint Water Management District
Shane Stocks	US Geological Survey
John Storm	US Geological Survey
Ronny Tackett	Public Service Commission
Mary Love Tagert	MS State University – GeoResources Institute
Mike Tagert	MS Department of Agriculture and Commerce
Shiquan Tao	MS State University – DIAL
Sam Testa	USDA – ARS – National Sedimentation Laboratory
James Thomas	MS State University – Extension Service
Joe Treadway	US Geological Survey, HIF Stennis Space Center
Christine Trigg	Univ. of Southern Mississippi – Gulf Coast Laboratory
Don Underwood	MS Soil & Water Conservation
Kim Usry	US Geological Survey
Jerome Vaughan	MS Department of Environmental Quality
Ryan Verseman	MS State University – Landscape Architecture
Michael Wade	US Geological Survey
Chad Wallace	MS Department of Transportation
Jim Weston	Univ. of Mississippi – Pharmacognosy Department
Andrew Whitehurst	MS Department of Wildlife
Amy Wilberding	Univ. of Southern Mississippi – Biological Sciences
Kristie Willett	Univ. of Mississippi – Pharmacology
Patricia Wilson	MS State University – GeoResources Institute
Van Wilson	US Geological Sciences

STATEMENT OF AAEO

This publication was supported in part by funds provided by the U.S. Department of the Interior, Washington, DC, as authorized under the Water Resources Act of 1984 (PL 98-242). Contents of this publication do not necessarily reflect the views and policies of the U.S. Department of the Interior, nor does mention of the trade names or commercial products constitute their endorsement of the recommendation by the U.S. Government.

Revenue derived from the sale of documents published by the Institute is used to defray the cost of publishing and mailing. Please make prepayment by check ($20.00) and mail to:

Mississippi Water Resources – GeoResources Institute
Box 9652
Mississippi State, MS 39762-9652

Mississippi State
UNIVERSITY