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The Mississippi Delta Management Systems Evaluation Areas Project, 1995-99

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DEDICATION

Many individuals associated with the Mississippi Delta Management Systems Evaluation Areas (MDMSEA) project deserve recognition and appreciation. The two individuals mentioned here have shown exemplary service to the MDMSEA project, and this report is dedicated to their honor.

Mr. Frank Gwin, Jr.

Mr. Gwin came to the MDMSEA project in 1995 as a retired farmer willing to serve as the project coordinator. His love and zeal for the project has led him to work countless hours above and beyond what was required. Without Frank's tireless devotion, the project simply would not have existed, at least not in its present scope. Frank helped coordinate numerous activities between the various research agencies and the farmers who participated in the project. He also actively sought as many opportunities as possible to promote the project in the Delta community, especially with children and educators of area schools. Frank always delivered on whatever was asked of him. In fact, the general conclusion of the agencies that have worked with Frank can be summed up with a quote, "You might as well go ahead and get Mr. Frank whatever he needs, because if you don't, he'll just worry you to death until you do." Everyone associated with the MDMSEA project has considered it a pleasure to work with Frank over the past 6 years. We all hope that Frank will continue to serve as project coordinator and help lead the project in its next phase.

Mr. Cecil Belk

This report is also dedicated posthumously to the family of Mr. Cecil Belk, who was a participating grower in the Beasley watershed. Mr. Belk, who passed away in 1998, was a friend to the project; he allowed researchers to do whatever was necessary on his portion of the Beasley acreage to complete their work. Mr. Belk never seemed to say no whenever we asked for a favor or needed his help. Mr. Belk always had the time to stop and talk to whomever was on his land at the time and ask how the research was doing. Many of the researchers have fond memories of working with Mr. Belk, and his participation in the MDMSEA project is truly missed.

ACKNOWLEDGMENTS

Numerous agencies have participated in the MDMSEA project since 1994. The editors wish to express their appreciation for the countless hours of hard work for all of those groups. It is difficult to account for every single group that has participated in the project, and we apologize if any particular agency is neglected. A few comments are listed below for some individual agencies and organizations:

- The farmers and landowners who have participated in the project — without your assistance, time, and support, the project would not have been possible;
- The grower organizations, specifically Mississippi Farm Bureau and the Delta Council — thank you for your support, technical assistance, and help with securing funding for the project;
- The agencies that helped with the planning, funding, installation, and maintenance of best management practices in the MDMSEA watersheds — USDA Natural Resources Conservation Service, Mississippi Soil and Water Conservation Commission, Mississippi Department of Environmental Quality, U.S. Environmental Protection Agency, USDA Farm Service Agency, Delta Wildlife, USDA Wildlife Services, and the U.S. Fish and Wildlife Service;
- The agencies and organizations that provided additional technical assistance, resources, or funding in support of the research efforts of the project — Yazoo Mississippi Delta Joint Water Management District; Mississippi Agricultural and Forestry Experiment Station; Pyrethroid Working Group; Mississippi Department of Wildlife, Fisheries, and Parks; U.S. Army Corps of Engineers; John Deere Company; and Caterpillar Corporation;
- The agencies that served on the Technical Steering Committee — thank you for your hard work and technical expertise in planning the direction and research framework for the project; and
- The scientists associated with the project from USDA Agricultural Research Service, the U.S. Geological Survey, Mississippi State University, and the University of Mississippi.

FOREWORD

This publication, Mississippi Delta Management Systems Evaluation Areas Project, 1995-99*, summarizes the vast amounts of research conducted since the project's inception in 1994. Research within this project involves a wide range of scientific disciplines — hydrology, water quality, ecology, microbiology, soils, agronomics, education, modeling, economics, and sociology. The publication includes an executive summary, a technical interpretation of MDMSEA research, an extended bibliography of MDMSEA publications, and 22 articles summarizing individual research efforts. You are encouraged to read the technical sections of the report and then refer to the articles at the end of the report for additional information and data where necessary. The editors and the MDMSEA Technical Steering Committee hope this publication will outline the significant strides we have made in documenting water resource issues within agricultural settings in the Mississippi Delta. We also hope that this publication will provide otherwise limited information concerning solutions to water resource challenges that may exist. Finally, we hope this publication will provide the necessary foundation for future research initiatives in the Mississippi Delta.*

Richard A. Rebich,
U.S. Geological Survey

Scott Knight
USDA Agricultural Research Service

CONTENTS

CONVERSIONS

English Unit	Multiplier	Metric Units
inch (in)	2.54	centimeter (cm)
foot (ft)	0.305	meter (m)
square mile (mi^2)	2.59	square kilometer (km^2)
acre (ac)	0.405	hectare (ha)
pound (lb)	0.454	kilogram (kg)
ton (t)	907	kilogram (kg)
pound per million gallon (lb/mil gal)	0.120	milligram per liter (mg/L)
pound per million gallon (lb/mil gal)	120	microgram per liter (µg/L)

TRADE NAMES FOR SELECTED PESTICIDES[1]

Chemical Name	Trade Name (producer)[2]
Herbicides	
atrazine	Atrazine (Drexel Chemical Co.); AAtrex (Ciba); Atrazine 4L (Sostram Corp.); numerous others
cyanazine	Bladex, Fortrol (American Cyanamid Co.); Bladex (Dupont Agricultural Products)
fluometuron	Cotoran (Ciba); Meturon (Griffin Corp); Cottonex (Makhteshim-Agan); Flo-Met (Micro Flo Co.)
glyphosate	Roundup (Monsanto); Glyphotox (Aimco Pesticides Ltd.); numerous others
metolachlor	Dual, Pennant, Dualor (Ciba and Ciba Ltd.)
norflurazon	Zorial Rapid 80, Evital, Predict, Solicam (Sandoz Agro, Inc.)
Insecticides	
azinphosmethyl	Gusathion, Guthion (Bayer); Crysthion 2L (Crystal Chemical Inter-America); Acifon (General Quimica, S.A.); Cotnion-Methyl (Makhteshim-Agan)
cyfluthrin	Attatox, Baythroid, Contur, Laser, Solfac, Tempo (Bayer)
cypermethrin	Ammo, Arrivo, Cynoff, Prevail FT (FMC Corp.); Cymbush (Zeneca Ag Products); numerous others
deltamethrin	Decis, K-Obiol, K-Othrine (AgrEvo, S.A.); Deltex (Sanex Inc.)
lambda cyhalothrin	Karate, Commodore, Demand, others (Zeneca Ag Products, Zeneca Agrochemicals, Zeneca Professional Products, and Zeneca Public Health)
methyl parathion	Bladan M, Folodol M, Metacide (Bayer); Prompt, Sweeper (Sanonda Co., Ltd.); numerous others

[1]Mention of a pesticide in this paper does not constitute a recommendation for use by the agencies and organizations involved in the MDMSEA project, nor does it imply registration under FIFRA as amended. Names of commercial products are included for the benefit of the reader and do not imply endorsement or preferential treatment.
[2]Farm Chemicals Handbook, 1996.

EXECUTIVE SUMMARY

A consortium of federal, state, local, and university representatives was formed in February 1994 to develop the Mississippi Delta Management Systems Evaluation Areas (MDMSEA) project. The MDMSEA project was designed to use field-scale working farms to evaluate primary pollutants in Delta water resources and to identify BMPs that are most effective in reducing the transport of those pollutants in surface water and groundwater. Three Mississippi Delta oxbow lakes and the surrounding agricultural watersheds were selected for study. Significant findings of the MDMSEA project are summarized in this information bulletin.

Premanagement Conditions and Evaluation of Primary Pollutants

Sediment

- Suspended and total solids data collected in 1996 indicated that all three MDMSEA lake ecosystems were stressed due to excessive sediment. Mean suspended-solid concentrations were 405 milligrams per liter (mg/L) for Thighman Lake, 429 mg/L for Beasley Lake, and 289 mg/L for Deep Hollow Lake in 1996.
- Adverse effects of sediment on phytoplankton negatively affected fisheries.
- Runoff samples from sites draining conventionally tilled fields had the highest concentrations and loads of suspended sediment throughout the study period. Suspended-sediment concentrations in edge-of-field runoff were approximately three times higher than that measured in the lakes.
- Sediment accumulated in the three MDMSEA lakes at an average rate that ranged from 0.2 to 0.9 inch per year during the study period.

Nutrients

- Average nitrate concentrations in the three MDMSEA lakes before the implementation of BMPs were 1.16 mg/L (Thighman), 0.53 mg/L (Beasley), and 0.39 mg/L (Deep Hollow). Less than 10 percent of the runoff samples from the untreated site had nitrate concentrations greater than 6 mg/L. Aquatic criteria for nitrate currently do not exist.
- Average ammonia concentrations in the three MDMSEA lakes before BMP implementation were much lower than EPA aquatic health criterion. The median ammonia concentration in runoff samples from the untreated site was comparable to that reported within the lakes.
- Because phosphorus binds very readily to sediment, high levels of total phosphorus in the lakes were likely due to high levels of sediment in runoff and in the lakes.
- MDMSEA research found that nitrogen and phosphorus concentrations in lakes and runoff were higher than some recommended criteria. However, these concentrations caused no measurable detrimental effects to aquatic systems such as exposure or nuisance plant growth.

Pesticides

- Herbicides were detected in lake water samples and (frequently) in edge-of-field runoff samples.
- In lake water samples from the three MDMSEA lakes collected in 1996 and 1997, fluometuron and a metabolite were found in maximum concentrations ranging from 5-11 µg/L and from 2-3 µg/L (micrograms per liter), respectively, when cotton was the major crop in the three watersheds. The highest concentrations and most rapid dissipation were observed in Thighman Lake, which also had the highest levels of bacterial populations and greatest amounts of measured enzyme activity. No detections of fluometuron were observed in any lake after September 1997.
- Insecticides were detected infrequently in runoff samples from the three watersheds. Only four detections of pyrethroids were recorded in runoff samples collected from 1998 and 1999. These pyrethroid detections were recorded for runoff samples collected shortly after an application, and concentrations were near the analytical detection limits.
- Altogether, 622 samples were collected from shallow groundwater wells installed in the three watersheds and were analyzed for 20 pesticides. There were only five pesticide detections in these samples, all of which were less than drinking water standards and aquatic health criteria.

BMPs and Water Quality

Cultural and Structural BMPs

- Cultural and structural management practices reduced total and suspended sediments in all three lakes. The greatest percent reduction in suspended sediment was at Deep Hollow Lake (approximately 80 percent), where both cultural and structural practices for erosion control were used. Reduction in suspended sediment improved water visibility by 108 percent in Deep Hollow and 36 percent in Thighman Lake. Although sediments were reduced 53 percent in Beasley Lake, visibility did not improve.
- While high pre-BMP suspended-sediment levels suppressed chlorophyll concentrations in the MDMSEA lakes, reductions in sediment loadings due to management practices contributed to corresponding increases in chlorophyll and improved productivity.
- Moderate differences in nitrate and ammonia were observed in the lakes after BMPs were in place for 3 years. Nitrate concentrations ranged from 4 percent higher in Beasley Lake to 27 percent lower in Thighman Lake in 1999 than those recorded in 1996. Ammonia concentrations ranged from 33 percent higher in Thighman Lake to 39 percent lower in Deep Hollow Lake in 1999 than those recorded in 1996.
- Total phosphorus in the MDMSEA lakes decreased, because of BMPs, between 31 and 55 percent from 1996-99. Filterable orthophosphate increased in all MDMSEA lakes during the study period.
- Nitrate concentrations in shallow groundwater in the three MDMSEA watersheds were low. High rates of denitrification were one possible cause for low levels of nitrate in MDMSEA soils and, ultimately, in shallow groundwater.
- Post-BMP fishery surveys indicated successful renovation of lakes protected with cultural or structural and cultural practices. Bass populations lacking before renovation were successfully restocked in Deep Hollow and Thighman. Restocking in Beasley Lake failed due to continuing poor water quality despite the presence of structural BMPs. Results indicated that cultural BMPs such as conservation tillage play a significant role in improving water quality and may be needed in addition to structural measures to improve fisheries in Mississippi oxbow lakes.
- Over several years (1997-99), Thighman Lake maintained the highest bacterial populations and enzymatic activity; Deep Hollow Lake, intermediate; and Beasley Lake, the lowest.
- Certain algae isolated from MDMSEA lakes degrade atrazine and fluometuron, while some bacteria isolates degrade metolachlor, propanil, and trifluralin.

Slotted Board Risers and Filter Strips

- Two sites were installed in the Beasley watershed to determine the effects of a slotted-board riser and the combination of slotted-board risers and filter strips on runoff. Suspended-sediment concentrations and loads at these two sites were nearly identical to the untreated runoff site.
- Heavier sediment (or bed load material) was not measured in the runoff at the slotted-board riser site during the study period. However, about 1 foot of heavier sediment particles was trapped in front of boards permanently installed since 1996. Suspended-sediment loads were reduced an additional 30 percent when supplemental boards were in place during nongrowing-season months.
- A slotted-board riser alone did not reduce nitrate in runoff since nitrate is water soluble and moves easily in solution. However, nitrate concentrations in runoff were lower at sites with combinations of slotted-board risers and filter strips.
- Neither slotted-board risers nor the combination of slotted board risers and filter strips played a significant role in reducing phosphorus concentrations in measured runoff.
- Fescue filter strips were shown to support microbial populations able to accelerate the degradation of certain herbicides.

Riparian Zones and Ditches

- MDMSEA research suggested that riparian areas were useful in mitigating the transport of sediment in runoff and should be considered part of an overall plan for reduction of nonpoint-source pollutants. Suspended-sediment concentrations were 84 percent lower at the exit of the Beasley riparian area compared with the untreated edge-of-field runoff site. While the MDMSEA project does not advocate the use of natural riparian areas for disposal of agricultural runoff, modifications of agricultural ditches that allow them to function more like natural riparian areas and wetlands should be considered in a watershed management plan.
- Riparian zones were shown to be zones of highly enhanced microbiological activity that provide suitable niches for microbial populations capable of degrading selected herbicides.

- Nitrate concentrations in runoff were reduced by drainage through riparian areas before entering the lakes and reduced further in the lakes due to biological processes. Bacterial populations capable of reducing nitrate were more plentiful in riparian soils than in cropped areas, suggesting the potential for vegetated agricultural ditches to function similarly to riparian areas.
- Riparian runoff sites averaged 39 percent less total phosphorus than the untreated runoff site.
- Riparian areas proved effective in degrading both herbicides and insecticides.

Conservation Tillage and Cover Crops

- MDMSEA research showed that conservation tillage with winter cover and conservation tillage with winter cover and a slotted-board riser reduced suspended-sediment concentrations in runoff by 48 and 62 percent, respectively, in the Deep Hollow watershed.
- Nitrate was shown to be lower in conservation tillage area soils than in soils from a nearby conventional tillage area in the Deep Hollow watershed. Lower nitrate was due to immobilization of nitrogen in organic residues accumulated in surface soils of conservation tillage fields. Conservation tillage with winter cover was also effective in reducing both nitrates and total phosphorus in runoff samples from the Deep Hollow watershed.
- MDMSEA research documented 50 percent less fluometuron in runoff from a conservation tillage/cover crop site than from an untreated edge-of-field runoff site.

Innovative BMPs

- Other innovative BMPs examined in MDMSEA included agricultural biotechnology to reduce insecticide use, hooded sprayer with weed-sensing technology to reduce herbicide use, and precision farming to limit fertilizer use. Results from cotton and soybean studies indicated there was an average of 73 percent reduction in glyphosate use on cotton and a 49 percent reduction in glyphosate for soybeans using the sensor sprayer over the course of the study.
- Surveys conducted in the Beasley watershed characterized spatial variability of soil properties and weed populations. Such information provides a database that can be used for precision application of chemicals. Data indicated that density of weeds increased where clay and organic matter were more than 30 percent and 2.8 percent, respectively. Thus, more uniform weed control could be achieved by varying preemergence herbicide rates, and effective weed control could be achieved with less herbicide in areas of sandier soils and low organic matter.
- Insecticides were largely undetected in runoff from either Bt or non-Bt cotton sites.

Additional Research Efforts and Future Directions

- **Numerical simulation —** The Annualized Agricultural Nonpoint-Source Pollution (AnnAGNPS) model was coded with available watershed data from the Deep Hollow watershed, and runoff events were simulated for comparison with actual field data. AnnAGNPS provided a reasonable estimate (+/- 15 percent) of runoff and sediment load based on comparisons of model predictions with measured field values. The model was used successfully to provide estimated sediment loads for various BMP scenarios.
- **Economics —** Researchers began a study in 1999 to determine the economic impact to producers who install and maintain BMPs on their land. The economic simulations will be used to estimate crop yields and profits for various BMP scenarios.
- **Education —** The Student-Teacher Research Institute — the Delta Experience (STRIDE) program was designed to introduce research methodology to Delta middle school teachers and students and to work side-by-side with MDMSEA scientists on existing projects. About 30 teachers and students and 50 researchers in 16 different agencies participated each year of the 3-year program. The experience exposed students to the daily activities of field researchers thus promoting the science fields for future career choices.
- **Sociology —** In 1997, researchers conducted a survey to help understand attitudes of Delta citizens concerning water quality and the adoption of BMPs. Results of the survey indicated that those located near bodies of water or those who use bodies of water for sports activities were more concerned with water quality issues and BMPs than those not located near bodies of water.
- **Current and future projects —** These projects will focus on further contaminant reduction methodology, including specifics needed to meet Total Maximum Daily Load requirements — a holistic approach for farmer decision-making, and improvement of natural resources.

INTRODUCTION

Agricultural activities are considered a major source of nonpoint-source pollution in the United States. Examples of nonpoint-source pollution have been documented in various agricultural regions like the Midwest (Pereira and Hostettler, 1993). Nonpoint-source pollutants include sediment (Duda and Johnson, 1985), as well as pesticides and nutrients (Mueller et al., 1995; Meade, 1995; and Gilliom et al., 1985). Legislation such as the Clean Water Act recognizes agricultural Best Management Practices (BMPs) as methods to reduce nonpoint-source pollution. BMPs are typically implemented on farms on a voluntary basis with funding provided through cost-share programs if available. However, since the late 1980s, legislation such as reauthorizations of the Clean Water Act and the Farm Bill began to contain language that implied the mandatory use of BMPs in agricultural communities to reduce nonpoint-source pollution.

The National Management Systems Evaluation Areas (MSEA) program began in the early 1990s as part of the United States Department of Agriculture (USDA) Water Quality Program, which was part of the Presidential Water Quality Initiative (Swader and Adams, 1994). MSEAs were established in five Midwestern states as a cooperative effort with the USDA, the United States Geological Survey (USGS), and other federal, state, and local agencies. The overall purpose of a MSEA was to research the economic viability of alternative farming methods to reduce overdependency on agricultural chemicals and to accelerate the transfer and adoption of such methods (Council for Agricultural Science and Technology, 1992). Scientists assess landscapes for their vulnerability to water contamination from farm operations, provide information about the behavior and effects of agrichemicals on watershed ecology, and identify economically/environmentally sound BMPs as components of farming systems to reduce possible farm-generated contamination of soil, water, air, and biological resources.

One of the most intensively farmed agricultural areas of the United States is the southern part of the Mississippi Alluvial Plain in Mississippi, a 7,000-square-mile area locally referred to as the Delta. Agricultural activities in the Delta differ significantly from those in other regions such as the midwestern United States. The humid, subtropical climate in the Delta allows a different array of crops and cultural practices than those common in other areas of the United States. These factors, in combination with high regional rainfall amounts and high rainfall erosivity, can increase the chances for soil erosion and chemical movement within Delta watersheds (McGregor et al., 1995).

In May 1993, a group of local, state, and federal agency representatives, Mississippi Delta growers, and Mississippi grower advocate groups met to discuss agricultural nonpoint-source pollution in the Delta. Many Delta growers stated or asked, “We’re tired of being blamed,” “Are we really causing a problem?” and “Where’s the data?” The growers were also concerned with the potential for mandatory BMP programs that could be imposed by future legislation, and that those BMP programs might be specific to some other agricultural region of the United States and not feasible for the Delta. Specifically, this group wanted credible data concerning the effects of farming practices on water quality and how BMPs could improve water quality in the Mississippi Delta without jeopardizing cost-effective farm production. The group that met in May 1993 suggested that the USGS, the USDA Agricultural Research Service (USDA-ARS), and Mississippi State University (MSU) coordinate the research activities for an agricultural nonpoint-source pollution study.

The National MSEA program was chosen as a suitable framework to evaluate agricultural nonpoint-source pollution in the Mississippi Delta. In February 1994, a consortium of federal, state, local, and university representatives was formed to develop the Mississippi Delta MSEA (MDMSEA) project. The MDMSEA project was designed to utilize field-scale working farms to evaluate the primary agriculture-related pollutants in the Delta and to identify BMPs that were most effective in reducing transport of those pollutants to surface water and groundwater. Results from the MDMSEA project could be used to revise recommendations for farm management and planning. Results could also be used to update existing programs, such as cost-share programs for growers who volunteer to install BMPs.

The primary research agencies (USGS, USDA-ARS, and MSU) began to seek funding for research in early 1994. The USDA-ARS received funding for research near the end of fiscal year 1994. The USGS received a commitment for cooperative funding through the Mississippi Department of Environmental Quality (MDEQ) in November 1995. Specific research proposals from MSU have been funded through several different funding entities since 1995. Many other agencies and organizations have participated in the MDMSEA project and have contributed technical expertise, funding, labor, and other resources. A listing of those organizations follows: USDA-Natural Resources Conservation Service (USDA-NRCS); Mississippi Soil and Water Conservation Commission; United States Environmental Protection Agency, Yazoo Mississippi Delta Joint Water Management District; USDA-Farm Services Agency (USDA-FSA); Delta Council; Mississippi Farm Bureau; Mississippi Agricultural and Forestry Experiment Station; Pyrethroid Working Group; USDA-Wildlife Services; Delta Wildlife; Mississippi Department of Wildlife, Fisheries, and Parks; United States Fish and Wildlife Service; Mississippi Commissioner of Agriculture; University of Mississippi; Delta State University; United States Army Corps of Engineers (USCOE); John Deere Company; and Caterpillar Corporation.

From an overall view, I would say it (MDMSEA project) is a very good cooperative effort among farmers and between the private and public sector. It is a program that is going to base future decisions on scientific, well-thought-out, well-planned practices and methods of farming, and not just reactionary things like you hear around the coffee shops, or like maybe you hear from people on TV when they talk about the environment and the damage that farmers are doing to the environment. We get blamed for some things that we probably don't do. We probably do some things that we can improve. But this project will be based on facts and show us just what we need to be doing to improve our environment and improve our farming practices.

Recent interview with Mr. Jack Harris
Owner-operator of Harris Farms
Beasley Lake Watershed

This report summarizes the results of selected research efforts from the beginning of the MDMSEA project in 1995 through fiscal year 1999. This report documents the project design and location. This report also documents the influence of agriculture-related activities on water quality in the study area and the overall effectiveness of BMPs during the study period.

PROJECT DESIGN AND LOCATION

The Technical Steering Committee (TSC), a consortium of scientists and agency representatives, is responsible for the administration and overall technical direction of the MDMSEA project. In early meetings in 1995, the TSC prepared a document referred to as the project framework, which included details such as the purpose, scope, and objectives of the project. Subsequent meetings included discussions covering a wide range of topics, such as project location, BMP selection and installation, and research needs. The following sections outline the overall project design and location based on those early meetings.

Purpose, Scope, and Objectives of the MDMSEA Project

The two purposes of the MDMSEA project were to assess how agricultural activities affect water quality in the Mississippi Delta and to increase the knowledge needed to design and evaluate BMPs as components of Delta farming systems. The original timeframe for completion of the MDMSEA project was 5 years. Cotton production was identified as the primary crop of interest, but crops such as soybeans and corn also were evaluated because they are integrated with cotton production in typical Delta farming operations. The TSC suggested that the MDMSEA project focus on “oxbow lake” watersheds. Oxbow lakes are remnants of old river channel meanders that are no longer connected to the existing river channel. Oxbow lake watersheds were chosen because they were considered closed systems, and all of the runoff from the watershed was assumed to drain directly into the oxbow lakes. Consequently, these lakes represented biological endpoints affected by most watershed management systems. Seven major objectives were identified within the framework of the MDMSEA project:

- **Assessment —** Conventional and alternative farming systems would be assessed with respect to their effect on hydrologic processes, sediment and erosion control, and agrichemical movement in surface runoff, crop root zones, and unsaturated zones. Conventional and alternative farming systems would also be assessed with respect to their potential impact on soil and water quality, ecological processes, and fisheries resources in the oxbow lakes studied.
- **Components —** Specific components of each watershed would be monitored and evaluated as to their role in pollutant fate and transport, such as the effects of soil and plant processes on pesticide movement and degradation; the effect of agronomic management on soil characteristics and plant residue accumulation; the effects of riparian zones on agrichemical movement; and the hydrologic interaction between oxbow lakes, groundwater, and river systems near the study watersheds.
- **Sampling protocol —** Intensive monitoring strategies would be implemented to assess the effects of agricultural activities on water quality and aquatic resources. In addition, sensitivity analyses would be used to determine optimal sampling strategies for runoff monitoring in the MDMSEA project.
- **Farming system —** Structural, vegetative, and cultural BMPs would be implemented and evaluated for potential use in the Mississippi Delta, such as reduced tillage practices for cotton or other high-intensity crops; precision pesticide application techniques; use of winter cover crops to reduce erosion; and field drainage network improvements.
- **Modeling —** Field- and watershed-scale models would be used to assess the differences in measured responses between conventional and BMP watersheds, to identify the causes of those differences, and to permit evaluation of BMP applications at other locations and in more combinations than can be physically assessed. If necessary, new components or algorithms would be developed to improve the accuracy of predictions.

We want policies to be formed out of good science. This project offers a real opportunity for accurate scientific data to be gathered and used. As future policy is formulated for non-point-source pollution or agricultural runoff, this will be the background for a good, strong scientific basis for those decisions. We are enthusiastic about MDMSEA from this point of view. Some of the great things that we found out that do in fact work that we thought were working to begin with, are some of the least expensive ones, like filter strips and overfall pipes with flashboard risers. Thankfully, these things that we have been doing that aren’t terribly expensive seem to take care of a big percentage of what might be perceived to be the problem. So you don’t have to spend big bucks to solve some of these things.

Recent interview with Mr. Don Linn
Kay Planting Company
Beasley Lake Watershed

- **Socioeconomic —** The potential effects of watershed-wide adoption of alternative farming systems and practices on production, farm income, water quality, and aquatic resources would be evaluated. The effects of the MDMSEA project on the attitudes and behaviors of Delta growers regarding the use of alternative farming systems would be assessed. Information sources to producers regarding current and alternative farming systems would be examined as to their effectiveness in communicating environmental issues.
- **Extension —** The MDMSEA project team would work to increase awareness and adoption of farming systems and practices that protect and enhance surface water and groundwater quality and associated aquatic resources.

Project Location

The TSC formed a Site Selection Subcommittee in March 1994 to locate three watersheds for study. Oxbow lake watersheds were selected because they offered the advantages of both edge-of-field sampling and receiving-water (oxbow lake) sampling. Small watersheds were chosen to facilitate improvements to a significant part of the watershed so that changes in water quality could be measured. Several criteria were considered for choosing the study watersheds:

- The surface area of the oxbow lake should be about 20 acres;
- The predominant crop in the watershed should be cotton;
- Accessibility must be adequate during rainfall events to allow service of sampling equipment;
- Watersheds should be close to each other to minimize travel time;
- Watersheds should be relatively isolated to discourage vandalism and fishing-access problems; and
- Landowners and operators must be willing to cooperate with the scientists and commit to the MDMSEA project for a minimum 5-year period.

Field representatives of the USDA-NRCS and USDA-FSA were consulted to identify potential oxbow-lake watersheds in their particular jurisdictions that met these criteria. The Site Selection Subcommittee recommended the following three oxbow-lake watersheds in Sunflower and Leflore counties (Figure 1) in northwestern Mississippi in August 1994:

(A) **Thighman Lake watershed (Sunflower County) —** The total drainage area of this watershed is approximately 3,700 acres, the largest of the three watersheds (Figure 2). The surface area of the lake is about 22 acres. Soils in the watershed vary from loam to very heavy clay. The primary row crop grown from 1995-96 in the Thighman watershed was cotton; however, in 1997, growers began to diversify from cotton to rice, corn, and soybeans because of market changes (Gwin, 2001, appended). By 1999, very little cotton was grown in the Thighman watershed.

(B) **Beasley Lake watershed (Sunflower County) —** The total drainage area of this watershed is approximately 2,100 acres, and the surface area of the lake is

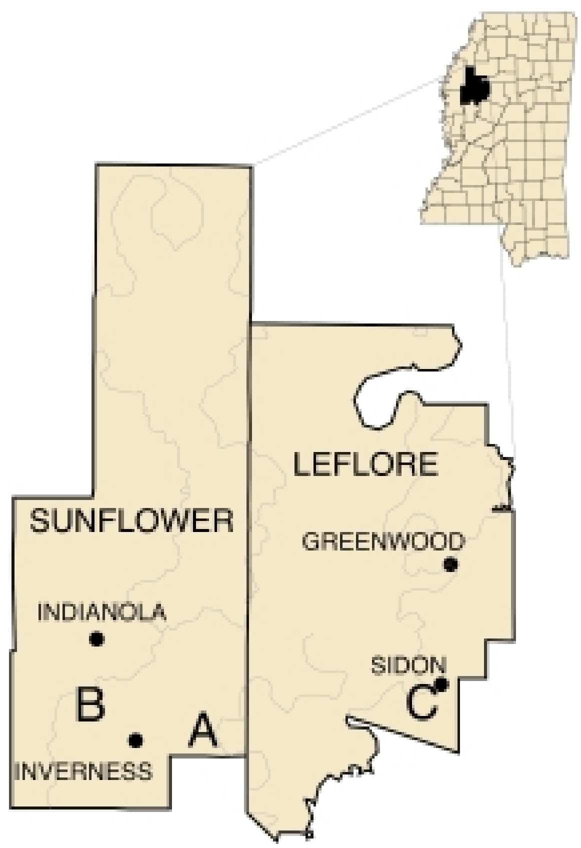


Figure 1. Mississippi Delta MSEA study watershed locations: (A) Thighman Lake watershed; (B) Beasley Lake watershed; and (C) Deep Hollow Lake watershed.

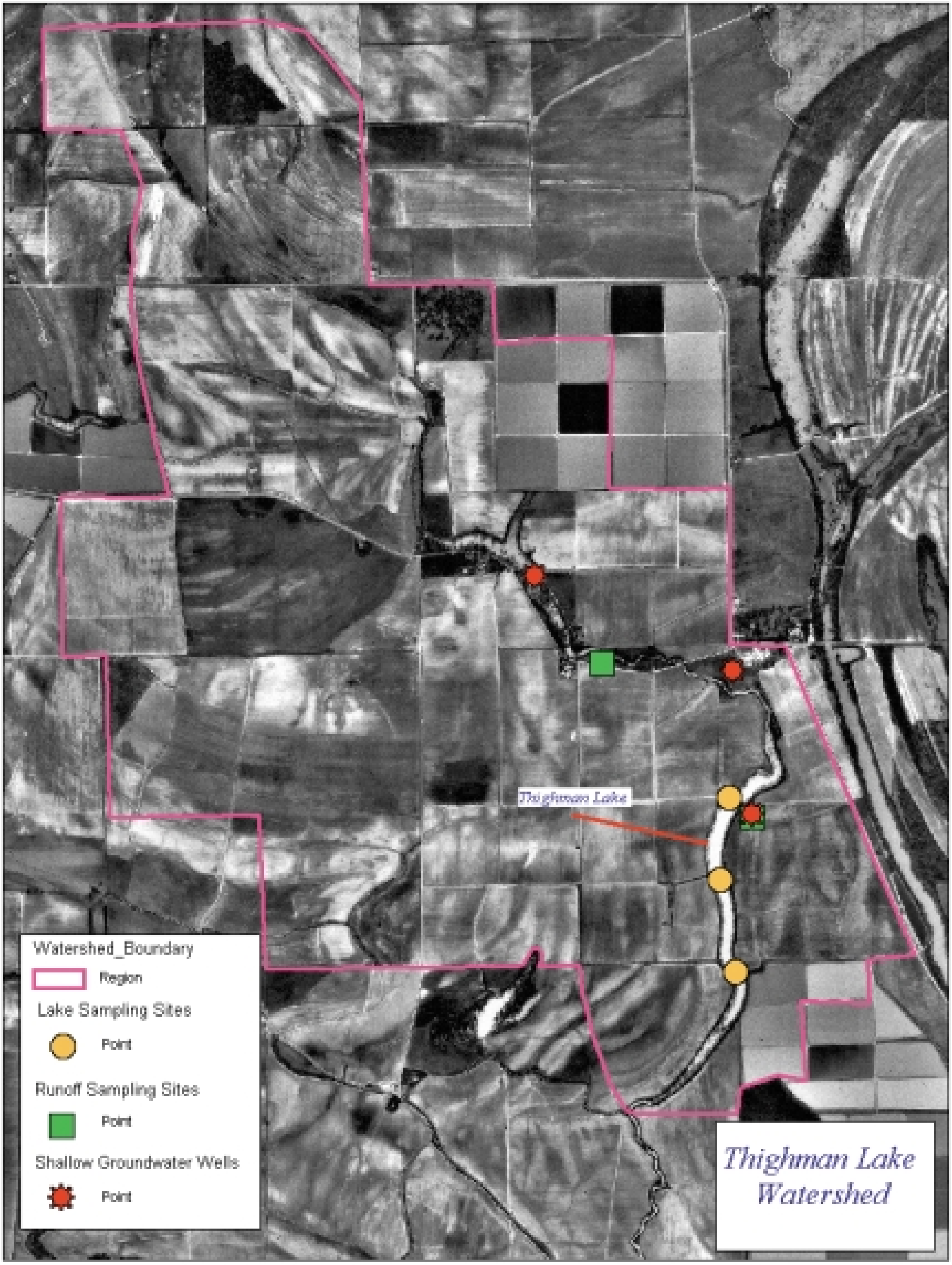


Figure 2. Research locations within the Thighman Lake watershed.

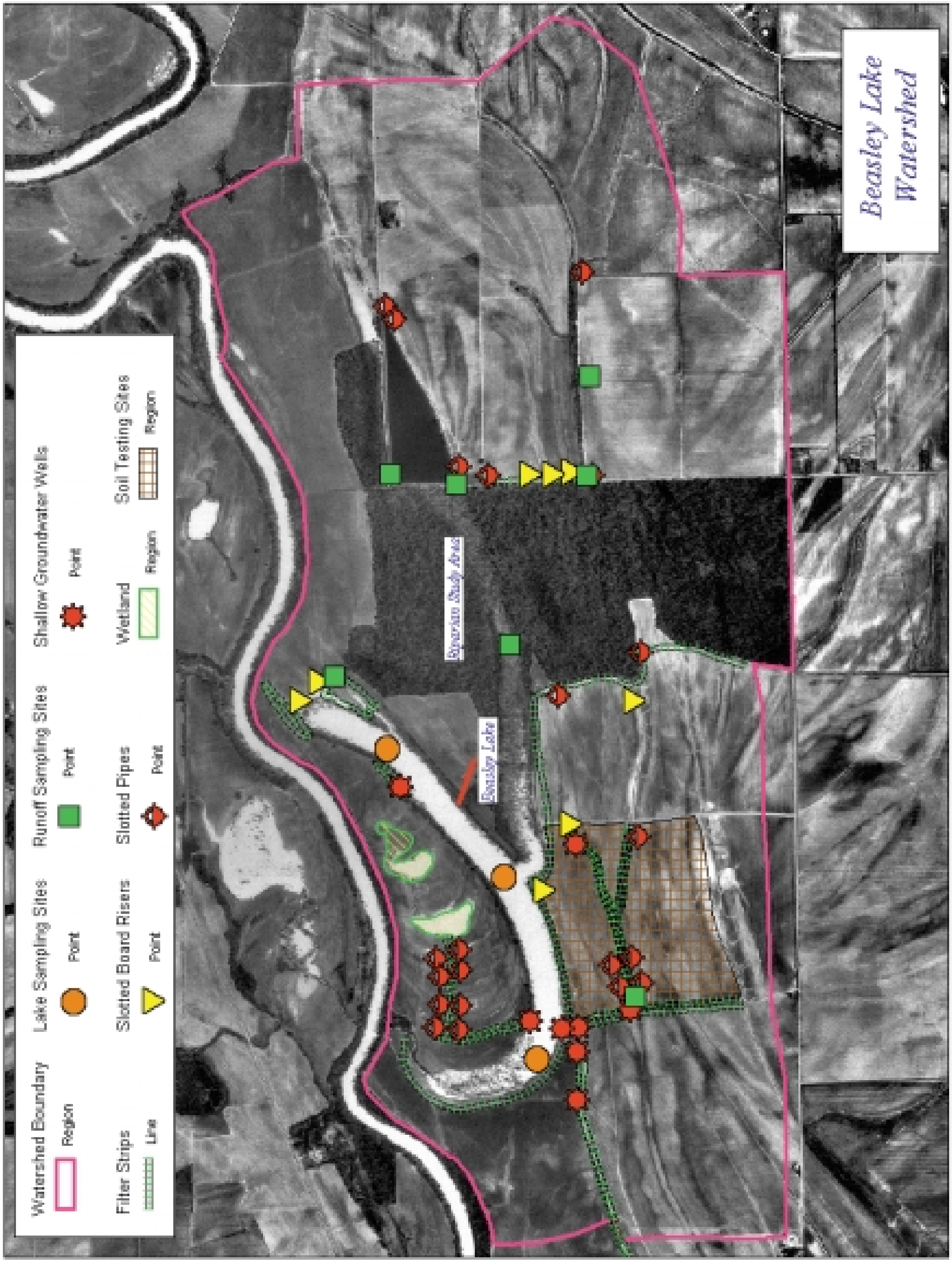


Figure 3. BMP and research locations within the Beasley Lake watershed.

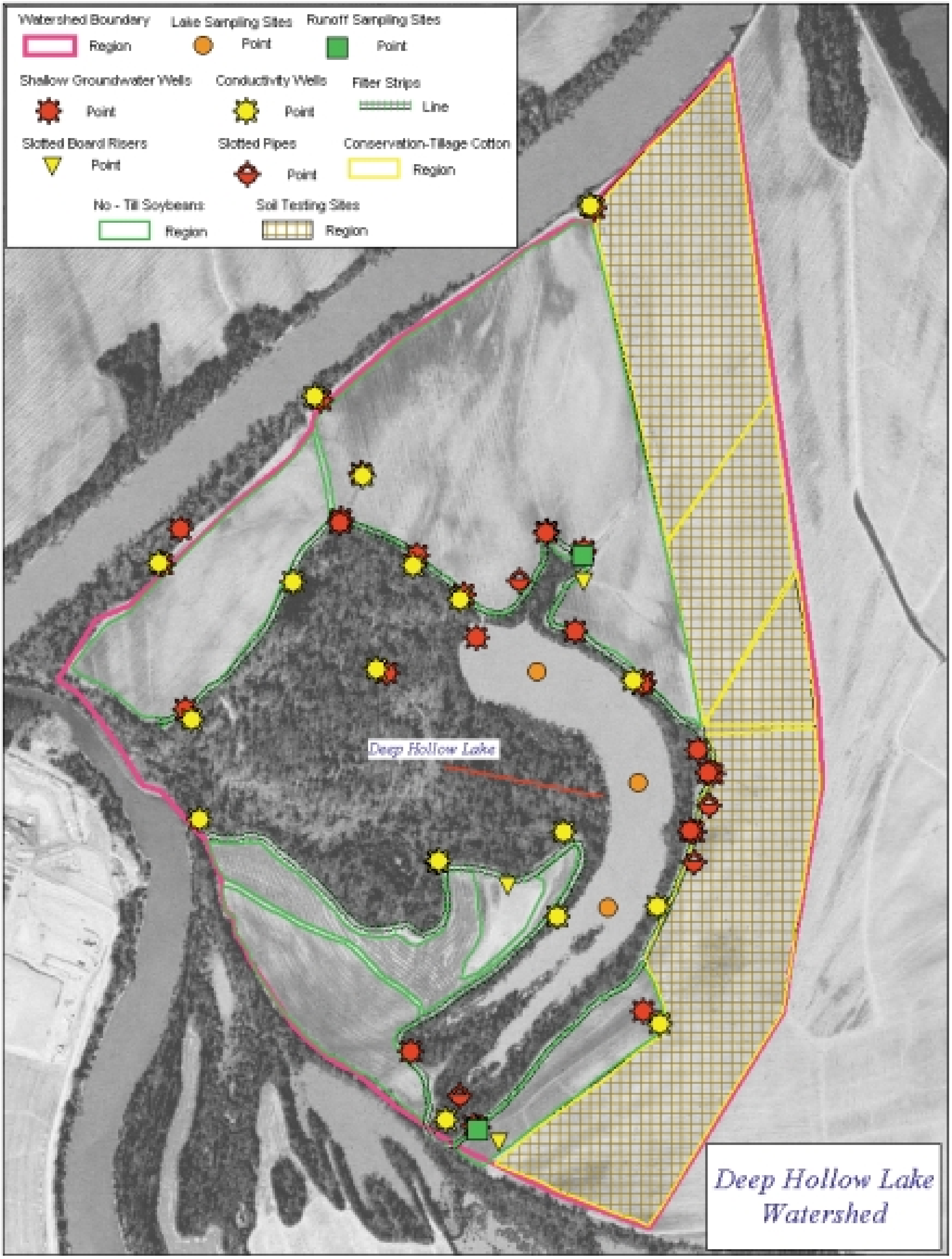


Figure 4. BMP and research locations within the Deep Hollow Lake watershed.

about 62 acres (Figure 3). The Sunflower River levee defines the northern part of the watershed boundary, and a large riparian area is located on the eastern side of the lake. Soils are generally loam to heavy clay. The Beasley watershed differs from the other two MDMSEA watersheds in that the difference in elevation from the top of the watershed boundary to the lake is about 18 feet (as opposed to differences of about 5 feet in the other two watersheds). As was the case in Thighman, cotton and soybeans dominated the Beasley watershed at the beginning of the project, with some shift to corn in 1998-99 as a result of changes in market and price (Gwin, 2001, appended).

(C) Deep Hollow Lake watershed (Leflore County) — The total drainage area of this watershed is approximately 500 acres, the smallest of the three watersheds (Figure 4). The surface area of the lake is about 20 acres. Cotton and soybeans were grown in this watershed from 1995-99. Much of the watershed has the loam soils that support cotton production (about two-thirds of the watershed), but heavier, clay soils are also present where soybeans were grown. The western side of the watershed is defined by the east levee of the Yazoo River, and a large riparian area lies between this levee and the lake.

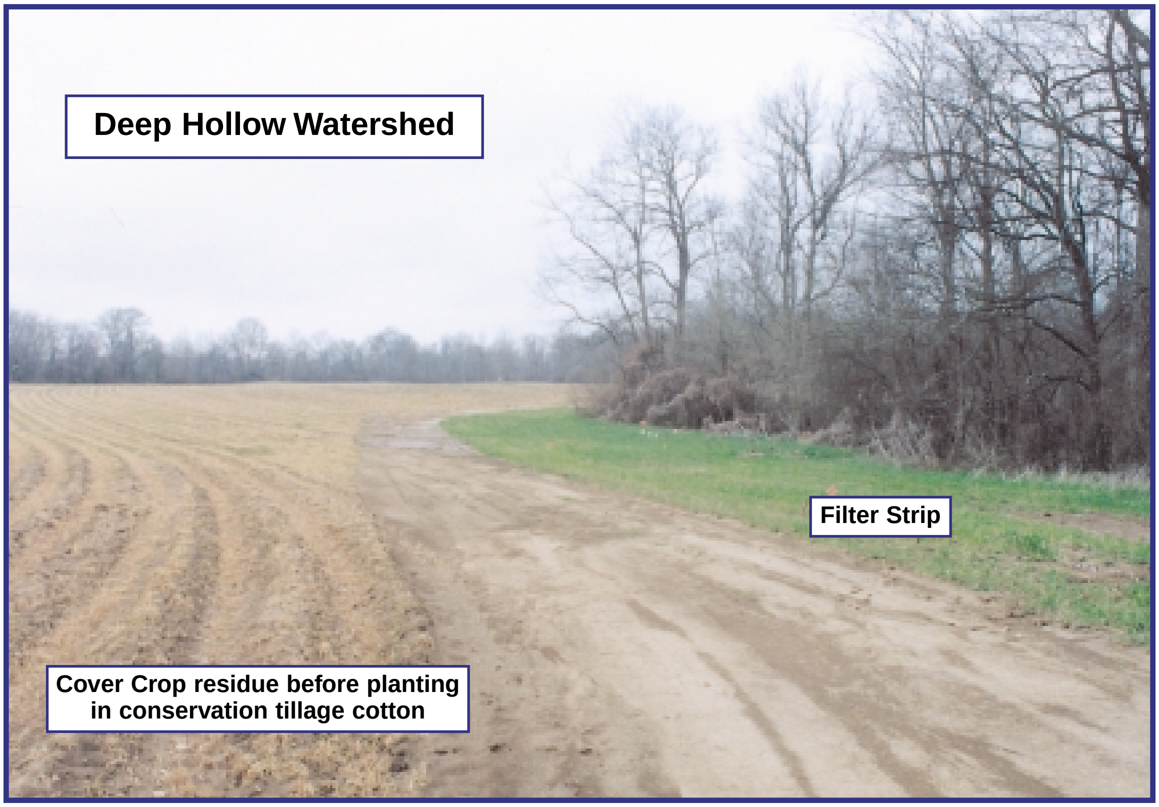
BMP Selection and Installation

After site selection, the TSC considered two options for BMP installation among the chosen watersheds. The first option was to distribute and study as many BMPs as possible in individual fields, resembling a traditional replicated-plot approach. However, this option did not lend itself to a complete watershed treatment of BMP systems for overall improvements in the oxbow lakes; nor was it feasible to instrument and research every field and runoff location. The second option was to distribute and study BMPs collectively as a system. An entire oxbow lake watershed would be treated with a system of BMPs so that changes in lake water quality could be observed over time for that specific system. This option likely resembled how potential mandatory BMP programs would be implemented. The disadvantage of this option was that improvements in lake water quality might not be linked to individual BMPs. The TSC selected the second approach.

> *The Delta is unique. Before the Mississippi River and its tributaries were contained within levees, in times of flood they meandered back and forth across the flood plain, leaving numerous oxbow lakes. These oxbow lakes have watersheds which drain into them that contain farmland and wooded areas ready-made for a study such as the Mississippi Delta MSEA (MDMSEA) project. There are more than 1500 of these lakes in the Mississippi Delta, varying in size anywhere from 15-20 acres to as much as 300 acres or more. The plan was to seek state and federal funding to study three of these lakes, their watersheds, and the farming practices used on them. The keys to the success of the project were the unselfish cooperation and participation of the farmers whose land was in the watersheds, the cooperation of the agencies involved (private, local, state, and federal), and the interest and acceptance of the people who were made aware of MDMSEA.*
>
> *Mr. Frank Gwin, Jr.*
> *Project Coordinator*
> *Mississippi Delta MSEA Project*

The TSC formed a BMP Subcommittee composed of growers and agency representatives in November 1994 to select the BMPs. The TSC instructed the BMP Subcommittee to identify one watershed to serve as a "control." BMPs would not be installed by the project in the control watershed, and researchers would document existing conditions (including any existing BMPs) and any changes over time. The second watershed would contain edge-of-field BMPs. The third watershed would contain edge-of-field BMPs and agronomic BMPs. BMPs in the second and third watersheds were selected based on erosion and sedimentation control primarily; however, pesticide and nutrient management and socioeconomic factors were also considered as selection criteria (see Parkman, 2001, appended, for details of BMP selection).

The BMP Subcommittee recommended the Thighman Lake watershed as the watershed where no MDMSEA-sponsored BMPs would be installed; however, the growers in the upper Thighman drainage began to use conservation tillage starting about 1997. The BMP Subcommittee recommended that only edge-of-field BMPs be installed in the Beasley Lake watershed. The edge-of-field BMPs were either structural, such as slotted-board risers and slotted inlet pipes, or vegetative, such as grassed filter strips and turn rows (BMP locations in the Beasley Lake watershed are shown in Figure 3). These BMPs were considered more economical than other BMPs considered for the MDMSEA project, but they were not expected to produce



the highest improvement to lake quality. The BMP Subcommittee recommended that the same edge-of-field BMPs used in the Beasley Lake watershed also be used in the Deep Hollow Lake watershed. In addition, agronomic BMPs would be included, such as conservation-till cotton and no-till soybeans, winter cover crops, and precision-application technology. These agronomic BMPs were expected to produce the highest level of lake quality improvement, but they were also considered to be the least economical to area growers (BMP locations in the Deep Hollow Lake watershed are shown in Figure 4).

After the selection and distribution of BMPs were finalized, the BMP Subcommittee recommended that installation should be under the direction of the USDA-NRCS through farm plans (Parkman, 2001, appended). This approach was suggested because farm plans are part of the conservation programs that growers normally use and are required for most cost-share programs. Several agencies worked together to fund and maintain BMPs at minimal or no cost to the participating growers (Rebich et al., 1996).

Research

Research by scientists of the USGS in Pearl, Mississippi, focused on the collection of stream flow data and water quality samples during runoff events (Rebich, 2001, appended). Nine stream flow and sampling sites were installed within the three MDMSEA watersheds. Site locations are shown in Figures 2-4 (complete site descriptions, Rebich, 2001, appended). Suspended-sediment, nutrient, and pesticide data from the nine sites were used to characterize the runoff in each of the three watersheds and to evaluate as many BMP combinations as possible.

Four laboratories of the USDA-ARS were involved with data-collection and research. Scientists at the National Sedimentation Laboratory in Oxford, Mississippi, focused their research efforts on the quality of shallow groundwater (Smith, 2001, appended), riparian area studies (Smith et al., 2001, appended), the assessment of the ecological health of the lakes (Knight et al.; 2001 a, b, appended), vertical crack development in Delta soils (Wells et al., 2001, appended), and numerical simulation models (Bingner and Yuan, 2001, appended). Shallow groundwater and lake sampling sites are shown in Figures 2-4.

Research by USDA-ARS scientists at the Southern Weed Science Laboratory in Stoneville, Mississippi, focused on spatial relationships on soil and weed properties (Gaston et al., 2001a, appended; Gaston et al., 2001b; Locke et al., 2001b); the influence of BMPs on soil quality (Locke et al., 2001a, appended); the impact of BMPs on microbial populations in the lakes and riparian areas (Zablotowicz et al., 2001; a, b, appended); and weed mapping (Bryson and Hanks, 2001, appended). Research by USDA-ARS scientists at the Application Production Technology Unit in Stoneville focused on precision technology in the area of equipment development (hooded herbicide sprayer with weed-sensing technology, Hanks and Bryson, 2001, appended). Research by USDA-ARS scientists at the Soil and Water Research Unit at Baton Rouge, Louisiana, and at the USGS included the study of insecticide loadings in surface runoff (Rebich et al., 2001, appended) and the use of weather forecasts to optimize timing of pesticide applications.

Research activities at MSU crossed a wide range of disciplines. MSU scientists were involved with agronomic research, specifically in the areas of herbicide dissipation in filter strips and riparian zones (Shaw et al., 2001, appended). Another MSU activity was in the area of sociological research to understand the attitudes of Delta citizens toward adoption of BMPs (Gill, 2001, appended). Scientists at MSU were also involved in economics research to determine the costs and benefits of BMPs to the farmers (Hite and Reinschmiedt, 2001, appended). Education-related activities at MSU were added to introduce research methodology to Delta middle school teachers and students and to work side-by-side with MDMSEA scientists on existing projects (Thibaudeau et al., 2001, appended).

Research activities and data collection efforts for the MDMSEA project were comprehensive by design. Research results presented in the next two sections of the report are organized according to the two purposes of the project and are based on selected articles appended at the end of this report.

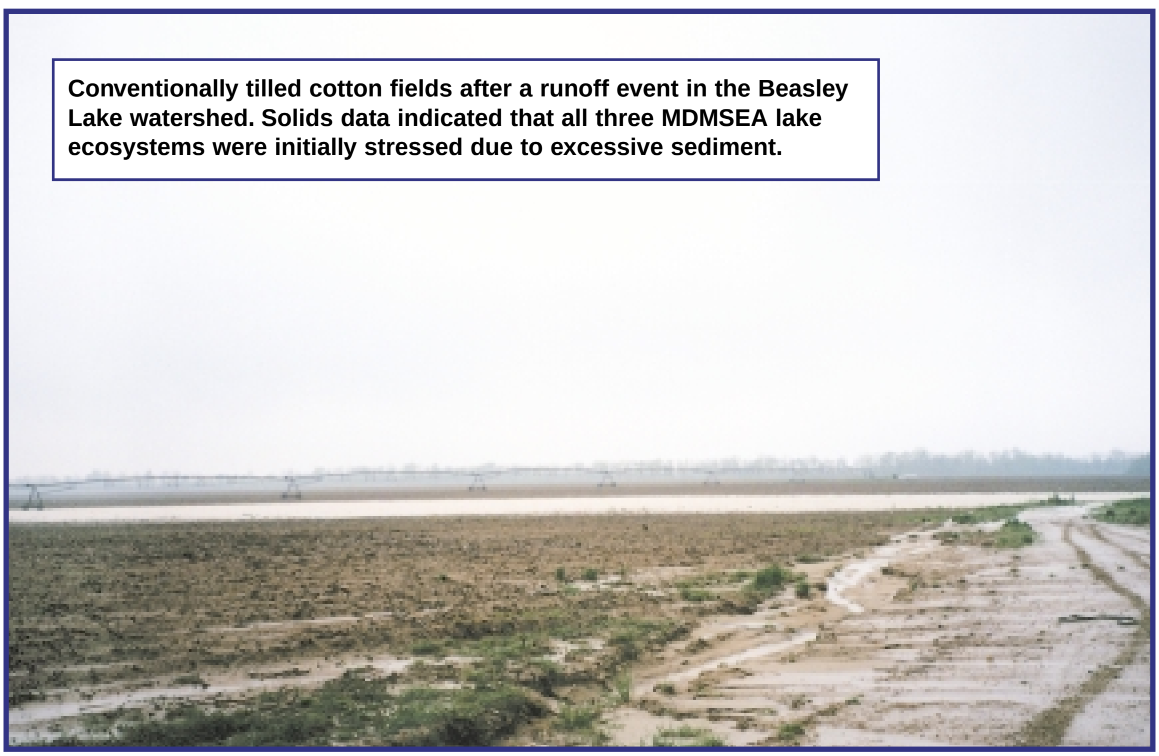
AGRICULTURE AND WATER QUALITY

Water quality and aquatic resource data that document premanagement conditions and that evaluate potential pollutants in the three MDMSEA watersheds are presented in this section. The data included in this section were collected before the implementation of BMPs in the three MDMSEA lakes (1995-96). Data collected throughout the study period from a runoff site in the Thighman watershed located at the edge of a conventional tillage cotton field are also included to describe runoff quality from an untreated field (note, this site is hereafter referred to as the Thighman runoff site, and pollutant concentrations from this site presented in this section are based on "storm-averaged" composite runoff samples). These data are presented according to three categories of nonpoint-source pollutants considered priorities for Delta agricultural watersheds: sediment, nutrients, and pesticides.

Sediment

Sediment has been identified as one of the leading nonpoint-source pollutants in the United States and in Mississippi (Fowler and Heady, 1981; State of Mississippi, 1999). Sediment from soil erosion has reduced water quality and fish populations in Mississippi lakes, causing a decline in productivity and recreational value (Cooper and Knight, 1978). Excessive sediment limits the amount of light penetration needed for optimum photosynthesis, thereby limiting the amount of primary productivity (phytoplankton) that sustains fish populations (Knight et al., 2001a, appended). Other problems include destruction of habitat in lakes caused by filling and by transportation of pollutants such as nutrients and pesticides bound to sediment particles.

Solids data collected in 1996 indicated that all three MDMSEA lake ecosystems were stressed due to excessive sediment (Knight et al., 2001a, appended). Mean suspended solid concentrations were 405 mg/L for Thighman Lake, 429 mg/L for Beasley Lake, and 289 mg/L for Deep Hollow Lake in 1996. Sediment accumulated in the three MDMSEA lakes at an average rate that ranged from 0.2 to 0.9 inch per year (Dr. Charlie Cooper, USDA-ARS, written communication, 2001). Cooper and Bacon (1980) reported that suspended sediment concentrations greater than 100 mg/L adversely affected primary productivity in lakes and streams. The levels of solids/sediment in the three MDMSEA lakes in 1996 caused low values of Secchi visibility (average was 13.4 cm) and chlorophyll (average was 17 µg/L).



Conventionally tilled cotton fields after a runoff event in the Beasley Lake watershed. Solids data indicated that all three MDMSEA lake ecosystems were initially stressed due to excessive sediment.

Adverse effects in primary lake productivity also had a direct impact on fisheries in the MDMSEA lakes. The standing stock of fish in the three lakes averaged about 216 pounds per acre in 1996 (Knight et al., 2001b, appended). Although this amount is normal for lakes (Cooper et al., 1963), much of the stock was made up of fish species such as gizzard shad and various species of gar and common carp — species typically associated with sediment-laden lakes. In addition, species richness was low for all of the three lakes with an average of 18 species per lake. Sport fishes were generally poorly represented in the three MDMSEA lakes with the exception of white crappie and some types of catfish. Although white crappie populations were significant, the overall size of the individual fish was considered small, averaging 0.67 to 1 ounce (Knight et al., 2001b, appended). Other water quality parameters such as pH (6.96 average) and dissolved oxygen (5.16 mg/L average) measured in the three lakes in 1996 were considered adequate to support sport fish.

Major portions of the Thighman, Beasley, and Deep Hollow watersheds (89, 62, and 47 percent, respectively) were planted in row crops such as cotton, soybeans, corn, rice, or milo (Gwin, 2001, appended). Row crop agriculture can be a major source of sediment to surface water (Meyer and Harmon, 1978). At the start of the project, cotton and soybeans were the dominant crops in each of the watersheds and typically were planted in conventional tillage.

MDMSEA watershed soils included fine-silty to fine-clay textures (Gaston et al., 2001a, appended; Gaston et al., 2001b). With frequent soil disturbance from conventional tillage operations, finely textured soils were easily transported during runoff events and remained suspended for long periods in runoff and lakes. Runoff samples from the Beasley and Thighman watersheds with many conventional tillage operations had the highest concentrations of suspended sediment throughout the study (Rebich, 2001, appended). The median suspended-sediment concentration in composite runoff samples collected at two sites in the Beasley watershed was 1,600 mg/L and 1,050 mg/L; one site in the Thighman watershed was 1,350 mg/L.

The average annual suspended-sediment load at the Thighman runoff site was 4.9 tons per acre per year (t/ac/yr) (Rebich, 2001, appended). The USDA-NRCS recommends 5 t/ac/yr as an estimate, or tolerance level, of the maximum annual rate of soil erosion that can occur over a sustained period without affecting crop productivity for fields in Sunflower County (U.S. Department of Agriculture, Soil Conservation Service, 1992). Although the sediment load from the Thighman runoff site was the highest of any of the MDMSEA runoff sites, it was below load values reported in the literature for conventional tillage operations in other locations in the Mississippi Delta (9.3 t/ac/yr from 1973-78 near Clarksdale, Mississippi) and in upland areas of Mississippi (8.6 t/ac/yr from 1990-93) (McDowell et al., 1988; Cullum et al., 1992). This sediment load was also much lower than experimental plot studies in upland areas of Mississippi where sediment loads from conventional tillage cotton averaged 33 t/ac/yr over an 11-year period (McGregor et al., 1996).

Nutrients

Fertilizer inputs are necessary to produce economically viable yields for most agronomic crops. Fertilizer applied to the soil surface is subject to runoff during storm events, resulting in increased levels of certain nutrients in associated water bodies. Although nutrients are necessary to sustain aquatic habitat, excessive nutrients in surface waters can be detrimental to aquatic life (USEPA, 1987). The following paragraphs describe the amounts and potential effects of nutrients measured in the lakes and runoff of the MDMSEA watersheds. Concentrations of nutrients in the three lakes measured prior to BMP installation and concentrations and loads of nutrients in runoff from the untreated site (Thighman runoff site) are compared with available standards, aquatic health criteria, and related research.

Nitrate — The primary source of nitrate in the surface waters of the MDMSEA watersheds is nitrogen fertilizer applied to fields in late spring and early summer. Average nitrate concentrations in the three MDMSEA lakes prior to the implementation of BMPs were 1.16 mg/L (Thighman), 0.53 mg/L (Beasley), and 0.39 mg/L (Deep Hollow) (Knight et al., 2001a, appended). No aquatic life standard currently exists for nitrate. For perspective purposes only, the nitrate levels in the lakes were lower than the drinking water standard of 10 mg/L; however, since the MDMSEA lakes were not used as drinking waters sources, this comparison is not directly applicable. The nitrate levels reported in the MDMSEA lakes prior to BMPs were similar to those reported for lakes in the Yazoo River Basin in 1969 (U.S. Army Corps of Engineers, 1975).

The median nitrate concentration in composite samples from the Thighman runoff site was 1.8 mg/L during the study period (Rebich, 2001, appended). Less than 10 percent of the composite samples from the Thighman runoff site had nitrate concentrations greater than 6 mg/L. The average annual nitrate load at the Thighman runoff site was 11 pounds per acre per year (lb/ac/yr), which was the highest of the MDMSEA sites where loads were calculated. This load is also higher than nitrate loads reported in previous studies. McDowell et al. (1988) reported an average nitrate load of 6 lb/ac/yr for a conventional tillage cotton field from 1973-78. Cullum et al. (1992) reported an average nitrate load of 2.3 lb/ac/yr for a conventional tillage soybean field from 1990-93 (supplemental nitrogen was not applied).

Ammonia — Both aquatic and terrestrial plants readily absorb ammonium ions. The ammonium ion is positively charged and can adsorb to clay particles; therefore, efforts to reduce soil erosion should affect ammonium concentrations. Ammonium is easily oxidized to nitrite, and since nitrite is unstable in aerated waters, nitrite is quickly oxidized to nitrate, the more stable form of nitrogen. Average ammonia concentrations in the three MDMSEA lakes before the implementation of BMPs were 0.168 mg/L (Thighman), 0.123 mg/L (Beasley), and 0.089 mg/L (Deep Hollow) (Knight et al., 2001a, appended). These lake concentrations were much lower than the USEPA (1987) aquatic health criterion of 1 mg/L at pH 7 and 30°C for exposure to ammonia.

The median ammonia concentration for composite samples from the Thighman runoff site during the study period was 0.05 mg/L (Rebich, 2001, appended). Less than 10 percent of the composite samples from the Thighman runoff site had ammonia concentrations greater than 0.5 mg/L. The average annual ammonia load at the Thighman runoff site was 0.99 lb/ac/yr, which was the highest average where loads were calculated. This load was also higher than ammonia loads reported in previous studies. McDowell et al. (1988) reported an average ammonia load of 0.63 lb/ac/yr for a conventional tillage cotton field from 1973-78. Cullum et al. (1992) reported an average annual ammonia load of 0.77 lb/ac/yr for a conventional tillage soybean field from 1990-93 (supplemental nitrogen was not applied).

Ortho-phosphorus — Ortho-phosphorus is a measure of phosphorus dissolved in the water and is the form that is directly available to aquatic plants. Before the implementation of BMPs, average ortho-phosphorus concentrations in the three MDMSEA lakes were 0.018 mg/L (Thighman), 0.032 mg/L (Beasley), and 0.019 mg/L (Deep Hollow) (Knight et al., 2001a, appended). No national standards exist for ortho-phosphorus at this time; however, for perspective purposes, the USEPA (1987) recommends that total phosphates (which include ortho-, pyro-, and polyphosphate) should not exceed 0.025 mg/L within a lake or reservoir to control accelerated eutrophication.

The median ortho-phosphorus concentration for composite samples from the Thighman runoff site was 0.09 mg/L during the study period. More than 75 percent of the ortho-phosphorus concentrations from the Thighman runoff site exceeded 0.06 mg/L. To control eutrophication, the USEPA (1987) recommends that total phosphates should not exceed 0.05 mg/L (as P) in a stream at a point where it enters a lake. It is expected that concentrations of ortho-phosphorus would be higher in edge-of-field runoff than in streams. The average annual ortho-phosphorus load at the Thighman runoff site was 0.53 lb/ac/yr. This load was lower than the average ortho-phosphorus load of 1.4 lb/ac/yr reported by McDowell et al. (1988) for conventional tillage cotton from 1973-78. The ortho-phosphorus load from the Thighman runoff site was higher than the average load of 0.43 lb/ac/yr reported by Cullum et al. (1992) for the conventional tillage soybean fields from 1990-93.

Total phosphorus — Total phosphorus is a measure of phosphorus on particulates plus phosphorus dissolved in the water. Average total phosphorus concentrations in the three MDMSEA lakes before the implementation of BMPs were 0.437 mg/L (Thighman), 0.496 mg/L (Beasley), and 0.522 mg/L (Deep Hollow) (Knight et al., 2001a, appended). The total phosphorus values in the lakes were relatively high in comparison with other areas of the United States (Knight et al., 2001a, appended).

Additional applications of phosphorus are not typically applied to sustain crop yield in the Delta. Because phosphorus binds very readily to sediment, high levels of total phosphorus in the lakes were likely due to high levels of sediment in runoff. The median total phosphorus concentration for composite samples from the Thighman runoff site was 0.8 mg/L during the study period (note, the Thighman runoff site had one of the highest median suspended-sediment concentrations and a higher sediment load than any other runoff site). For perspective purposes, the USEPA (1987) recommends that total phosphorus not exceed 0.1 mg/L for a desired goal of preventing plant nuisances in streams or other flowing waters that do not discharge directly into lakes or impoundments. The average annual total phosphorus load at the Thighman runoff site was 4.6 lb/ac/yr.

Overall influence of nutrients — MDMSEA research indicated that selected nutrient concentrations in the lakes before BMP implementation and nutrient concentrations and loads from runoff from the untreated site were higher than some standards, recommendations, or other research. However, it did not appear that these concentrations or loads caused any detrimental effects to aquatic systems from exposure or from nuisance plant growth.

Pesticides

Pesticides are probably the highest profile and most highly publicized pollutant in the study area and the rest of Mississippi and the U.S. With the humid, subtropical climate and long growing season in the Mississippi Delta, a variety of pesticides (U.S. Department of Commerce, 1995) are used, and frequent applications are often necessary to control the intense weed and insect pressures that exist. The concerns with pesticides focus on not only the potential impact to human health but also the impact on aquatic and wildlife habitat.

MDMSEA pesticide research primarily focused on the occurrence and distribution of selected herbicides and insecticides in edge-of-field runoff and shallow groundwater. Lake water sampling for pesticides was limited to the understanding of fate and transport mechanisms for specific pesticides. Data presented in the following paragraphs are limited to one cotton herbicide (fluometuron) for samples collected in each lake prior to the implementation of BMPs, and selected herbicide and insecticide data collected at the Thighman runoff site during the study period. Because the purpose of the shallow groundwater research was to determine if BMPs increased agrichemical transport to groundwater (Smith, 2001, appended), the shallow groundwater pesticide data are presented in the next section of this report.

Herbicides — Water column samples from each lake were analyzed for the herbicide fluometuron and one of its degradation products, de-methylfluometuron (Zablotowicz et al., 2001a, appended). Fluometuron is primarily used as a soil-applied herbicide at planting or postemergence and is used on most cotton acreage in the Mississippi Delta. The highest concentrations of fluometuron were 11.2 µg/L (Thighman Lake, June 1997), 5.7 µg/L (Beasley Lake, July 1997), and 5.0 µg/L (Deep Hollow Lake, June 1997) (Zablotowicz et al., 2001a, appended). There are no current aquatic health criteria for fluometuron in lakes (Nowell and Resek, 1994).

Runoff samples were analyzed for 14

Anything we do on this project needs to be farmer-friendly. We don’t want to do a bunch of exotic stuff, or buy a bunch of exotic equipment. People looking at this project have to say, “Yeah, I can do that!” Our approach has been real practical things that basically anybody could do.

As a cotton and soybean farmer, my livelihood is closely tied to the use of farm chemicals. My outlook on the risks associated with the use of pesticides is definitely influenced by the exposure of myself, my farm labor, their families, and, of course, my wife and my two boys. We apply some chemicals ourselves and have most of them custom-applied by airplane. Exposure is not risk free, but it is extremely safe when following labeled directions, which we do.

A farmer-sponsored research project (Mississippi Delta MSEA) to measure nonpoint pollution from farm runoff and validate Best Management Practices (BMPs) shows the greatest promise for addressing concerns. An example of a BMP would be a grass filter strip around this oxbow lake. The grass slows down water runoff, traps soil (and chemicals attached to the soil particles), and helps keep the lake cleaner. Fortunately, there are world-renowned toxicologists, epidemiologists, chemists, and other scientists staking their professional careers on truthful science-based risk assessment. Knowing this instead of having fear as the motivator is the good news.

Recent interview with Mr. Philip Barbour
Renter and operator of Riverside Plantation
Deep Hollow Lake Watershed

herbicides: acetochlor, alachlor, atrazine, cyanazine, fluometuron, metolachlor, metribuzin, molinate, norflurazon, prometryn, propanil, propazine, simazine, and trifluralin. Samples were also analyzed for nine degradation products: cyanazine-amide, deethylatrazine, deisopropylatrazine, deisopropylprometryn, demethylfluometuron, demethylnorflurazon, 3,4-dichloroanaline, trifluromethyl analine (TFMA), and trifluromethyl phenyl urea (TFMPU). The three most frequently detected compounds at the Thighman runoff site were fluometuron (97 percent), norflurazon (74 percent), and cyanazine (51 percent) (Rebich, 2001, appended).

Fluometuron was detected at concentrations at or above 0.05 µg/L (analytical detection limit) in 97 percent of the composite samples from the Thighman runoff site during the study period (Rebich, 2001, appended). The median fluometuron concentration was 1.6 µg/L, and the maximum concentration was 108 µg/L. For perspective purposes only, all of the fluometuron concentrations in composite samples from the Thighman runoff site were lower than the drinking water standard of 90 mg/L (Nowell and Resek, 1994) except for one sample. Of the fluometuron applied in 1997 and 1998, 7.3 percent and 6.4 percent, respectively, were transported offsite in runoff.

Few recent studies exist in the Mississippi Delta documenting fluometuron concentrations in surface waters. Coupe (2000) reported that fluometuron was detected in about 75 percent of the river samples from the Bogue Phalia near Leland, Mississippi (drainage area is 484 square miles), from 1996-98. The median and maximum concentrations for fluometuron were 0.07 µg/L and 6.6 µg/L, respectively, in the Bogue Phalia. It is expected that concentrations of fluometuron in edge-of-field runoff would be much higher than concentrations in rivers due to dilution and processing in river systems. Therefore, fluometuron data presented from Coupe (2000) [and norflurazon and cyanazine data presented by Coupe (2000) and Slack (1992) in subsequent paragraphs] are intended to provide the reader some perspective for the MDMSEA data; direct comparisons are not applicable.

Norflurazon is a soil-applied herbicide for cotton and soybean systems. Norflurazon was detected at concentrations at or above 0.05 µg/L (analytical detection limit) in 74 percent of the composite samples from the Thighman runoff site (Rebich, 2001, appended). The median concentration of norflurazon was 0.68 µg/L, and the maximum concentration was 7.3 µg/L. No aquatic health criteria currently exist for norflurazon. Coupe (2000) reported that norflurazon was detected in less than 50 percent of the river samples from the Bogue Phalia. The median and maximum concentrations for norflurazon were <0.024 µg/L and 1.24 µg/L, respectively, in the Bogue Phalia.

Cyanazine is a herbicide that can be applied preemergence and postemergence on cotton and corn. Cyanazine was detected at concentrations at or above 0.05 µg/L (analytical detection limit) in 51 percent of the composite samples from the Thighman runoff site (Rebich, 2001, appended). The median and maximum concentrations were <0.05 µg/L and 29 µg/L, respectively. Cyanazine concentrations exceeded the aquatic health criterion (2 µg/L) in less than 25 percent of the samples. It is noteworthy that these high concentrations (greater than 2 µg/L) occurred in 1997 only; by 1999, concentrations of cyanazine were at or near the detection limits. Based on information supplied by the grower in the drainage area of the Thighman runoff site in the 1996 and 1997 growing seasons, cyanazine was applied on cotton acreage at planting in the spring. Typically, several large runoff events occur each year shortly after planting, resulting in high concentrations of cyanazine in the runoff in 1996-97. However, in the 1998 and 1999 growing seasons, the growers began to apply cyanazine only as a lay-by treatment, which typically occurs in the summer during dry conditions. Thus, runoff events occurred infrequently and at longer periods after application, resulting in low concentrations of cyanazine in the runoff.

Coupe (2000) reported that cyanazine was detected in 100 percent of the river samples from the Bogue Phalia that were collected from February 1996 through January 1998. The median and maximum concentrations for cyanazine were 0.046 µg/L and 2.7 µg/L, respectively, in the Bogue Phalia. Slack (1992) reported only one detection of cyanazine for stream samples collected annually from 1988 to 1991 at eight sites in the bluff hills area of the Yazoo Basin. A concentration of 0.1 µg/L was detected in March 1989 at Fannegusha Creek near Howard, Mississippi (drainage area is 103 square miles, Slack, 1992).

Insecticides — In 1996, the ARS Soil and Water Research Unit, in Baton Rouge, Louisiana, analyzed runoff samples for insecticides. From 1996 to 1997, the insecticide analyses included the organophosphates, methyl parathion and azinphosmethyl, and the pyrethroids, cypermethrin and cyfluthrin. These insecticides are important throughout cotton-producing areas in the Mississippi Delta. However, very few samples for insecticide analyses were available during that time due to infrequent storm events and low sample volumes. In addition, the method detection limits for those early analyses were quite high (see Rebich et al., 2001, appended, for detection limits). In 1998, emphasis was placed on low-level analyses of pyrethroid insecticides. Additional samplers were installed to ensure that samples would be collected for as many runoff events as possible. Analyses for the pyrethroids, lambda-cyhalothrin, and deltamethrin were also added in 1998.

Methyl parathion and azinphosmethyl were not detected in any of the edge-of-field composite runoff samples from 1996-98, even when a runoff event occurred shortly after application (Rebich et al., 2001, appended). The reasons for this lack of detections included high method detection limits and the short half-lives for these organophosphate chemicals. For water samples analyzed for pyrethroids from 1996-97, there were no detections, likely due to the high method detection limits. From 1998-99, after the methods were changed to more sensitive techniques with lower detection limits, there were four detections of pyrethroids, all of which occurred in the 1999 sampling period (Rebich et al., 2001, appended). These detections occurred shortly after application and had very low concentrations at or near the detection limits. It is likely that the overall lack of detections during the 1998-99 period is the result of higher-than-expected dissipation rates and low application rates.

Overall influence of pesticides — Very little can be stated at this point about the influence of pesticides on the aquatic systems of the MDMSEA lakes. Herbicides were detected in lake samples and were detected frequently in composite runoff samples. Fluometuron, norflurazon, and cyanazine concentrations at the Thighman runoff site were typically lower than drinking water standards and aquatic health criteria, but they were higher than concentrations found at a nearby river during the same time. This is not unexpected considering the effects of dilution in the river. Maximum concentrations of the same three herbicides at the Thighman runoff site were fluometuron, 108 µg/L; norflurazon, 7.3 µg/L; and cyanazine, 29 µg/L (greater than the aquatic health criterion).

Insecticides were detected infrequently in composite runoff samples from the three watersheds. Early in the study, sample availability was infrequent, and the detection limits for insecticide analyses were likely too high to adequately detect and quantify insecticide concentrations in the runoff samples. However, when samples were made more available and methods were modified for lower detection limits, four detections of pyrethroids were recorded in runoff samples collected from 1998-99. These pyrethroid detections were recorded for runoff samples collected shortly after an application, and the concentrations were near the detection limits.

BMPS AND WATER QUALITY

As previously mentioned, the MDMSEA lake ecosystems were considered stressed at the start of the project due to excessive sediment. Water can efficiently detach and transport soil through two primary mechanisms: water flow and raindrop impact. The key to controlling sediment is therefore linked to controlling these two mechanisms.

BMPs installed in the Beasley and Deep Hollow watersheds were primarily designed to address soil erosion and transport by reducing the effects of water flow and raindrop impact. Structural and vegetative methods of reducing water velocities included slotted pipes, slotted-board risers, grass buffer strips, and grassed waterways. Cultural practices such as conservation tillage and cover crops were also used to help reduce the erosive effects of water flow and raindrop impact. The residue from conservation tillage or cover crops also was expected to dissipate energy, reduce water velocities, and provide a barrier between the soil and flowing water.

Slotted-board riser in the Beasley watershed.

Although the BMPs used in the MDMSEA watersheds were designed primarily to reduce soil erosion and transport, it was hoped that other potential contaminants such as nutrients and pesticides attached to soil particles would be reduced as well. However, some nutrients and pesticides do not readily attach to sediment and can remain dissolved in the runoff and the lakes for long periods, thus requiring alternative BMPs for removal. In addition, the use of cultural practices such as conservation tillage and cover crops sometimes resulted in an increase in nutrient and pesticide infiltration into shallow groundwater systems (Locke and Bryson, 1997). To address this concern, MDMSEA researchers sampled shallow groundwater wells in each watershed to document potential contamination caused by infiltration of nutrients and pesticides.

The following sections present data and research findings that document the effects of BMPs installed in each MDMSEA watershed on water quality and aquatic systems during the study period. The sections are organized according to the effects of BMPs on sediment and chlorophyll, fisheries, nutrients, and pesticides. Each section includes discussions of lake, runoff, shallow groundwater, and soil quality where applicable (note, pollutant concentrations from runoff sites presented in this section are based on storm-averaged composite runoff samples).

BMP Effects on Sediment and Chlorophyll

Delta lakes are known for their sports fish production and recreational value. If suspended sediment concentrations are low enough to provide suitable light penetration, oxbow lakes provide conditions conducive to photosynthesis, primarily via phytoplankton, and may support a sustainable sport fishery. Current tillage practices in the Mississippi Delta region often result in soil erosion that can lead to increased turbidity in the oxbow lakes and subsequent inhibition of photosynthesis. This turbidity can be persistent in areas with high-clay soils. Although nutrients such as phosphorus are commonly associated with Delta soils and isolated oxbow lakes tend to load nutrients, these systems may become energy starved and very unproductive due to lack of light penetration. Because phytoplankton forms the foundation of the food web, anything that inhibits phytoplankton production will consequently reduce fish growth and reproduction.

Combinations of cultural and structural management practices lowered total and suspended sediments in all three MDMSEA lakes (Knight et al., 2001a, and Zablotowicz et al., 2001a). The greatest percent reduction (76-80 percent) in suspended sediment was at Deep Hollow Lake, which featured a combination approach to erosion control (Knight et al., 2001a, appended; Zablotowicz, et al., 2001a). The reduction in suspended sediment improved Secchi visibility in two of the MDMSEA lakes. Before BMP establishment, Secchi visibility was low, averaging less than 17 cm in the three MDMSEA lakes. Low Secchi visibility indicated that the lakes were sediment-stressed. Secchi visibility increased from an average of 12 cm in 1996 to an average of 25 cm in 1999 in Deep Hollow Lake, representing a 108 percent increase. Secchi visibility also improved 36 percent on Thighman Lake because of tillage-practice changes by the growers in that watershed. Although suspended sediments were reduced by 53 percent in Beasley Lake, Secchi visibility was only improved from 14 cm in 1996 to 17 cm in 1999.

Cooper and Bacon (1980) reported that phytoplankton was adversely affected when suspended sediments exceeded 100 mg/L. At this concentration of suspended sediments, chlorophyll concentration was reduced to less than 20 µg/L, resulting in lower photosynthetic output from phytoplankton. Cooper et al. (1995) demonstrated that when suspended sediments were reduced, chlorophyll concentration doubled. While high pre-BMP suspended sediments likely suppressed chlorophyll concentrations in the MDMSEA lakes to an average of 16.9 µg/L, reductions in sediment loadings due to management practices contributed to corresponding increases in chlorophyll ranging from 61 to 629 percent for all MDMSEA oxbows (Knight et al., 2001a, appended). In addition, algal populations in the Deep Hollow watershed were consistently higher than the other two watersheds, and algal populations in the Thighman watershed increased in 1998 (Zablotowicz, 2001a, appended).

From the onset of the project, it was expected that multiple BMPs would be required to effectively reduce sediment concentrations in the oxbow lakes to elicit an ecological response. Because each oxbow lake served as a sampling unit subject to the cumulative effects of the watershed BMPs, impact of individual BMPs cannot be reliably extracted from the lake data. However, some inferences about specific BMPs were made as the result of analysis of runoff samples collected at the edge-of-field locations.

Winter wheat cover crop shortly after chemical "burn down" in the Deep Hollow watershed. Suspended sediment was reduced by 80 percent in Deep Hollow Lake as a result of the combination approach to erosion control.

Two runoff sampling sites were installed in the Beasley watershed to determine the effects of a slotted-board riser and the combination of slotted-board risers and filter strips on runoff quality. Median suspended-sediment concentrations at these two sites were nearly identical to the median concentration from the Thighman runoff site (Rebich, 2001, appended). Suspended-sediment loads at the slotted-board riser site were not statistically different from loads at the Thighman runoff site. However, two boards have been permanently installed at the slotted-board riser site since 1996. Supplemental boards were installed on top of the permanent boards seasonally at this site each year (typically during the non-growing season months, October through March). Although heavier sediment (or bed load material) was not measured in the runoff at this site during the study period, about 1 foot of heavier sediment was trapped in front of the permanent boards. Suspended-sediment loads also were reduced about 30 percent when supplemental boards were in place.

The large riparian area in the Beasley watershed located east of the lake provided MDMSEA researchers an excellent opportunity to understand the ability of riparian areas to mitigate nonpoint-source pollution. Three runoff sampling sites were installed within this riparian area — two sites on the east side and one site on the west. The sites on the east side of the riparian area were actually located on drainage ditches considerable distances away from the edge of the cropped fields. Median suspended-sediment concentrations were an average of 79 percent lower at the east sites and 84 percent lower at the west site of the riparian area, respectively, than the median concentration measured at the Thighman runoff site (Rebich, 2001, appended). The low concentrations at the riparian sites reflected the ability of drainage ditches and the riparian area at Beasley to trap sediment from runoff. The data suggest that riparian areas are useful in sediment mitigation and could be considered part of an overall plan for reduction of nonpoint-source pollutants. Modifications of agricultural ditches that allow them to function more like natural riparian areas and wetlands also could be considered as a means to reduce sediment loss.

Two runoff sampling sites were installed in the Deep Hollow watershed to determine the effects on runoff quality of conservation tillage with a cover crop, and the combination of conservation tillage with a cover crop and a slotted-board riser. Median suspended-sediment concentrations were 62 percent lower at the conservation tillage site and 48 percent lower at the combination site than the median concentration at the Thighman runoff site (Rebich, 2001, appended). The average annual suspended-sediment load was 1.5 t/ac/yr at the conservation tillage site, which is 70 percent lower than the average annual load at the Thighman runoff site. The average annual sediment load at the conservation tillage site was higher than the average annual sediment load for a 5.3-acre, no-tillage soybean field in the uplands of Mississippi, which was 0.22 t/ac/yr (Cullum et al., 1992).

BMP Effects on Fisheries

Each MDMSEA lake was renovated (rotenone was used to remove existing species of fish) and restocked with largemouth bass (*Micropterus salmoides*), a mix of bluegill (*Lepomis macrochirus*) and redear sunfish (*Lepomis microlophus*), and channel catfish (*Ictalurus punctatus*) at rates of 50, 500, and 150 per acre, respectively, to compare the effects of BMP systems on fish in each lake. Fishery surveys indicated successful renovation at Thighman and Deep Hollow Lakes, where the greatest improvements in water quality were observed (Knight et al., 2001b, appended). Fish survey numbers in Thighman Lake, where growers began to use conservation tillage in the watershed in 1997, improved from 80 fish in 1998 to nearly 90 fish in 1999. Species numbers in Thighman Lake improved from nine species in 1998 to 11 in 1999. Increased species for Thighman Lake may be from species introduced from other portions of the drainage area, escapees from adjacent catfish ponds, or fish released by fishermen. Fish survey numbers in Deep Hollow Lake, where comprehensive structural and cultural BMPs were installed, improved from nearly 80 fish in 1998 to nearly 90 fish in 1999. Species numbers in the Deep Hollow Lake decreased slightly from nine species in 1998 to eight species 1999. Bass populations, lacking in all of the lakes prior to renovation and restocking, were maintained in Deep Hollow Lake (although a slight decrease from seven in 1998 to six in 1999) and were improved in Thighman Lake (from nine in 1998 to 11 in 1999).

Beasley Lake showed declines in both fish populations and diversity. Fish survey numbers in Beasley decreased from 70 fish in 1998 to 15 fish in 1999, and fish species decreased from 11 in 1998 to six in 1999.

Bass populations decreased from 11 caught in 1998 to none caught in 1999 (Knight et al., 2001b, appended). These declines happened even though about one-third of the Beasley watershed drains through the large riparian area on the east side of the lake and structural and vegetative BMPs were installed within the other two-thirds of the watershed. As stated earlier in this report, differences in elevations from the top of the Beasley watershed to the lake were about 18 feet as opposed to 5 feet in the other two MDMSEA watersheds. Such elevation differences were problematic when trying to slow runoff and remove sediments using edge-of-field structural and vegetative BMPs. MDMSEA research indicated that for watersheds like Beasley,

Fish surveys indicated that renovation was most successful in Deep Hollow and Thighman Lakes.

Paddlefish caught during lake renovation at Deep Hollow in 1996.

BMP Effects on Nutrients

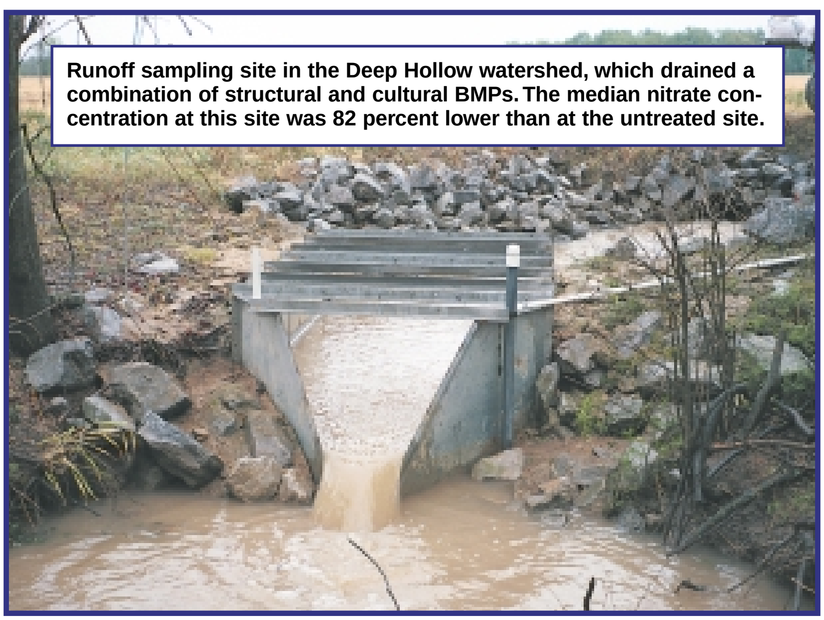
Nutrient levels in lakes — For all three MDMSEA lakes, moderate differences in nitrate and ammonia levels were observed after the BMPs were operational for 3 years. Nitrate concentrations were 27 percent lower in Thighman Lake, 4 percent higher in Beasley Lake, and 2 percent lower in Deep Hollow Lake in 1999 than those recorded in 1996 before BMP installation. Ammonia concentrations were 33 percent higher in Thighman Lake, 13 percent higher in Beasley Lake, and 39 percent lower in Deep Hollow Lake in 1999 than those recorded in 1996 (Knight et al., 2001a, appended). One explanation for the higher ammonia concentrations at Thighman could be the increased corn acreage in the Thighman watershed from 1997-99; corn typically requires additional applications of nitrogen fertilizers during the growing season.

Filterable orthophosphate levels increased from 53 to 144 percent in all lakes during the study period (Knight et al., 2001a, appended). Total phosphorus decreased 32 percent in Thighman Lake, 31 percent in Beasley Lake, and 55 percent in Deep Hollow Lake from 1996-99. Total phosphorus reductions generally followed the same pattern as suspended sediment reductions in each lake, although all concentrations of total phosphorus remained above 0.2 mg/L.

There was concern that as BMPs reduced sediments in the lakes, fish populations could decline due to excessive plant growth caused by increased light penetration and elevated nutrient levels; phosphorus was high in all three lakes, and at Thighman Lake, ammonia increased during the study period. However, fish populations and species generally increased at Thighman and Deep Hollow Lakes during the study period as the lakes became more productive (Knight et al., 2001b, appended). No excessive plant growth was observed in these two lakes.

Nutrient levels in runoff — The median nitrate concentration and the average annual nitrate load in the runoff from the Beasley slotted-board riser site were similar to corresponding data from the Thighman runoff site. However, the median nitrate concentration at the combination slotted-board riser and filter strip site at Beasley was 58 percent lower than the median concentration at the Thighman runoff site. The median nitrate concentrations in runoff at the riparian sites in the Beasley watershed averaged 81 percent lower than the median concentration at the Thighman runoff site.

MDMSEA research suggested that nitrate leaving agricultural areas could be reduced in riparian areas before entering the lakes and reduced further in the lakes due to biological processes. Aerobic heterotrophic bacterial populations and fluorescent pseudomonads (both capable of reducing nitrate by respiration and denitrification) were tenfold and hundredfold greater, respectively, in riparian soils than in cropped areas in the Beasley watershed (Zablotowicz et al., 2001b, appended). Zablotowicz et al. (2001b, appended, and 2001c) also observed that pseudomonads were present in the lakes. The bacterial populations were highest in the presence of elevated levels of organic material and water content associated with riparian soils. This research explains why nitrate levels in the runoff in the Beasley riparian area were low, but it could also explain why nitrate levels were low at the Beasley combination site. The long channel above the Beasley combination site was heavily vegetated during the study period. Organic material and water content in the vegetated channel were not measured but were likely higher than the organic material and water content in the cropped areas in the Beasley watershed. This research gives further evidence that agricultural ditches can function similarly to natural riparian areas and should be considered in watershed planning and BMP design.



Runoff sampling site in the Deep Hollow watershed, which drained a combination of structural and cultural BMPs. The median nitrate concentration at this site was 82 percent lower than at the untreated site.

The median nitrate concentrations at both Deep Hollow runoff sites were an average of 82 percent lower than the median concentration at the Thighman runoff site. The average annual nitrate load at the conservation tillage/cover crop site was 74 percent lower than the nitrate load at the Thighman runoff site. Nitrate was shown to be lower in the soils of the conservation tillage areas of the Deep Hollow watershed than in soils from a nearby conventional tillage area (Locke

2001a, appended). The lower nitrate was due to immobilization of nitrogen in the organic residues accumulated in the surface soils of the conservation-tillage fields. Therefore, the low nitrate concentrations in the runoff from the Deep Hollow sites were likely due to lower soil nitrate available for transport.

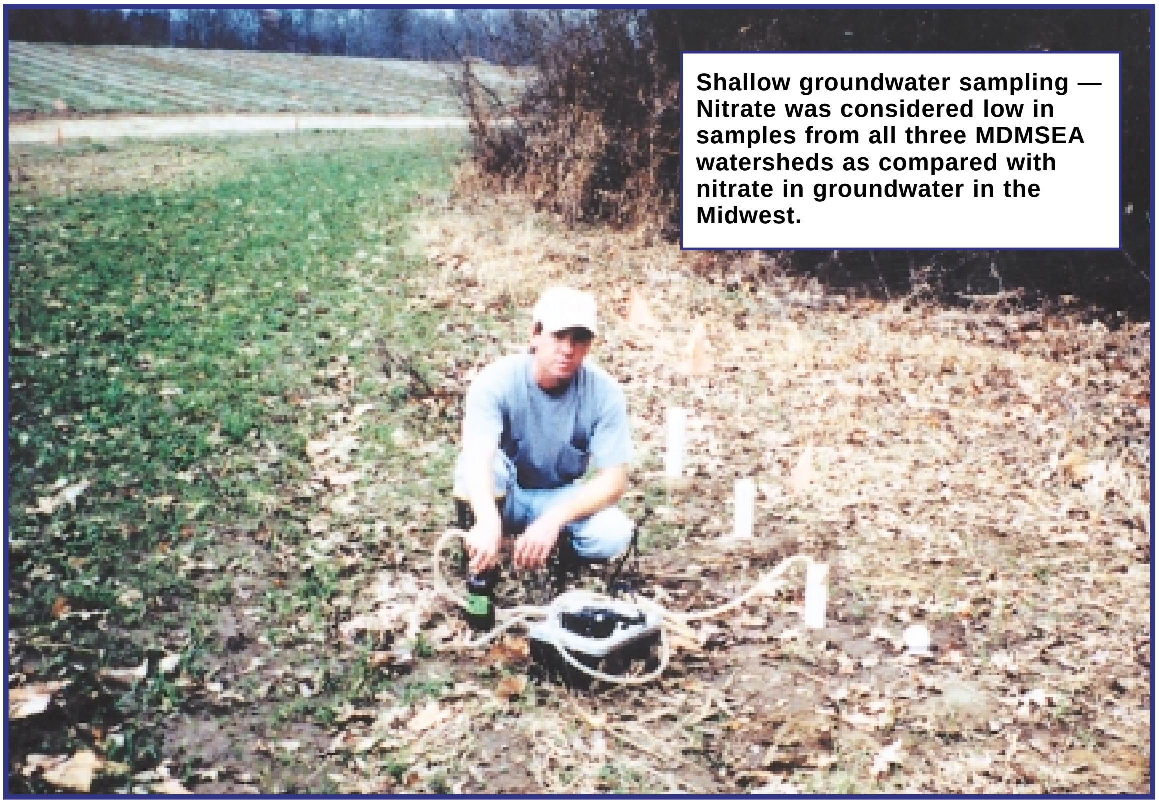
During the study period, the median orthophosphorus concentrations for runoff at the BMP sites were not significantly different when compared with the median concentration at the Thighman runoff site. The median total phosphorus concentrations at the slotted-board riser site and the combination site in the Beasley watershed were higher than the median concentration at the Thighman runoff site. The median total phosphorus concentrations at the riparian sites in the Beasley watershed averaged 39 percent lower than the Thighman runoff site. The median total phosphorus concentrations at the two Deep Hollow runoff sites were similar to the median concentration at the Thighman runoff site. However, the average annual total phosphorus load was 28 percent lower at the Deep Hollow conservation-tillage/cover-crop site than the average annual load at the Thighman runoff site.

Soil samples from the Deep Hollow watershed indicated that phosphorus was positively related to organic material and clay and negatively related to sand content (Locke et al., 2001a, appended). In the Deep Hollow watershed, as well as within other oxbow lake watersheds in the Delta, sandier soils are typically found in the higher elevations near the watershed boundary, and clay soils are found in the lower elevations closer to the lakes. The higher concentrations of phosphorus in the soils nearest to Deep Hollow lake were attributed to the movement of phosphorus downslope in runoff and due to the higher levels of organic matter and clay in the lower elevations of the watershed. Locke et al. (2001a, appended) indicated that the affinity of phosphorus for clay particles likely enhanced its movement with sediments in runoff. Therefore, total phosphorus should be reduced somewhat by BMPs that reduce sediment in runoff. Runoff data from the BMP sites summarized in the previous paragraph indicated that total phosphorus was generally lower in runoff at sites where sediment was also low.

Nutrient levels in shallow groundwater — The original Midwest MSEA programs were primarily designed to address concerns about excessive nitrate levels in groundwater (Hatfield and others, 1993). Mississippi soils and environmental conditions are much different from those in the Midwest, which in turn could affect nutrient degradation rates in soils and infiltration to shallow groundwater. Delta soils are high in clay content and organic matter (Locke et al., 2001a, appended), and deep vertical cracks often form in Delta soils during the drier summer months. These vertical cracks could increase the potential downward movement of agrichemicals in soils and into shallow groundwater during storm events (Wells et al., 2001, appended).

Another factor that could influence agrichemical movement in groundwater is the hydrologic response of groundwater to stage fluctuations in nearby streams or rivers. For the Deep Hollow watershed, groundwater levels were more dependent on stream responses to rainfall events (the Yazoo River is adjacent to the Deep Hollow watershed) than recharge from the surrounding watershed (Adams and Davidson, 2001, appended). Because Delta oxbow lakes are either adjacent or in close proximity to their “parent” rivers or streams, groundwater quality in Delta oxbow lake watersheds could also then be more dependent on river quality than infiltration from the watershed.

Nitrate averaged 0.57 mg/L in shallow groundwater in the three MDMSEA watersheds in 1998, which is considered low (Smith et al., 2001, appended). By comparison, nitrate in groundwater at the Midwest MSEA locations averaged 1.6 mg/L in Iowa, 12.8 mg/L in Minnesota, 7.1 mg/L in Missouri, 29.2 mg/L in Nebraska, and 4.7 mg/L in Ohio for the years 1990-92 (Hatfield et al., 1993). High denitrification rates were considered one cause for low levels of nitrate in MDMSEA soils and, ultimately, in shallow groundwater (Smith et al., 2001, appended). Based on soils data collected in the Deep Hollow watershed, where conservation tillage was practiced, another explanation for low concentrations of nitrate in the soils is immobilization from plant residues in the surface soils or less organic nitrogen being mineralized (Locke et al., 2001a, appended).



Shallow groundwater sampling — Nitrate was considered low in samples from all three MDMSEA watersheds as compared with nitrate in groundwater in the Midwest.

BMP Effects on Pesticides

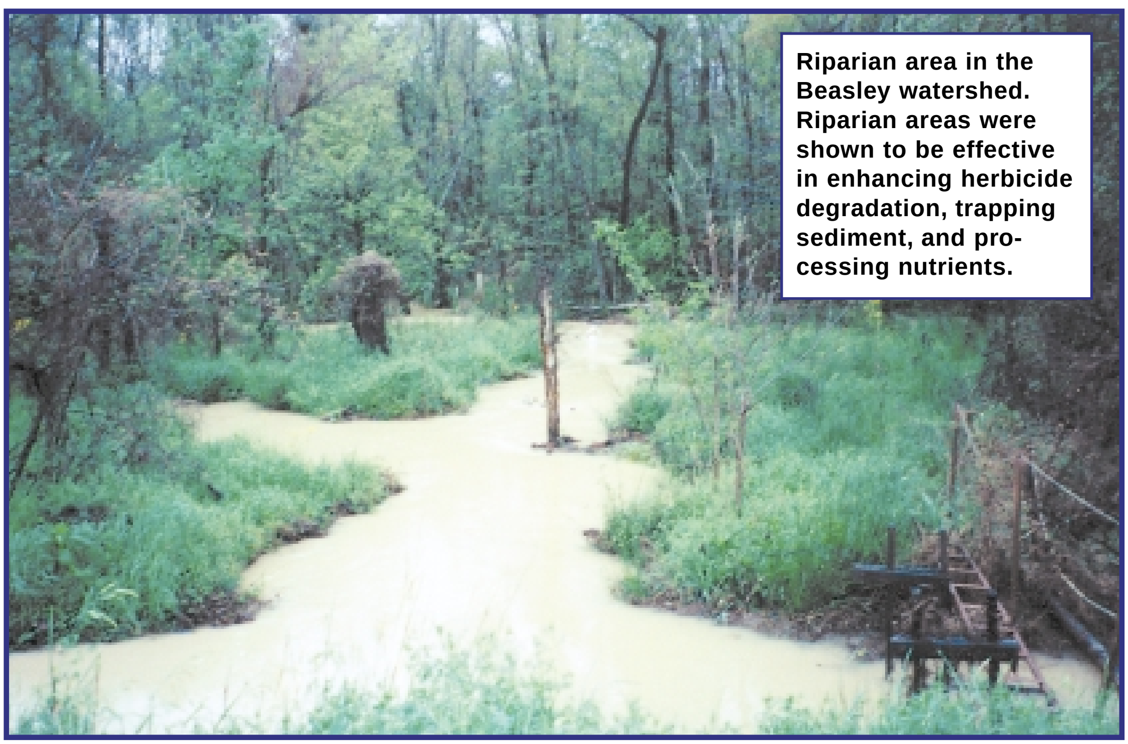
Pesticide levels in lakes — Discussion of the effects of BMPs on pesticide levels in the MDMSEA lakes is limited to fluometuron and de-methylfluometuron. Although fluometuron and de-methylfluometuron were both observed in lake samples from all three MDMSEA lakes in 1997, fluometuron concentrations in all three lakes were generally lower in 1999 than in 1997 due to decreased cotton acreage and subsequent decreased fluometuron use. However, some of the reductions in fluometuron could be attributed to biodegradation by certain algae and bacteria. Bacterial and algal populations were generally greater in Deep Hollow and Thighman Lakes than in Beasley Lake during the study period. Certain species of algae present in MDMSEA lakes, such as *Ankistrodesmus* and *Selenastrum*, were shown in laboratory studies to participate in the degradation of fluometuron and atrazine via *N*-dealkylation (Zablotowicz et al., 1998).

Pesticide levels in runoff and soils — Rebich (2001, appended) compared concentrations and loads of selected herbicides at two BMP runoff sites (slotted-board riser site in the Beasley watershed and the conservation tillage/cover crop site in the Deep Hollow watershed site) with concentrations and loads at the Thighman runoff site during the study period. Fluometuron, norflurazon, and cyanazine were the only three herbicides that were commonly detected among the three sites during the study period. In general, concentrations of these three compounds were lower at the two BMP sites than at the Thighman runoff site (Rebich, 2001, appended). For fluometuron, 3 percent of the fluometuron applied at the slotted-board riser site in the Beasley watershed was present in the runoff in 1997. Three percent and 1 percent of the fluometuron applied at the conservation-tillage/cover-crop site in the Deep Hollow watershed were present in the runoff in 1997 and 1998, respectively. These data represented about 50 percent less fluometuron in the runoff from the two BMP sites than in the runoff from the Thighman runoff site, which averaged 6 percent in 1997-98 (Rebich, 2001, appended).

Because some of the herbicides used in the MDMSEA watersheds were water-soluble, there was concern that BMPs designed for sediment would be ineffective in reducing herbicides in runoff. However, MDMSEA research demonstrated that soil influenced by an established fescue filter strip can degrade the herbicide fluometuron (Shaw et al., 2001, appended). Fluometuron half-life in an established tall-fescue filter strip was estimated to be 12 days, which was 43 days more rapid than in a new filter strip soil. Along with the addition of plant residues, the rapid degradation in established versus new filter strip soil could be attributed, in part, to the growth of dense vegetation compared with the less dense new strip. Living vegetation not only contributes to degradation in soil by uptake and metabolism, but its root exudates can enhance microbial populations (Zablotowicz and Hoagland, 1999). Therefore, fluometuron degradation should increase with time in new filter strip soils as organic matter increases through additions of plant residue materials, which provide substrate for microbial activity and populations. Soils protected by filter strips have the potential to degrade fluometuron more rapidly than non-filter-strip areas, as well as to serve as physical barriers for transport.

Natural and constructed wetlands situated between agricultural lands and receiving water bodies have been shown to enhance agrichemical processing and retention of agrichemicals (Hammer and Bastian, 1989; Cooper et al., 1993). While there are many similarities between the physical characteristics and biochemical processes of riparian areas and wetlands, the ability of a natural riparian area to trap and process pesticides is not well characterized or documented. As previously mentioned, the large riparian area in the Beasley watershed provided MDMSEA researchers an excellent opportunity to study the potential mitigating effects of a riparian area on pesticides in runoff. Fluometuron degradation was greater in riparian soils than in cropped areas (Shaw et al., 2001, appended). Within the riparian area, fluometuron half-life decreased by 49 days at the entrance of the riparian area due to more aerobic conditions in the soils at the entrance than at the exit. Research by Zablotowicz et al. (2001b, appended) supported the Shaw et al. (2001, appended) findings in that fluometuron degradation (by N-demethylation) in soil samples collected from the Beasley watershed in 1997 was between two- and fourfold greater in the Beasley riparian area soils than in soils from cropped areas. Fluometuron degradation was enhanced in the riparian area due to higher levels of organic matter and soil moisture and increased enzyme activities.

In other riparian area research, results of a controlled-release runoff experiment from 1998-99 indicated that the applied pyrethroid insecticides were transported almost exclusively in the sediment carried in the runoff (Smith et al., 2001, appended). In March 1998, data from sediment traps generally showed decreasing insecticide concentration as the controlled-release runoff passed through the riparian area. During the study, lambda cyhalothrin concentrations decreased from 6.8 µg/kg at the riparian entrance to 3.5 µg/kg near



Riparian area in the Beasley watershed. Riparian areas were shown to be effective in enhancing herbicide degradation, trapping sediment, and processing nutrients.

the riparian exit. Cyfluthrin concentrations decreased from 2.2 µg/kg at the riparian entrance to nondetectable the riparian exit. Pyrethroid concentrations in the injected runoff also decreased over time. Lambda cyhalothrin concentrations decreased from 6.8 mg/kg in March 1998 to an average of about 2 µg/kg in October 1998. Cyfluthrin concentrations decreased from 2.1 µg/kg in March 1998 to nondetectable by September 1998. This work supported the idea that vegetated drainage ditches also could mitigate the movement of applied pyrethroids in runoff. Vegetated drainage ditches are similar to riparian zones in many respects — generally heavily populated with aquatic plants during the months of the year when pyrethroids are applied.

Pesticide levels in shallow groundwater — Altogether, 622 samples collected from shallow groundwater wells installed in the three watersheds from 1996-98 were analyzed for approximately 20 pesticides: herbicides – trifluralin, atrazine, alachlor, metolachlor, norflurazon, cyanazine, and pendimethalin; non-pyrethroid insecticides – methyl parathion, chlorpyrifos, dieldrin, and chlorfenapyr; pyrethroid insecticides – bifenthrin, lambda cyhalothrin, cyfluthrin, zeta-cypermethrin, esfenvalerate, and deltamethrin; and the organochlorine insecticide DDT and its metabolites, DDE and DDD. There were only five detections in all of the samples, all in the Beasley watershed in 1996 (Smith, 2001, appended). Norflurazon was detected once at 0.4 µg/L, and metolachlor was detected four times ranging from 3-8 µg/L. These detections were considered low and were less than drinking water standards and aquatic health criterion (USEPA, 1987).

In the controlled-release experiment mentioned earlier, a slurry containing the pyrethroids, lambda cyhalothrin and cyfluthrin, was introduced into the riparian area at the Beasley watershed (Smith et al., 2001, appended). The initial concentrations of both compounds after release of the slurry averaged about 0.02 µg/L in shallow groundwater in January 1998 but were nondetectable by August 1998.

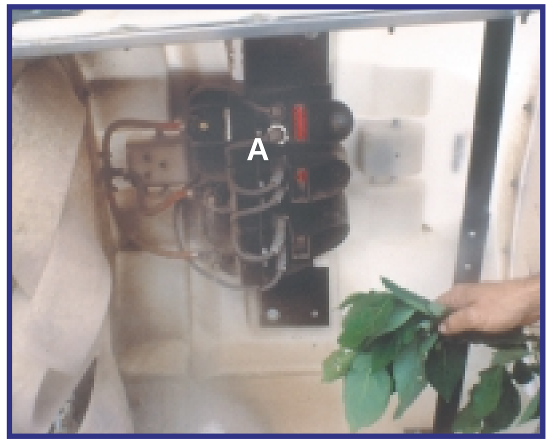
The public never sees all I do to protect the land. Why would I make 10 to 12 tilling trips across the field to erode my soil and pay $6 an acre each time I do it when three or four trips will do? Farming is all I've ever done, and it's all I ever want to do. To learn that the groundwater was not polluted and we're not leaking chemicals like some people say — that has been worth whatever I've done for the project, just to find out that's not the case. Those who don't respect the land don't farm very long. If you want to make money farming, you had better do it in an environmentally sound manner. It doesn't make sense to destroy the soil that keeps your family fed.

Recent interview with Mr. Floyd Anderson, Jr.
Owner and operator of the Anderson Planting Company
Thighman Lake Watershed

Innovative BMPs — The previous paragraphs summarized MDMSEA research that showed reductions in pesticide concentrations in runoff, soils, and shallow groundwater using edge-of-field structural BMPs, filter strips, and riparian areas. However, other innovative technologies were also studied by MDMSEA researchers who focused on reducing the use of pesticides. These technologies included agricultural biotechnology to reduce insecticide use, hooded sprayer with weed-sensing technology to reduce herbicide use, and precision farming to limit herbicide use.

Agricultural biotechnology, promising high crop yields and dramatic reduction in pesticide use, has been promoted as the way to feed the world's escalating population and reduce environmental concerns about farming. Cotton has been genetically engineered to be resistant to certain lepidopteron insect pests (Bt cotton). Runoff samples from sites that had Bt cotton and from sites that had non-Bt cotton were compared by Cullum et al. (2001, appended). There were only four detections of pyrethroids in runoff from the Bt sites during the study period. These detections occurred in runoff samples that were collected within 15 days after application, and all of the concentrations were at or near the analytical detection limits. Methyl parathion was detected only four times in runoff from the Bt sites. As in the case of pyrethroid insecticides, detections occurred within 15 days after application, with concentrations at or near the detection limits or below aquatic life guidelines. Pyrethroid insecticides and methyl parathion were not detected in runoff samples from the non-Bt sites. This lack of detection could have been due to one of many factors, including low application rates, infrequent storm events after applications, missed sampling opportunities, high analytical detection limits at the beginning of the study, low sediment concentrations in the samples due to BMPs installed in the watersheds (both pyrethroids and organophosphates bind fairly readily to sediment), and higher-than-expected degradation rates for the insecticides studied.

Herbicide application with sensor-controlled hooded sprayer. Results indicated an average of 73% reduction in herbicide use in cotton and 49% reduction in soybeans without reduction in yields.



Spectral sensors (A) mounted in spray hoods.

One of the more innovative solutions for reducing herbicide application was the evaluation of sensor-controlled spray technology (Hanks and Bryson, 2001, appended). In the Deep Hollow watershed, cotton and soybean crops were planted in rows spaced approximately 1 m apart and grown under conservation-tillage practices. Cultivation was eliminated to reduce erosion and herbicide movement. Twenty-nine species of weeds were present in cotton fields, and 90 species of weeds were present in soybean fields according to surveys conducted from 1995-96 (Bryson and Hanks, 2001, appended). A hooded-sensor sprayer was used to apply glyphosate for postemergence weed control. The plant sensors used unique spectral differences in green living plants and bare soil to provide “real-time” detection of weeds so that herbicide was dispensed between crop rows only when a weed (green color) was present. Results indicated an average of 73 percent reduction in glyphosate use on cotton and a 49 percent reduction in glyphosate use on soybeans over the course of this study (Hanks and Bryson, 2001, appended). In addition, the sensor-controlled hooded sprayer effectively reduced weed populations in the cotton and soybean fields in the Deep Hollow watershed with the exception of several viney and woody species typically associated with reduced-tillage systems (Bryson and Hanks, 2001, appended). The environmental benefits of a sensor-controlled hooded sprayer included reduction of the total amount of glyphosate needed and reduction of secondary weed infestations. These benefits allowed producers to eliminate in-season cultivation, ultimately reducing soil erosion.

Precision farming is being used more and more to minimize inputs of agrichemicals, thus lowering costs to producers and minimizing environmental impacts. Surveys of soils, weeds, crop yields, and other production parameters can be produced for growers in an effort to pinpoint where agrichemicals are most needed within specific fields. Although precision farming was not considered in the overall BMP farm plans used in the MDMSEA project, surveys were conducted in the Beasley watershed in 1996 to describe the spatial variability of soil properties and weed populations (Gaston et al., 2001, appended; Gaston et al., 2001b; Locke et al., 2001b). Such information provided a database that could be used later for precision application of agrichemicals. Soil from a 100-acre cotton field was characterized for organic carbon, pH, texture, and microbial activity. Weed counts were conducted 6 weeks after herbicide application. The surveys indicated that weeds increased with increasing organic carbon and clay content. The density of total and controlled weeds was significantly greater where clay was greater than 30 percent and organic carbon was greater than

1.6 percent (Gaston et al., 2001a, appended; Gaston et al., 2001b). Also, there was a tendency for weeds to recur where clay or organic carbon was relatively high, indicating localized weed persistence and the need for more aggressive control. More uniform weed control could be achieved by varying preemergence herbicide application rates, and effective weed control could be achieved with less herbicide in areas of sandier soils and low organic carbon (Gaston et al., 2001, appended).

Weed mapping in the Beasley watershed.

ADDITIONAL RESEARCH EFFORTS

The intent of the previous sections was to document the impact of agricultural activities and BMP improvements to water quality. However, as part of the seven objectives of the MDMSEA project, there were other research efforts that did not fall into these two broad categories. These additional research efforts (numerical simulations, economics, education, and sociology) are summarized in the following sections.

Numerical Simulation

Researchers at the ARS National Sedimentation Laboratory began a study in 1999 to determine the capabilities of the Annualized Agricultural Nonpoint-Source Pollution model (AnnAGNPS) to evaluate the effectiveness of alternative farming operations used in the Mississippi Delta MSEA Project (Bingner and Yuan, 2001, appended). The model was coded with available watershed data from the Deep Hollow watershed, and runoff events were simulated for comparison with actual field data. Results of the simulations indicated that AnnAGNPS provided a reasonable estimate (+/- 15 percent) of long-term, monthly, and annual runoff and sediment load in the Deep Hollow watershed based on comparisons of model predictions with measured field values. In addition, the model was used successfully to provide estimated sediment loads for various BMP scenarios.

Economics

Researchers at Mississippi State University also began a study in 1999 to determine the economic impact to producers who install and maintain BMPs on their land (Hite et al., 2001, appended). These researchers will be working very closely with the researchers at ARS, since the output from the AnnAGNPS model will be used as input for economic models. Preliminary simulations using input from other Delta locations indicated that if farming operations were changed from conventional tillage to conservation tillage, cotton yields would not be affected but soybean yields would decrease by 1.8 percent in the first 5 years. Overall profit would increase by $12.75 per acre for cotton but would decrease by $4.54 per acre for soybeans. Changes in profit reflect increased costs in herbicide and other chemicals and savings from reduced cultivation. In long-term simulations, cotton yields and profits did not change, but soybean yields and profits increased (Hite et al., 2001, appended).

Education

Educators at MSU recently completed a grant funding the Student-Teacher Research Institute — the Delta Experience (STRIDE) (Thibaudeau et al., 2001, appended). The STRIDE program was designed to introduce research methodology to Delta middle school teachers and students and to have them work side-by-side with MDMSEA scientists on existing projects. About 30 teachers and students and 50 researchers in 16 different agencies participated each year of the 3-year program. Students traveled to each MDMSEA watershed and worked with the researchers in collecting samples and recording data. The students also traveled to each of the research agencies to observe areas of research other than MDMSEA. The experience exposed students to the daily activities of field researchers, thus promoting the science fields for future career choices. The collaborative effort also helped the students with science-related projects during the school year.

Delta middle school students and teachers work with MSEA scientists in a STRIDE session.

Sociology

In 1997, MSU researchers mailed a survey to several hundred residents throughout the entire Delta region to gain insight into their attitudes concerning water quality and the adoption of BMPs in the Delta (Gill, 2001, appended). Results of the survey indicated that those who live or operate farms near oxbow lakes or other bodies of water were more concerned with water quality issues and BMPs than those not located near bodies of water. In addition, those who use the bodies of water for sports activities, such as hunting and fishing, were much more concerned about water quality and BMPs than those who did not. A follow-up survey is planned to determine whether attitudes have changed over the span of the MDMSEA project.

FUTURE DIRECTIONS

Recent litigation has prompted much debate concerning bodies of water that exceed designated use criteria due to nonpoint-source pollution. The Clean Water Act provides a mechanism to mandate environmental restrictions on nonpoint-source pollution through the development of Total Maximum Daily Loads (TMDLs). Since potential restrictions could dramatically affect agribusiness, future research into water quality in the MDMSEA project will likely shift toward providing producers a “catalog” of BMPs that are both practical and economical in meeting these potential restrictions.

Significant strides have been made since 1994 to meet the purpose and objectives of the MDMSEA project. However, the MDMSEA project has been limited in many ways as well. For example, some of the data collection did not begin until the 1996 fiscal year due to late funding and timing of BMP installation. Therefore, only 3 years of complete data exist for the late-funded research. In addition, several research areas such as watershed modeling and the economic analyses of the BMPs are just now being funded. While the MDMSEA project is being conducted using sound scientific methods, it is also a demonstration project on working farms that are dynamic. From year to year, changes, such as crop rotation, can take place within each watershed. For these reasons, the Technical Steering Committee of the MDMSEA project intends to extend the project past the original deadline of fiscal year 1999 and to extend the various research funding commitments as well. A listing of some of the activities that are proposed for the MDMSEA project extension follows.

- The USGS and ARS will continue to evaluate changes in runoff quality, lake quality, and fisheries in all three watersheds.
- BMPs at Beasley will be upgraded “to take Beasley to the next level” of water quality improvement for the least amount of costs. BMP research will include additional ditch studies, filter strip/slotted board riser combinations, and residue management.
- The ARS will place less emphasis on the analysis of pesticides in shallow groundwater since few subsurface detections occurred over the past 4 years. The emphasis of the shallow groundwater program will be refocused to study denitrification rates.
- Other research and sampling efforts by the ARS will include soil quality factors (especially in mixed cropping systems) and additional ditch studies to determine fate and transport mechanisms of nutrients and pesticides.
- The ARS National Sedimentation Laboratory will continue conducting numerical modeling of the Deep Hollow and Beasley watersheds using the AnnAGNPS model. The Thighman watershed and lake quality component of the model will be included if funding is secured. If this model is proven effective, resource managers could use it to evaluate BMPs before their implementation, thus reducing planning time and overall costs.
- Agricultural economists at Mississippi State University will continue conducting economic analyses of the farming operations and BMP comparisons. MSU scientists will be working closely with ARS scientists who are developing the numerical models. Using the AnnAGNPS model output and farm budget data related to the MDMSEA watersheds, MSU researchers will be able to estimate potential profitability and runoff reduction associated with various types of BMPs.
- USEPA and MDEQ has approved a 319 project developed by the Mississippi Soil and Water Conservation Commission for MDMSEA. The fall of 1998 was the start date for the 319 project, which was scheduled to continue for 3 years. The project provided funds to continue the maintenance for the BMPs at Deep Hollow and Beasley and to improve the educational awareness aspects of the project, such as guided tours. An additional 319 project was approved for fiscal year 2000 to provide funds to install BMPs at the Thighman watershed.

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APPENDIX A

Bibliography of MDMSEA Publications

PUBLICATION TITLE	AUTHORS	YEAR	TYPE
A MANAGEMENT SYSTEM EVALUATION AREA (MSEA) PROJECT FOR THE MS DELTA	Schreiber, Jonathon; Cooper, CM; Knight, Scott; Smith, Jr. Sammie	1996	Proceedings: American Water Resources Assoc. 301-310
AGRICHEMICAL MOVEMENT IN CORN AND SOYBEAN TILLAGE PRACTICES IN NORTHERN MISSISSIPPI	Cullum, Robert; Smith, Jr., Sammie; Schreiber, Jonathon	1995	Proceedings: Clean Water - Clean Environment - 21st C; 1:53-56
AGRICULTURAL AMELIORATION IN THE WETLAND RIPARIAN AREAS OF THE MISSISSIPPI DELTA MSEA	Smith Jr., S; Schreiber, JD; Cooper, CM; Knight, SS; Rodrique, P		Slides
AGRICULTURAL TRANSPORT IN CORN ON FRAGIPAN SOILS IN NORTHERN MISSISSIPPI	Cullum, Robert; Smith, Jr., Sammie; Schreiber, Jonathon	1995	Proceedings: MS Water Resources Conf. 1995
ALGAE AND BACTERIA INFLUENCE HERBICIDE FATE June 4, 1999	Weaver-Messick, Tara	1999	ARS News Service
ALGAL METABOLISM OF HERBICIDES BY N-DEALKYLATION	Zablotowicz, Robert; Locke, Martin; Schrader, KK; Knight, Scott	2000	Weed Sci. Soc. Am. Abstr. 40:87
ALGAL TRANSFORMATION OF FLUOMETURON AND ATRAZINE BY N-DEAKYLATION	Zablotowicz, Robert; Schrader, Kevin; Locke, Martin	1997	Project Summary
AIGAL TRANSFORMATION OF FLUOMETURON AND ATRAZINE BY N-DEALKYLATION	Zablotowicz, Robert; Schrader, KK; Locke, Martin	1998	J. Environ. Sci. Health 33: 511-528
ASSESSMENT OF AGRICULTURAL NONPOINT SOURCE POLLUTION IN MS DELTA - MSEA	Pote, JW; Rebich, Richard; Schreiber, Jonathon	1996	Proceedings: The Delta - Connecting Pts of View for Sust'nable Nat'l Res.
ASSESSMENT OF TOTAL MAXIMUM DAILY LOADS (TMDLs) IN THE YAZOO DRAINAGE BASIN, NORTH MISSISSIPPI - A Regional Perspective	Lizotte, RE; Moore, MT and Cooper, CM	2000	Poster

PUBLICATION TITLE	AUTHORS	YEAR	TYPE
ATTITUDE ADJUSTMENT OF GOVERNMENTAL, UNIVERSITY AND OTHER ORGANIZATION PERSONNEL WITHIN AN INTEGRATED CATCHMENT MANAGEMENT PROJECT	Schreiber, Jonathon; Foster, GR; Rebich, Richard; Cooper, CM	1997	Proceedings: Int'l Conf. On Advancing Integrated Resource Mgt. Processes and Policies
BENEFITS OF VARIOUS BEST MANAGEMENT PRACTICES IN REDUCING HERBICIDES IN RUNOFF WATER	Shaw, David	1998	MS Water Resources Research Instit. 1998 in Review
BENEFITS OF VARIOUS BEST MANAGEMENT PRACTICES IN REDUCING HERBICIDES IN RUNOFF WATER	Shaw, David	1999	USGS Grant Proposal
BEST MANAGEMENT PRACTICES FOR IMPROVED WATER QUALITY IN MISSISSIPPI DELTA WATERHSED AND LAKES	Cooper, Charles	2000	USDA-ARS National Programs
BEST MANAGEMENT PRACTICES IMPROVE LAKES	Bennett, David	1997	Delta Farm Press 02 May 1997
BIOTRANSFORMATION OF THE HERBICIDES FLUOMETURON AND PROPANIL BY GREEN ALGAE AND CYANOBACTERIA	Zablotowicz, Robert; Schrader, KK; Locke, Martin	1997	Amer. Soc. Microbiology
CHEMICAL STABILITY AND DE-ESTERIFICATION OF FENOXAPROP-ETHYL BY PURIFIED ENZYMES, BACTERIAL EXTRACTS AND SOILS	Zablotowicz, Robert; Hoagland, RE: Staddon, WJ; Locke, Martin	2000	J. Agric. Food Chem. 2000 48:4711-4716
COMPARATIVE MITIGATION OF CHLORPYRIFOS, ATRAZINE AND METOLACHLOR …USING CONSTRUCTED WETLANDS	Moore, Matt; Rodgers, Jr., JH; Smith, Jr., Sammie, Cooper, CM		20th Annual SETAC Conf.
COMPARATIVE SORPTION OF FLUOMETURON AND METABOLITES IN CONSERVATION AND CONVENTIONAL TILLAGE SOILS	Locke, Martin; Zablotowicz, Robert	2000	Weed Sci. Soc. Am. Abstr. 40:88
COMPARISON OF ENZYME-LINKED IMMUNOASSAY WITH GAS CHROMATOGRAPHY/MASS SPECTROMETRY FOR ANALYSIS OF THE COTTON HERBICIDE FLUOMETURON	Bastian, K Chad; Thurman, E Mike; Rebich, Richard	1998	Proceedings: MS Water Resources Conf. 1998
CONFIRMATION OF AN ENZYME-LINKED IMMUNOASSAY TO DETECT FLUOMETURON IN SOIL	Shankle, Mark; Shaw, David; Boyette, Michelle	2000	5 Year Report

PUBLICATION TITLE	AUTHORS	YEAR	TYPE
CONSTRUCTED WETLANDS TO MITIGATE AGRICULTURAL PESTICIDE RUNOFF	Moore, Matt; Gillespie, Jr, WB; Rodgers, Jr, JH; Cooper, CM; Smith, Jr., Sammie	1998	19th Annual SETAC Conf.
CONSTRUCTED WETLANDS TO PREVENT ADVERSE EFFECTS OF CROPLAND RUNOFF - A Modeling and Empirical Approach	Cooper, CM	2001	USDA-ARS National Programs
CONSTRUCTED WETLANDS TO PREVENT ADVERSE EFFECTS OF CROPLAND RUNOFF - A Modeling and Empirical Approach	Cooper, CM; Smith Jr, S; Moore, MT	1999	Project Summary
CONTRASTING TOXICITIES OF ACETYLCHLOLINESTERASE-INHIBITING INSECTICIDES…	Moore, Matt: Huggett, DB, Gillespie, WB; Rodgers, JH; Cooper, CM		SETAC Conference
CONTROLLED WATER TABLE DEPTH TO IMPROVE WATER QUALITY	Willis, Guye; Southwick, Lloyd; Fouss, James	1995	Proceedings: MS Water Resources Conf. 1995
COTTON HERBICIDES IN THE SURFACE WATERS OF THE MISSISSIPPI ALLUVIAL PLAIN (THE DELTA)	Coupe, Richard; Rebich, Richard		Water Resources Engineering 1998, Vol 2, 1212-1217
CRACKING MODES OF AN EXPANSIVE MISSISSIPPI DELTA SOIL	Wells, RR; Prasad, SN; Romkens, Matt	2000	5 Year Report
CRACKING MODES OF AN EXPANSIVE MISSISSIPPI DELTA SOIL	Wells, RR; Prasad, SN; Romkens, Matt	2000	Proceedings: MS Water Resources Conf. 2000
CYFLUTHRIN PERSISTENCE IN SOIL AS AFFECTED BY MOISTURE, ORGANIC MATTER AND REDOX POTENTIAL	Smith, Jr., Sammie; Willis, Guye; Southwick, Lloyd	1995	Bull. Env. Contam. Toxicol. (1995) 55:142-148
DEGRADATION AND ADSORPTION OF METOLACHLOR IN GRASS FILTER STRIPS	Staddon, WJ; Locke, Martin; Zablotowicz	1998	Am. Soc. Agronomy
DEGRADATION OF 2,4-D AND FLUOMETURON IN COVER CROP RESIDUES	Zablotowicz, Robert; Locke, Martin; Smeda, RJ	1998	Chemosphere 37 (15): 87-101
DELTA MSEA BENEFITS LOCAL ECOLOGY	Lee, Jill (USDA Agricultural Research, March 1999)	1999	USDA-ARS magazine
DETECTION OF PERSISTENT ORGANIC POLLUTANTS IN THE MS DELTA USING SEMIPERMEABLE MEMBRANE DEVICES	Zimmerman, LR; Thurman, EM; Bastian, KC	1999	Proceedings: MS Water Resources Conf. 1999

PUBLICATION TITLE	**AUTHORS**	**YEAR**	**TYPE**
DETERMINISTIC ASSESSMENT OF AGRICULTURAL NONPOINT SOURCE POLLUTION IN MDMSEAs	Rebich, Richard; Schreiber, Jonathon; Pote, JW	1995	Proceedings: MS Water Resources Conf. 1995
DEVELOP IMPROVED CONSTRUCTED WETLANDS TECHNIQUES; DEVELOP A PC BASED WETLAND MANAGEMENT TOOL FOR WETLAND EVALUATION WITHIN WATERSHEDS	Cooper, CM S; Moore, MT		Project Summary
DEVELOP SUSTAINABLE INTEGRATED WEED MANAGEMENT SYSTEMS FOR COTTON, SOYBEANS AND OTHER CROPS	Molin, William; Bryson, Charles; Reddy, Krishna	2003	USDA-ARS National Programs
DITCHES - A Simple, Inexpensive Way to Improve Surface Water Quality	Moore, MT; Cooper, CM; Smith Jr., S	2000	ARS News Service
DITCHES HELP IMPROVE SURFACE WATER QUALITY		2000	ARS News Service
ECOLOGICAL EVALUATION OF SEDIMENT STRESSED OXBOW LAKES IN THE MDMSEA PROJECT	Knight, Scott; Cooper, CM; Cash, Ben	2000	North American Benthological Soc. Web
ECONOMIC ANALYSIS OF THE MS DELTA MANAGEMENT SYSTEMS EVALUATION AREA	Hite, Diane; Intarapapong, W; Reinschmiedt, Lynn	2000	5 Year Report
EDGE OF FIELD ECOSYSTEMS FOR WATER QUALITY IMPROVEMENT	Cooper, Charles	2003	USDA-ARS National Programs
EFFECT OF CONTROLLED WATER TABLE ON RUNOFF LOSSES OF SOIL-APPLIED CHEMICALS	Southwick, Lloyd; Willis, Guye; Fouss, James; Rogers, James; Carter, Cade	1996	Proceedings: MS Water Resources Conf. 1996
EFFECT OF DRIFT-REDUCING ADJUVANTS ON SPRAY APPLICATION PARAMETERS	Hanks, James	1999	USDA-ARS National Programs
EFFECT OF PLOT SIZE ON RUNOFF OF HERBICIDES AND SUSPENDED SEDIMENT	Southwick, Lloyd; Fouss, James; Bengston, RL	1999	Proceedings: MS Water Resources Conf. 1999
EFFECTS OF FARMING SYSTEMS PRACTICES ON MS DELTA MSEA LAKE WATER QUALITY	Knight, Scott; Cooper, CM; Cash, Ben	2000	5 Year Report
EFFECTS OF PH ON CHEMISTRY STABILITY, BACTERIAL EXTRACTS AND SOILS	Zablotowicz, Robert; Hoagland, RE: Staddon, WJ; Locke, Martin	1999	Weed Sci. Soc. Of America 39:289
ENVIRONMENTAL FATE OF FLUOMETURON IN A MISSISSIPPI DELTA WATERSHED	Locke, Martin, Zablotowicz, Robert and Gaston, Lewis	2001	ACS Book Series

PUBLICATION TITLE	**AUTHORS**	**YEAR**	**TYPE**
ENVIRONMENTAL FATE OF FLUOMETURON IN A MISSISSIPPI DELTA WATERSHED	Locke, Martin, Zablotowicz, Robert and Gaston, Lewis		Slides
ENVIRONMENTAL FATE OF FLUOMETURON IN SOIL INFLUENCED BY BEST MANAGEMENT PRACTICES (BMPs)	Shaw, David; Shankle, Mark; Kingery, William	2000	5 Year Report
ENVIRONMENTAL QUALITY ASSESSMENTS OF SOIL AND WATER IN MSEA WATERSHEDS	Locke, Martin and Zablotowicz, Robert		Poster
EROSION AND SEDIMENT RESEARCH IN THE USDA-ARS	Bennett, SJ; Alonso, Carlos	1997	USGS Sediment Workshop Proceedings
EVALUATIION OF ANNAGNPS ON MISSISSIPPI DELTA MSEA WATERSHEDS	Yuan, Yongping; Bingner, Ron	2000	Project Summary
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FARMERS AND SCIENTISTS LEAD THE WAY TO IMPROVE WATER QUALITY	Breazeale, Linda	1998	MAFES Research Highlights
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FATE OF CHLORPYRIFOS, ATRAZINE AND METOLACHLOR FROM NONPOINT SOURCES IN WETLAND MESOCOSMS	Moore, Matt		U of Miss Doctoral Dissertation

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FISHERY EVALUATION OF MS DELTA MANAGEMENT SYSTEMS EVALUATION AREA OXBOW LAKES	Knight, Scott; Cooper, CM; Welch, Terry	2000	5 Year Report
FLUOMETURON …A RIPARIAN FOREST EPIPEDON	Shankle, MW; Shaw, DR; Kingery, WL; Boyette, M; Medlin, CR; Locke, MA	1998	Agricultural Research, pp 4-8
FLUOMETURON ADSORPTION TO RIPARIAN FOREST SOIL	Shankle, Mark, Shaw, David; Kingery, William; Smith, MC; Locke, Martin	1998	Weed Sci. Soc. Am. Abstr. 38:12.4
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FLUOMETURON DEGRADATION IN FIELD CAPACITY AND SATURATED SOIL FROM A RIPARIAN FOREST EPIPEDON	Shankle, Mark; Shaw, David; Kingery, William; Boyette, Michelle; Medlin, CR; Locke, Martin	1999	Weed Sci. Soc. Am. Abstr. 39:290
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FLUOMETURON INTERACTIONS IN CROP RESIDUE MANAGED SOILS	Locke, Martin; Zablotowicz, Robert; Gaston, Lewis	1995	MAFES Special Bulletin 88-7
FLUORESCENT PSEUDOMONAS ISOLATES FROM MS DELTA OXBOW LAKES - In Vitro Herbicide Transformations	Zablotowicz, Robert; Locke, Martin; Hoagland, RE	2001	Env. Toxicol. and Water Quality 16: 9-19
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GROWER ASSISTED RESEARCH IS A SUCCESS		2000	ARS News Service
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HERBICIDE REDUCTION IN NO TILL ROW CROP PRODUCTION SYSTEMS	Hanks, James; Bryson, Charles	1996	Weed Science Soc. Of America Meeting
HERBICIDE REDUCTION IN NO-TILL ROW CROP PRODUCTION SYSTEMS	Hanks, James; Bryson, Charles		
HERBICIDES IN THE SURFACE WATER OF THE YAZOO RIVER BASIN, MISSISSIPPI	Coupe, Richard	1996	Proceedings: MS Water Resources Conf. 1996
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IMPACT OF MSEA ON THE ECOLOGY OF MS DELTA WATERSHEDS AND OXBOW LAKES	Knight, Scott; Cooper, CM; Smith Jr., Sammie	2004	USDA-ARS National Programs
IMPACT OF VEGETATIVE GRASS FILTER STRIPS ON HERBICIDE LOSS IN RUNOFF	Shaw, David; Webster, Eric	1995	Proceedings: MS Water Resources Conf. 1995
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IMPROVING SOIL AND WATER QUALITY IN MISSISSIPPI WATERSHEDS USING BEST MANAGEMENT PRACTICES	Locke, Martin; Zablotowicz Robert; Gaston, Lewis; Reddy, Krishna	1998	IUPAC 9th International Congress
IN FIELD/EDGE OF FIELD MANAGEMENT PRACTICES FOR IMPROVEMENT OF SOIL AND WATER QUALITY	Cullum, Bobby; Cooper, CM; Smith Jr., Sammie; Schreiber, Jonathon	2004	USDA-ARS National Programs
INFLUENCE OF BEST MANAGEMENT PRACTICES (BMPs0 ON FLUOMETURON DEGRADATION	Shankle, Mark; Shaw, David; Kingery, William; Locke, Martin; Boyette, M; Rankins, A	1998	South. Weed Sci. Soc. Am. Abstr. 51:229
INFLUENCE OF HERBICIDE DESSICATED COVER CROPS ON BIOLOGICAL SOIL QUALITY IN THE MS DELTA	Wagner, SC; Zablotowicz, Robert; Locke, Martin; Smeda. RJ; Bryson, Charles	1995	MAFES Special Bulletin 88-7
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INNOVATIVE FARMING SYSTEMS FOR ENVIROMENTAL MANAGEMENT OF AGRICULTURAL WATERSHEDS IN MS DELTA	Cullum, Bobby; Cooper, CM; Smith Jr., Sammie; Schreiber, Jonathon; Dabney, Seth; Romkens, Matt; Locke, Martin; Zablotowicz, Robert; Hanks, James; Bryson, Charles	2004	USDA-ARS National Programs
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INSTITUTIONAL ARRANGEMENTS FOR THE MS DELTA MSEA	Schreiber, Jonathon; Rebich, Richard	1997	Proceedings: Int'l Conf. On Advancing Integrated Resource Mgt. Processes and Policies
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MEASUREMENT OF 1999 DROUGHT CONDITIONS IN MISSISSIPPI	Turnipseed, Phillip; Long, Lloyd	2000	Proceedings: MS Water Resources Conf. 2000
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MICROBIOLOGICAL CHARACTERISTICS AND FLUOMETURON CONCENTRATIONS IN SURFACE WATER FROM OXBOW LAKES IN THE MS DELTA MSEA PROJECT	Zablotowicz, Robert; Locke, Martin; Knight, Scott	2000	MS Water Resources Conf.
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MICROBIOLOGICAL CHARACTERISTICS OF A MISSISSIPPI DELTA FORESTED RIPARIAN ZONE	Zablotowicz, Robert; Locke, Martin; Staddon, William; Shankle, Mark; Shaw, David; Kingery, William	1998	Am. Soc. Agron. Abstr. 90:325
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MISSISSIPPI DELTA MANAGEMENT SYSTEMS EVALUATION AREA		1996	USGS 96-342
MISSISSIPPI DELTA MANAGEMENT SYSTEMS EVALUATION AREA PROJECT - BMP Implementation/Information/Education			EPA Region 4 Project/Grant Summary
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MISSISSIPPI DELTA MSEA REPORTER	Smith, Jr., S	1995	Newsletter, Vol. 1 (1)
MISSISSIPPI DELTA MSEA REPORTER	Smith, Jr., S	1996	Newsletter, Vol. 2 (1)
MISSISSIPPI DELTA MSEA REPORTER	Smith, Jr., S	1996	Newsletter, Vol. 2 (2)
MISSISSIPPI DELTA MSEA REPORTER	Smith, Jr., S	1996	Newsletter, Vol. 2 (3)
MISSISSIPPI DELTA MSEA REPORTER	Smith, Jr., S	1997	Newsletter, Vol. 3 (1)
MISSISSIPPI DELTA MSEA REPORTER	Smith, Jr., S	1997	Newsletter, Vol. 3 (2)
MISSISSIPPI DELTA MSEA REPORTER	Smith, Jr., S	1998	Newsletter, Vol. 4 (1)
MISSISSIPPI DELTA MSEA TRACER DYE STUDIES ON DEEP HOLLOW LAKE	Shields, Doug	1999	NSL Web
MISSISSIPPI SOIL AND WATER CONSERVATION COMMISSION			5 Year Report
MITIGATION CAPABILITIES OF AGRICULTURAL DITCH WETLANDS	Moore, Matt; Bennett, ER; Smith, Jr. Sammie; Cooper, CM	1999	3rd Nat'l Workshop on Constructed Wetlands
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N-DEALKLYATION OF THE HERBICIDES ATRAZINE AND FLUOMETURON BY GREEN ALGAE	Zablotowicz, Robert; Schrader, KK; Locke, Martin	1998	J. Environ. Sci. Health, Sec B33, 511-528
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NUTRIENT ISSUES IN MISSISSIPPI	Royals, Barry		MDEQ
NUTRIENTS IN GROUND AND SURFACE WATERS FROM A CONVENTIONAL AND NO TILL WATERSHED	Schreiber, Jonathon	1992	Proceedings: MS Water Resources Conf. 1992
OPERATION OF WATER QUALITY CONTROL SYSTEM FOR WATER QUALITY IMPROVEMENT	Fouss, James; Rogers, James; Willis, Guye	1995	Proceedings: MS Water Resources Conf. 1995
OVERVIEW OF THE MANAGEMENT SYSTEMS EVALUATION AREA PROJECT IN THE MISSISSIPPI DELTA	Locke, Martin		Slides
OVERVIEW OF THE MANAGEMENT SYSTEMS EVALUATION AREA PROJECT IN THE MISSISSIPPI DELTA	Locke, Martin		
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PERFORMANCE OF AGRONOMIC AND STRUCTURAL MANAGEMENT PRACTICES ON CROP YIELD IN THE MDMSEA	Dabney, Seth	2001	USDA-ARS National Programs
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PREDICTING INCIPIENT PONDING AND INFILTRATION INTO CRACKED SOIL	Prasad, SN; Romkens, Matt; Wells, RR; Neely, R	1999	Proceedings: 19th Annual AUG Hydrology Day; 343-356
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PRELIMINARY ANALYSIS OF MSEA LAKE WATER QUALITY	Knight, Scott; Cooper, CM; Cash, Ben	2000	5 Year Report
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RESEARCHERS, FARMERS REVIVE MISSISSIPPI LAKES		1999	Environmental News Network
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SPATIAL EFFECTS ON FLUOMETURON SORPTION IN SOIL FROM TWO MISSISSIPPI DELTA OXBOW LAKE WATERSHEDS	Locke, Martin; Gasston, Lewis; Zablotowicz	1998	Weed Sci. Soc. Of America 38:15.12.3
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SPATIAL VARIABILITY OF SOIL NUTRIENTS IN FIELDS UNDER CROP RESIDUE MANAGEMENT… IN THE MS DELTA	Staddon, WJ; Locke, Martin; Zablotowicz, Robert; Dabney, Seth	1999	Am. Soc. Agron. Abstr. 91:139
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SPATIAL VARIABILITY OF SURFACE SOIL PROPERTIES AND WEED POPULATION AT TWO SITE IN THE MS DELTA	Gaston, Lewis; Locke, Martin; Zablotowicz, Robert; Reddy, Krishna	2001	Soil Sci. Soc. Am. J. 65, in press
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THE EFFECT OF BEST MANAGEMENT PRACTICES ON FLUOMETURON SORPTION	Shankle, Mark; Shaw, David; Kingery, William	1998	Proceedings: MS Water Resources Conf., 90-94
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WEED SHIFTS AT DEEP HOLLOW	Hanks, James		Southern Weed Science Society
WEED SHIFTS IN DEEP HOLLOW WATERSHED, LEFLORE COUNTY, MS	Bryson, Charles; Hanks, James E	2000	5 Year Report
WEEDS IN REDUCED TILLAGE COTTON - MS Delta Management Systems Evaluation Area	Bryson, Charles; Hanks, James	1997	Proceedings: Southern Weed Science Society
WHAT I DID ON SUMMER VACATION: WATER RESEARCH	Geuder, Maradith Walker	1999	MSU Alumnus
WILLINGNESS TO PAY FOR PRECISION APPLICATION TECHNOLOGY TO REDUCE AGRICULTURAL NONPOINT POLLUTION	Hite, Diane; Hudson, D; Parisi, D	2000	Proceedings: MS Water Resources Conf. 2000
WINDOW ON APPLYING SOLUTIONS - Protecting and Preserving Water for the Future			MSU Engineering
WORKING GROUP ON WATER QUALITY: The Mississippi Delta Management System Evaluation Area		1997	USDA

APPENDIX B
Agency Notes

Agricultural activities are perceived as the major source of nonpoint source pollution in the United States. Agriculture receives most of the blame for adverse water quality and ecological conditions which is assumed to result from surface runoff of sediments, bacteria, nutrients, and pesticides. However, the Mississippi Delta Management Systems Evaluation Area (MDMSEA) project is showing, through sound scientific procedures, that most farmers are good stewards of the land and that farmers are not blatantly polluting surface water and groundwater.

The watershed-based research project has proven that the use of best management practices (BMPs) can control erosion, reduce concentrations of pesticides and nutrients, and improve water quality. Project benefits include new knowledge on the positive effectiveness of: 1) winter cover crops, 2) conservation tillage, 3) weed-sensing herbicide applicators, 4) riparian zones, 5) filter strips, and 6) slotted-board risers.

The Mississippi Delta MSEA project and the associated research activities involved to make the project a success, was made possible by the strong working relationship exhibited by the landowners, the federal, state, and local agencies, the universities sector, and the farmer advocacy groups. The Mississippi Farm Bureau Federation is proud to be involved in the Mississippi Delta MSEA project. This project should play an important role in helping agriculture develop answers to questions involving regulatory control of nonpoint source pollution.

Brent Bailey, Director
Natural and Environmental Resources
Mississippi Farm Bureau Federation

Delta Council is pleased to have played an integral role in the development and implementation of the Management Systems Evaluation Area (MSEA) Project over the past eight years.

Beginning with the passage of the Clean Water Act in 1972, Delta Council worked with federal and state agencies to establish several pilot programs for the study of non-point agricultural runoff studies. Many positive results aimed at evaluating numerous land treatment practices to reduce sediment loss and non-point source runoff were generated from this work.

However, the concept of the MSEA Project --- developed in 1993 and 1994 --- improved drastically on the earlier work: an interagency cooperative agreement aimed at the development of data for non-point water quality initiatives that would be of tremendous values in terms of identifying strategies to address non-point water quality issues in the future. Delta Council worked with the federal and state agencies to help identify farmer cooperators, funding sources, and other collaborators as the project progressed.

Delta Council, working through farmer input, continued to recognize the importance of the MSEA Project and supported it in any manner possible. The MSEA Project has been a well-conceived and carefully organized effort that the people of the Delta feel will pay huge dividends for the future enhancement of water quality efforts in the Yazoo Basin and across the Lower Mississippi Valley. There is abundant evidence that stream quality, fish habitat, fisheries population, and the over-all aquatic habitat of the region has drastically improved since the early work of the 1970's, and the MSEA Project has assisted tremendously in identifying economically feasible approaches that can be adopted on a voluntary basis by farmers in the region which would continue to accelerate the improved conditions of water quality in all our surface water streams and lakes.

Chip Morgan, Executive Vice President
Delta Council

A multi-agency endeavor called the Management Systems Evaluation Areas (MSEA) project is underway in the Delta to evaluate agricultural practices that farmers could adopt that will ultimately lead to improvements in water quality and fish populations in Delta lakes. The 3 MSEA study lakes were renovated in the summer and early fall of 1996. The Mississippi Department of Wildlife, Fisheries, and Parks (MDWFP) participated in this important cooperative project by assisting with the renovations. On each lake, the MDWFP collected acre-fish population survey data to help document what fish population was present during renovation and as data base for future comparative use. The MSEA lakes were stocked with bluegill and catfish in fall of 1996 and stocked with largemouth bass in spring 1997. The fish that were stocked were raised in MDWFP hatcheries. The MDWFP continues to lend technical support, and manpower, to the research effort of this project. The MSEA Project has wide support and is a major endeavor towards the restoration of Delta Lakes.

Garry Lucas
Mississippi Department of Wildlife, Fisheries, and Parks

The Natural Resources Conservation Service in Mississippi is very proud to be a part of an integrated project such as the Mississippi Delta Management Systems Evaluation Area (MDMSEA) project. As our mission encompasses a productive land with a quality environment we are indeed excited and privileged to be a partner in providing valuable technical and management assistance to the MSEA Project. The expected benefits from this partnership effort fits well into our mission and NRCS, goals and objectives for accomplishing that mission. The anticipated research results and products will benefit American agriculture and ultimately the American people. We are proud to be a catalyst in the formation of these results and products.

Homer Wilkes, State Conservationist
U.S. Department of Agriculture, Natural Resources Conservation Service

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The mission of Delta Wildlife is to conserve, enhance, and restore wildlife habitat in the Mississippi Delta region. And as agriculture continues to dominate the region's landscape, resource scientists and conservation groups must continuously strive to identify better conservation practices for agricultural lands to ensure a sustainable future for our natural resources, including wildlife.

The MSEA Project proposed a project in which natural resource conservation practices could be further developed and monitored as their effectiveness was documented. Delta Wildlife felt it was crucial to participate in this project as the outcome of this project could lead to a better understanding of Best Management Practices and how they effect wildlife and fisheries.

Over the past 5 years, Delta Wildlife has donated more than 50 water control structures to the MSEA Project sites. These structures were constructed to the specifications recommended by the NRCS and other MSEA cooperative agencies. Each of these structures provided significant sediment retention from adjacent croplands and an opportunity to manage winter water for soil conservation and wildlife benefits. The structures provided by Delta Wildlife have proven to be significant in the overall effectiveness of the BMPs implemented on all the MSEA watershed lakes. In addition, Delta Wildlife also erected several dozen wood duck nesting structures, blue bird nesting structures, and bat boxes around the MSEA watershed lakes.

Trey Cooke
Delta Wildlife

Mississippi State University (MSU) was one of the three research units that first promoted the idea of a Mississippi Delta MSEA Project. Researchers in the Water Resources Research Institute and the Mississippi Agricultural and Forestry Experiment Station were already beginning to see data from the Midwest MSEA projects used as a new standard for controlling nonpoint source pollution. It was clear that unless the South had its own data, many of the practices best suited to Southern crops would not be considered acceptable.

Over the years of the MDMSEA project, MSU has led the efforts in Economics and Sociology. MSU has also helped coordinate management of the three lake sites and has been a major contributor in sample analyses. Major projects involving MSU have examined the fate of pesticides crossing filter strips, carried out preliminary examination of the fisheries populations in all three lakes, and examined the riparian ecosystem.

Mississippi State University has taken great pride in its involvement in this project. Coordinating the efforts of this many agencies and companies is a mammoth task, but no other approach would have produced the necessary consensus on the value of these management practices. This project marks the future for watershed-scale evaluation of water quality systems.

Jonathan Pote, Associate Vice President for Research
Mississippi State University

During the early days of MSEA, the Farm Service Agency (FSA) played an important role in the project. FSA had well-established relationships with most, if not all, of the parties that would become partners in the project. In particular, FSA knew the farmers who would be the key to getting the project up and running. This relationship had been developed over the years through farmer participation in conservation, commodity, and price support programs administered by FSA.

As the project evolved, FSA's records of program participation have been a valuable point of reference. In addition, by having a representative on the Technical Steering Committee, FSA has been able to serve as an intermediary among farmers, scientists, and federal farm program requirements. This has allowed the project to take advantage of certain conservation incentive programs and to stay in compliance with various program requirements applicable to the farmers involved.

Hopefully, the lessons we all learn from the MSEA project will give farmers more proven techniques that will assist them in their ongoing struggle to balance environmental concerns with economic realities in a way that will sustain both ecosystems and incomes.

Steve Melton
U.S. Department of Agriculture, Farm Service Agency

The Mississippi Department of Environmental Quality has been pleased to participate in the Mississippi Delta MSEA Project. This project will provide water quality and economic data for the best management practices, which are recommended for the control of nonpoint source pollution runoff from agricultural activities. The information gained from these activities will be extremely important to the Department and the agriculture industry in determining the appropriate practices for improving the quality of water in the Mississippi Delta.

Charles H. Chisolm, Executive Director
Mississippi Department of Environmental Quality

USDA, APHIS, Wildlife Services is charged with the responsibility of resolving wildlife and human conflict. The program strives to manage the damage caused by wildlife by providing environmentally balanced wildlife damage management services that are safe, effective, and practical. Over the past five years the Wildlife Services program in Mississippi has been providing beaver damage management services at various MESA project locations in the Mississippi Delta. We have used an Integrated Pest Management (IPM) approach to prevent or minimize beaver caused damage. The IPM approach incorporates beaver population management through the use of trapping and shooting, physical exclusion through the use of barriers at culverts, and water resource management through the use of Clemson Beaver Pond Levelers installed in the beaver dam. We believe that our involvement in the MESA Program has been and continues to be a necessary part of the success of this important research project.

Bo Sloan
U.S. Department of Agriculture, Wildlife Services

The Mississippi Soil and Water Conservation Commission (MSWCC) Board and Executive Director realized the potential importance of the Mississippi Delta MSEA project from the very beginning and were eager to become involved. In fact, the MSWCC has been involved with this project before the Technical Steering Committee was formed. A staff person has served on the Technical Steering Committee almost from the very start of the project. Other staff members have also been heavily involved with many of the Information/Education Activities. The MSWCC Staff have coordinated, hosted, sponsored and assisted with several educational field days, tours, workshops and activities. The most significant involvement of the MSWCC to the MSEA Project is providing funds for installation of Best Management Practices (BMPs) within the Deep Hollow and Beasley Watersheds. These funds were provided through the MSWCC's 319 Water Quality Program funded by a grant from the Mississippi Department of Environmental Quality and the Environmental Protection Agency. The MSWCC administers the project on the state level with assistance from Leflore County Soil & Water Conservation District and the Sunflower County Soil & Water Conservation District on the local level. The MSEA 319 Water Quality Project's Objectives are:

1. *To improve water quality by demonstrating the economic benefits and effectiveness of selected BMPs in targeted areas.*
2. *To apply BMPs to agricultural lands in the demonstration project area so as to reach the desired outcome of reduced runoff and sedimentation.*
3. *To inform and educate researchers, agency personnel, teachers, students and the general public about BMPs that benefit water quality.*

Gale Martin, Executive Director
Rick Hagar, MDMSEA liaison
Mississippi Soil and Water Conservation Commission

The USDA Agricultural Research Service (ARS) Mid-South Area is committed to promoting and implementing quality research programs that meet the needs of the agricultural community and society at large. The Mississippi Delta Management Systems Evaluation Areas (MSEA) project is an excellent example where USDA-ARS joined other Federal and state agencies, partners, and customers to develop and demonstrate the means by which water and soil resources of the Mississippi Delta can be improved and sustained while providing economically viable management strategies to growers. Not only have we gained new information through research efforts, but lessons were learned from the farmers cooperating in the project. Growers care deeply about the environment and are struggling to balance the economics of farming with environmental responsibility. The economic climate is competitive, and issues, such as the assessment of total maximum daily load limits (TMDLs), make it extremely challenging to operate. As the Mississippi Delta MSEA project moves into the next phase of activity, USDA-ARS scientists will adapt research objectives to meet these challenges.

Edgar G. King
Director, Mid-South Area
USDA-ARS

The Mississippi Agricultural and Forestry Experiment Station (MAFES) is pleased to participate in the cooperative effort of the Mississippi Delta Management Systems Evaluation Area (MDMSEA) Project through the involvement of researchers and extension specialists from the Delta Research & Extension Center (DREC). The mission of MAFES is to "improve the state's agricultural industries and well being of all Mississippians" by maintaining a "continuum of research discovery and education to keep Mississippi agricultural producers viable and competitive in a global economy." In addition to insuring the viability of Mississippi agricultural producers, MAFES specialists have a dual goal of protecting the environment and improving the natural resources of Mississippi. With ever-increasing scrutiny of agricultural practices that impact surface water pollutants, both by Government agencies and public opinion, agricultural producers must comply with production practices that may significantly impact their economic profitability. MAFES views the MDMSEA Project, with its goal to evaluate primary pollutants in Mississippi Delta water sources and validation of best management practices (BMPs) that are most effective in reducing the transport of pollutant to surface and ground water, as a significant effort to help Mississippi agriculture producers meet the demands of increasing environmental concerns, yet maintain their profitability. The work conducted by the MDMSEA project is critical for the future success of Mississippi agricultural producers.

Over the past 5 years, MAFAS scientist have served on the Technical Steering Committee of the MDMSEA Project and played a significant role in facilitating the link between researchers and farmers. Over the next five years, the MDMSEA will focus on the decision-making process agricultural producers must make with regard to protection of water quality. The extension specialists of MSU-ES will be the primary mechanism by which the information and recommendations of the MDMSEA Project will be disseminated to agricultural producers and therefore critical for its future implementation and success.

James W. Smith
Head, Delta Research and Extension Center
Stoneville, Mississippi

The U.S. Geological Survey (USGS) has participated in the Mississippi Delta Management Systems Evaluation Areas project since its inception in 1994. The USGS, Mississippi District, co-hosted strategy meetings with several Statewide agencies and organizations prior to the establishment of the project. The purpose of the USGS is to provide information to help others meet their needs to manage, develop, and protect America's water, energy, mineral, and land resources. By participating in the MDMSEA project, the USGS meets this overall purpose by providing resource managers the information they need to understand agricultural nonpoint source pollution in the Mississippi Delta. Specifically, the USGS has participated in the project by providing leadership in the form of a co-chairmanship to the Technical Steering Committee, which is the multi-agency committee that oversees the project. The USGS has also participated as a research agency by collecting hydrologic and water-quality data from nine runoff sites in the three MDMSEA oxbow lake watersheds. The USGS hopes to continue serving in these capacities to help resource planners understand and design systems that mitigate agricultural nonpoint source pollution in the Mississippi Delta.

Michael L. Plunkett, District Chief
U.S. Geological Survey, Mississippi District

In 1997, the Pyrethroid Working Group (PWG), composed of then-member companies Zeneca Ag Products, Aventis Crop Products, Bayer Corporation, DuPont Ag Products, FMC Corporation and Valent USA Corporation) initiated a financial and technical collaboration with the MDMSEA scientists. Having just completed detailed remote sensing and modeled assessments of the potential for foliar pyrethroid insecticides to impact oxbow lakes within Yazoo County, MS, the opportunity to partner with the MDMSEA agencies in the areas of data management and insecticide sampling from three oxbow lake watersheds was of particular interest to the PWG scientists.

During the next three years, the PWG-MDMSEA collaboration initiated the organization and management of grower information from the three MDMSEA watersheds in one central database. In addition, the collaboration enabled collection of discrete samples of runoff from the nine sampling stations located within the Deep Hollow, Beasley and Thighman Lake watersheds for insecticide analyses. Both efforts will provide the Delta community critical information that will help address water resource management needs.

Mary Nett, consultant
Pyrethroid Working Group

The Yazoo Mississippi Delta Joint Water Management District (YMD) works with landowners and agencies to develop watershed plans for the Delta to solve water quality and water supply problems. Information from the MSEA project will play a vital role in YMD's programs to implement practical water quality programs for the Delta.

MSEA will provide locally based results about how conservation activities work in the Delta. YMD will use the MSEA information to develop practical and effective water quality programs. Without MSEA, YMD would be forced to use incomplete information or information from other parts of the country where the affects of conservation practices may be different than in the Delta.

Delta residents, landowners and water quality agencies will all benefit from the improved conservation and water quality data collected as part of the MSEA project.

Dr. Dean Pennington, Executive Director
YMD Joint Water Management District

APPENDIX C
Research Articles

SUBSURFACE COMMUNICATION BETWEEN DEEP HOLLOW LAKE AND THE YAZOO RIVER

Gray Adams and Gregg Davidson, University of Mississippi

PROJECT SUMMARY

A total of 17 shallow wells were installed around Deep Hollow Lake in an effort to characterize the hydrologic connection between Deep Hollow Lake, the Yazoo River, and the groundwater system. Current data indicates that there is a direct subsurface connection between the groundwater and both Deep Hollow Lake and the Yazoo River. Water levels in the wells respond rapidly to changes in the river and lake levels. The data also suggests that groundwater flow from the lake reaches the river during low river stages. During high river stages, groundwater originating from both the lake and river typically flows toward an intermediate hydraulic trough that carries groundwater away from the river around the northern edge of the lake.

CURRENT PROJECT STATUS

Monitoring Wells

Seventeen wells have been completed at Deep Hollow Lake (Fig. 1). The wells were cased using 2 in ID PVC pipe with a 5 ft screened interval. The screened interval was packed with coarse sand. Bentonite pellets were used to seal the well between the screened interval and the surface. Well depths range from 13.5 to 27.2 ft below the surface (Table 1). Most wells penetrate a surficial clay unit that ranges in thickness from 8 to 15 ft, and are completed in a silty-sand unit underlying the clay. The silty-sand unit is approximately 110 ft thick based on the geologic log of a 123-ft deep water well installed in a nearby field in July, 1998. Only two of the wells do not penetrate a thick clay unit: wells DHg9 and DHg16. Well DHg9 is completed in dredged sediments that were deposited just west of the lake when the U.S. Army Corps of Engineers dug the Sidon cutoff in 1942. The bottom of the well does not reach the clay unit. Water levels in DHg9 suggest that a perched water table has formed on top of the clay in this area. Well DHg16 lies between the southern tip of the lake and the Sidon backwater and penetrates alternating intervals of medium and fine sand, and clay.

Well elevations were surveyed and are reported relative to Sea Level (Table 1). A temporary benchmark was established by nailing a metal plate into a tree near the boat ramp to the lake. Longitude and latitude locations of each well were determined using a global positioning system (GPS).

Analysis of Auger Cuttings

Cuttings representing the different sediments encountered below the clay layer were collected from each well. Grain size distributions have been determined for the silty-sand from wells DHg1 through DHg9 (Table 2). The mean grain diameter (d_{50}) in wells DHg1 through DHg8 ranged from 45 to 90 μm. (By definition, 50% of the sample, by mass, has a grain diameter equal to or larger than d_{50}.) The d_{50} for well DHg9, completed in the dredged sediments, was much higher at 250 μm.

Well Water-Level Measurements

Water levels were monitored manually from February, 1998 to August, 1999. Pressure transducers for detailed, automated monitoring were installed in early April, 1998. Transducers were periodically rotated from well to well in order to obtain a detailed monitoring cycle on each well. The pressure transducers were programmed to take readings every 3-12 minutes.

Lake and River Water-Level Measurements

Both Deep Hollow Lake and the Yazoo River were monitored using staff gauges. A staff gauge was installed in the lake in February, 1998. The U.S. Army Corps of Engineers installed a lock in the Yazoo River at the Deep Hollow Site and attached staff gauges on both sides of the river. These gauges were monitored from the completion of the structure in January, 1998 until August, 1999.

Hydraulic Conductivity of Shallow Aquifer

Slug tests were performed on all wells. Slug tests were completed by pouring water into the well at the start of the test and monitoring the change in water level over time with a pressure transducer. Use of a transducer in the narrow well bore precluded the use of a solid slug. Three consecutive tests were run on each well with readings every 0.5-2.0 sec. Hydraulic conductivity (K) estimates (Table 1) were calculated using Aquifertest© (Waterloo Hydrogeologic, Inc.). If the potentiometric surface of the aquifer was above the elevation of the bottom of the clay layer during a slug test, the Bouwer & Rice method of analysis for confined aquifers was used. If the potentiometric surface was below the bottom of the clay layer at the time of the test, then the Hvorslev method of analysis for unconfined aquifers was used.

RESULTS AND DISCUSSION

Water-level data collected from February, 1998, through August, 1999, demonstrate that Deep Hollow Lake and the Yazoo River are both connected to the underlying shallow aquifer. Hydraulic connection is evident from the proportional rise and fall of water levels in wells with changes in lake and river levels. Figure 2a compares the changes in river levels with changes in a nearby well (DHg3). The river stage was recorded daily by the Army Corps of Engineers and well data was collected by a pressure transducer every 3 minutes. Water levels in the well track changes in the level of the river with delays that appear to range from approximately 0.5 to 1.5 days.

Figure 2b shows the correlation between the lake and well-water levels. The lake data was recorded manually with variable frequency, and data from nearby well DHg6 was collected by a pressure transducer every 3 minutes. The two lines track fairly closely. The delay between peak lake levels and well-water levels can only be determined approximately due to limited data points from the lake, but is of the same magnitude as observed for the river-aquifer system.

It is still unknown whether leakage from the lake forms a saturated or unsaturated zone immediately below the lake. Unsaturated leakage would simply form a mound in the potentiometric surface below the lake. In either case, flow resulting from leakage through the lake bottom is away from the lake in all directions. Leakage appears to be highest at the southern end of the lake (Figs. 3 and 4). Higher leakage rates could be expected if the clay unit is much thinner in this region, or if a sand rich unit, such as a channel sand deposit, crosses beneath the lake at the southern end. One well at the southern extreme, DHg16, does have an anomaly in the clay unit. Sand and silt layers are interspersed with the clay that could result in higher vertical conductivity, but the measured hydraulic conductivity at this well was low (Table 1). The wells nearest the high point in the groundwater mound, such as DHg6, penetrate the same thick clay unit found in the other wells.

Connection between the lake and the perched aquifer within the woods is also a means of lake-water/groundwater interaction. During the study, water levels in well DHg9 (completed within the perched aquifer) were higher than lake levels during the winter months and lower than lake levels during the summer months. The lake thus appears to be a source of perched water during the drier summer months, and a sink during the wetter winter months. The decline in perched water levels during the summer is probably a combined result of seepage from the perched aquifer into the underlying regional aquifer, and losses due to plant uptake and transpiration.

Groundwater originating from the lake appears to enter the river during periods of low river stage (Figs. 3 and 5a). Mounding of the groundwater beneath the lake, and possibly beneath the Sidon backwater, results in groundwater flow in roughly the opposite direction of river flow before discharging into the river. During high river stages (Figs. 4 and 5b), the level of the river rises above the water table in the shallow aquifer, and water flows from the river into the shallow aquifer. A temporary groundwater trough forms between the lake and river that ultimately directs groundwater flow away from the river around the northern edge of the lake.

CONCLUSIONS

The Yazoo River and Deep Hollow Lake are connected to the underlying aquifer. The lag time between changes in river or lake level, and water levels in adjacent wells varies from approximately 0.5 to 1.5 days. Groundwater originating from the lake reaches the river during periods of low river stage. Flow reverses during high river stage, with river water entering the aquifer and meeting water from the lake in a groundwater trough. Groundwater flow in the trough travels parallel to, but in the opposite direction of the river, and then away from the river around the northern edge of the lake.

Losses from the lake to the groundwater appear to be concentrated near the southern end of lake. This would suggest that the underlying sediments are more transmissive in this region, but the wells drilled in the immediate area encountered the same thick clay layer observed in the other wells. The only exception is well DHg16, located at the extreme southern edge of the lake. Clay layers encountered in this well were much thinner, and were interspersed with layers of sand.

ACKNOWLEDGMENTS

This research is funded through a specific cooperative agreement with the USDA-ARS-National Sedimentation Laboratory (C. M. Cooper and S. Smith, Jr., collaborators).

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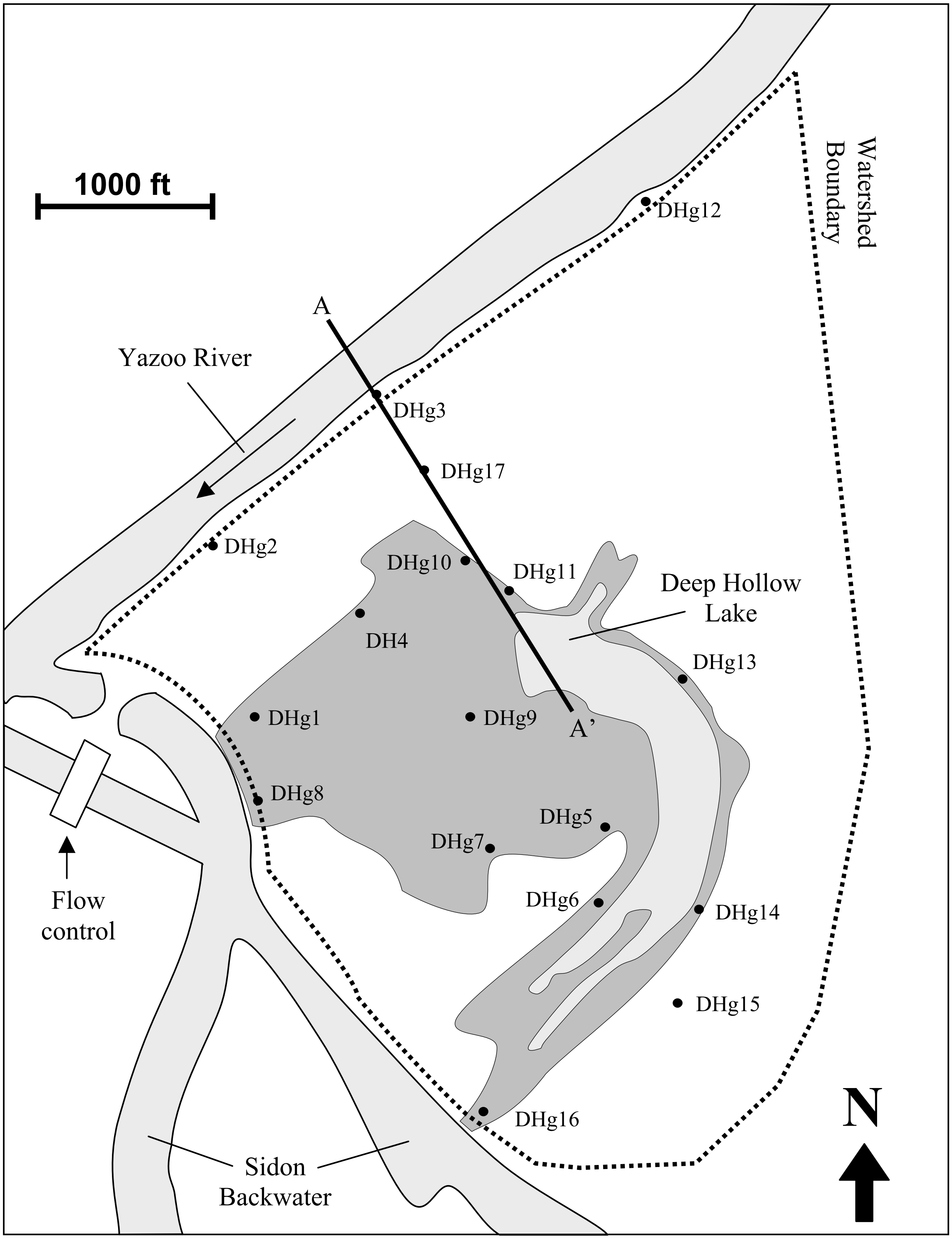

Figure 1. Well locations and cross section line A-A'. The darker area around the lake is forested. The remaining land is cultivated.

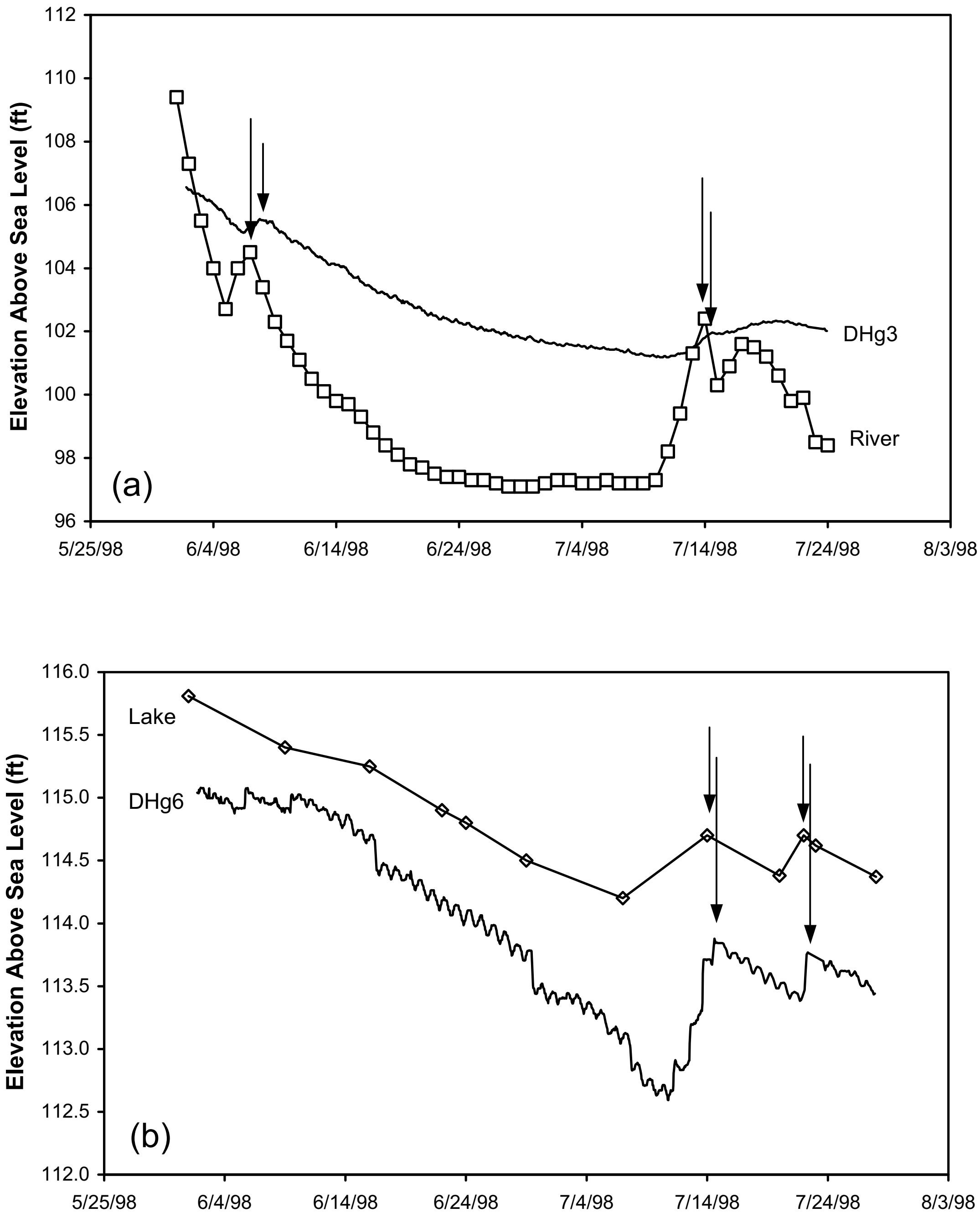

Figure 2. (a) Changes in the level of the Yazoo River and adjacent well DHg3 over time. The time delay between the two sets of arrows shown in the figure is 1.5 days for the early set, and 0.5 days for the later set. (b) Changes in the level of Deep Hollow Lake and adjacent well DHg6 over time. The time delay between the two sets of arrows shown in the figure is approximately 0.5 days for each set. (Note difference in vertical scale for the two graphs.)

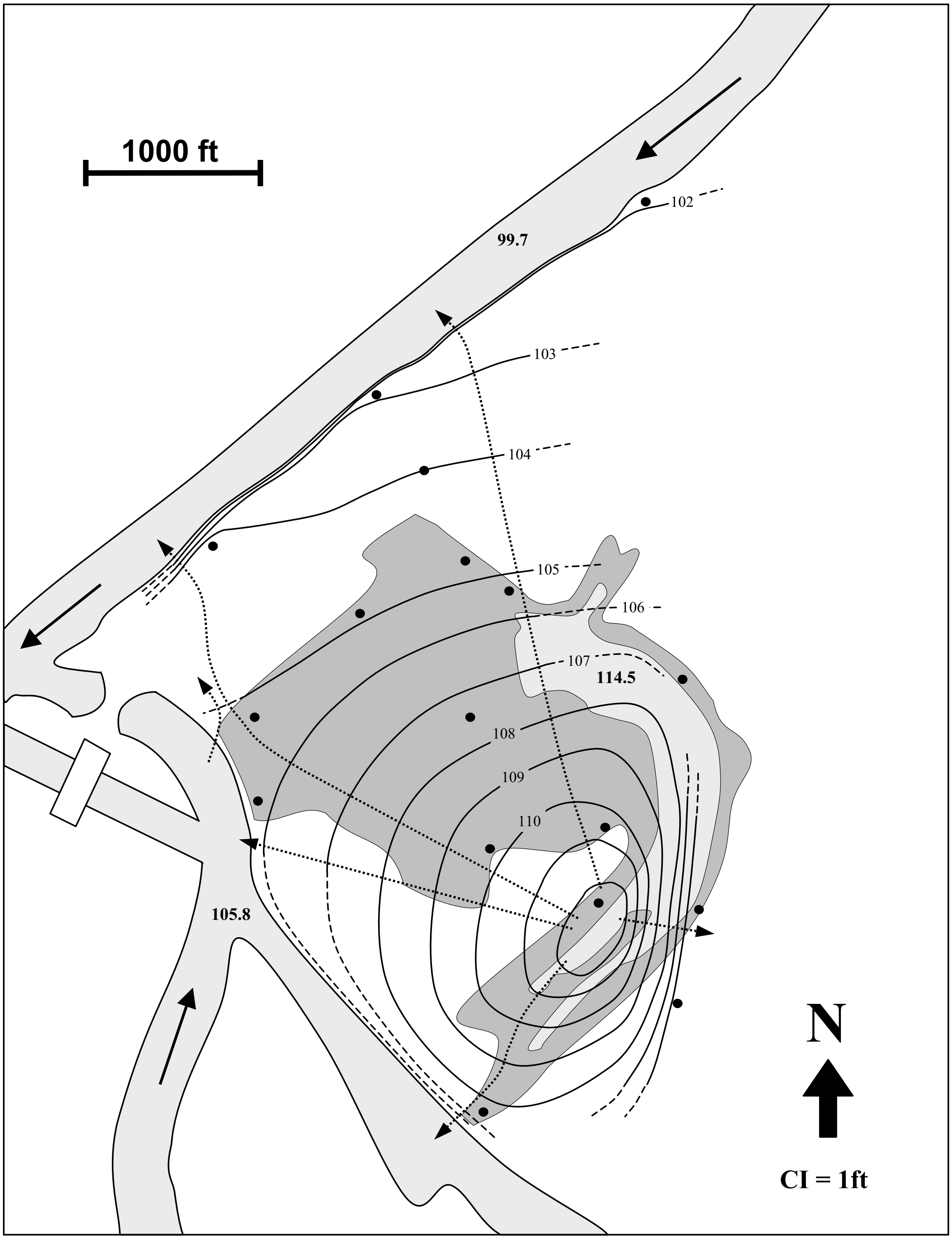

Figure 3. Contour map of the potentiometric surface of the aquifer during low river stage on 6/18/99.

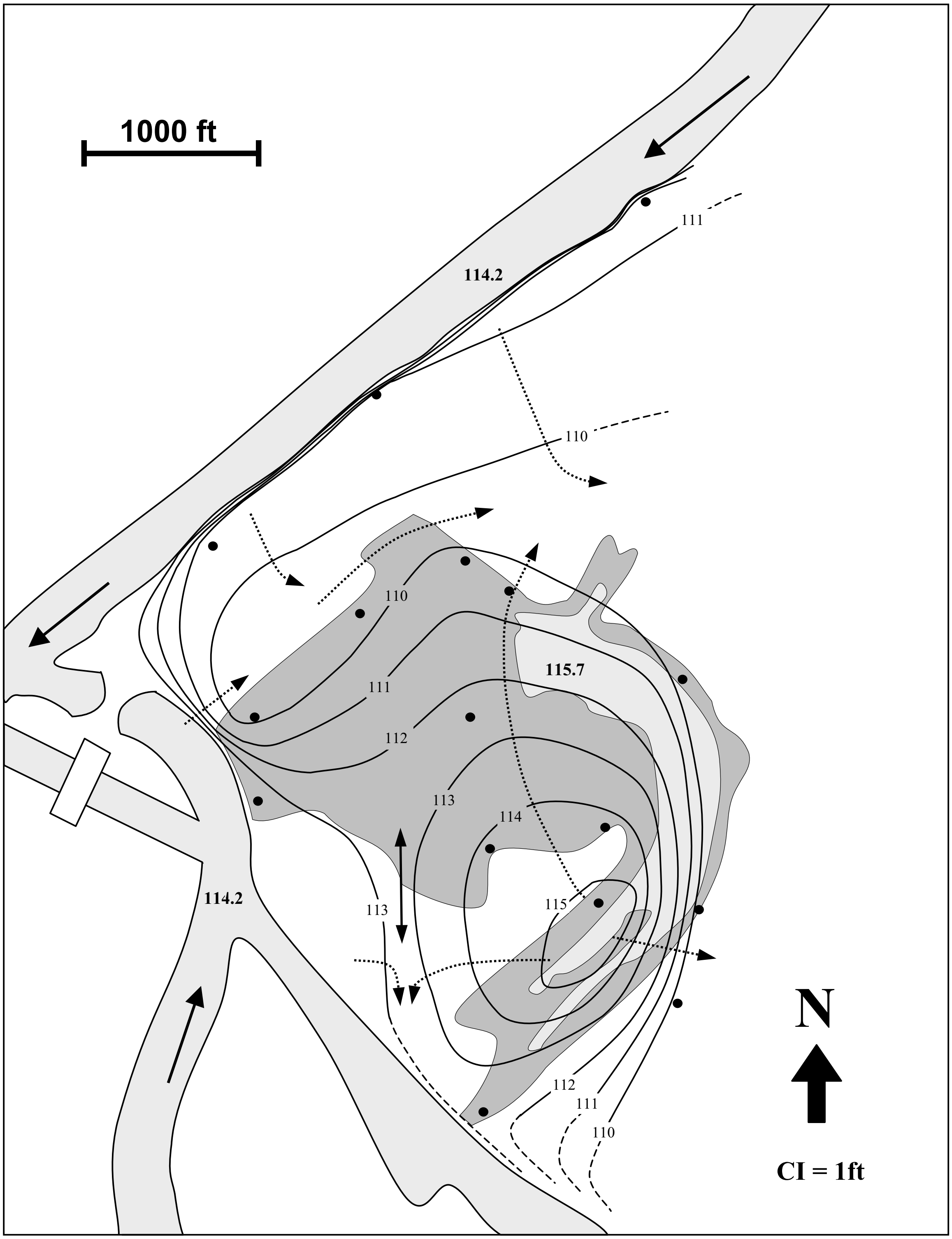

Figure 4. Contour map of the potentiometric surface of the aquifer during high river stage on 2/21/99.

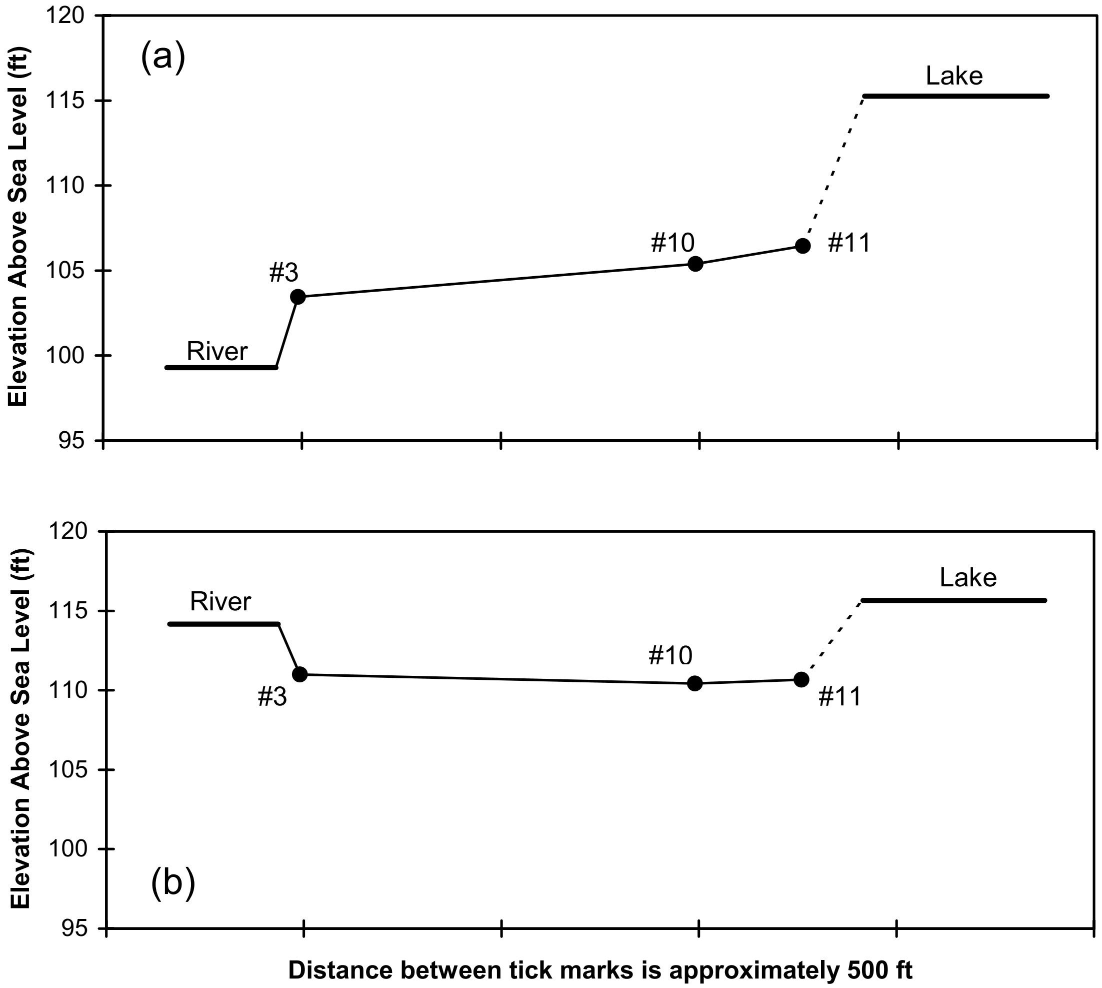

Figure 5. Cross-section A-A' from Figure 1 during (a) low river stage on 6/16/98, and (b) high river stage on 2/21/99. Vertical exaggeration is approximately 20x. (Note: well DHg17 was installed after 2/99).

Table 1. Monitoring-well surface elevation, depth, hydraulic conductivity, and location at Deep Hollow Lake. "K" is the hydraulic conductivity of the water-producing unit in each well.

Well ID	Elevation (feet)	Depth (feet)	K (ft/day)	Latitude	Longitude
DHg1	114.8	13.8	3.9	N33°24'53.33"	W090°14'34.20"
DHg2	119.6	20.2	1.6	N33°25'02.73"	W090°14'36.92"
DHg3	122.6	22.2	0.7	N33°25'10.71"	W090°14'26.29"
DHg4	118.4	22.6	2.0	N33°24'59.15"	W090°14'27.40"
DHg5	116.2	23.1	1.0	N33°24'47.60"	W090°14'11.78"
DHg6	117.3	19.3	3.3	N33°24'43.42"	W090°14'12.10"
DHg7	115	17.1	1.3	N33°24'46.43"	W090°14'19.17"
DHg8	112.9	23.1	0.3	N33°24'49.03"	W090°14'33.79"
DHg9	122.2	13.5	14.1	N33°24'53.41"	W090°14'20.42"
DHg10	119.6	21.7	1.0	N33°25'01.88"	W090°14'20.58"
DHg11	122.4	21.2	2.0	N33°25'00.20"	W090°14'17.80"
DHg12	122.2	26.7	50.2	N33°25'21.17"	W090°14'09.05"
DHg13	121.2	27.2	1.6	N33°24'55.54"	W090°14'06.96"
DHg14	120.4	17.7	0.7	N33°24'43.31"	W090°14'05.72"
DHg15	121.3	24.4	3.6	N33°24'38.18"	W090°14'07.16"
DHg16	111.9	16	0.3	N33°24'32.39"	W090°14'19.54"
DHg17	117.5	21.8	1.0	N33°25'06.62"	W090°14'23.48"

Table 2. Grain size distribution of well cuttings from the water-producing units where each well is completed.

Well	Percent of Mass (grain diameter is in μm)						d_{50} (μm)
	>500	500-250	250-125	125-63	63-45	<45	
DHg1	0.00	0.09	27.03	44.35	6.12	22.40	54
DHg2	0.00	0.00	5.74	60.66	11.76	21.84	66
DHg3	0.00	6.36	16.92	26.28	10.40	40.04	45
DHg4	0.00	0.00	14.14	44.64	11.38	29.84	49
DHg5	0.00	18.55	56.04	10.83	1.62	12.96	90
DHg6	0.00	13.46	50.39	18.38	3.11	14.66	80
DHg7	0.00	21.41	49.25	9.46	2.74	17.14	89
DHg8	0.00	7.46	47.98	17.13	3.58	23.85	70
DHg9	30.42	29.74	28.25	7.41	0.89	3.29	250

EVALUATION OF ANNAGNPS ON MISSISSIPPI DELTA MSEA WATERSHEDS

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Oxford, Mississippi

ABSTRACT

Pollutants entering a water body can be very destructive to the health of that system. BMP's can be used to reduce these pollutants, but understanding the most effective practices can be difficult. Watershed models are an effective tool to aid in the decision making process of selecting the BMP that is most effective in reducing the pollutant loading, but is also the most cost effective. The Annualized Agricultural Non-Point Source Pollution model (AnnAGNPS) is one such tool and was used to estimate runoff and sediment yield for the Deep Hollow watershed of the Mississippi Delta MSEA project. The AnnAGNPS predicted results were compared with MSEA monitored data in order to test the prediction capability of the model. Test results show that AnnAGNPS provides a reasonable estimate (±15%) of long term monthly and annual runoff and sediment yield without calibration. AnnAGNPS is a tool suitable for long term evaluation of the effects of BMP's and can be used for ungauged watershed simulation of runoff and sediment yield.

INTRODUCTION

The improvement of water resources in the United States has been an issue of significant societal and environmental concern for many years. Agriculture's contribution to nonpoint source pollution can be a major impairment to water quality (NRCS, 1997). The impairment to surface water quality due to sediment and nutrient transport from agricultural cropland has been estimated to range from $2.2 billion to $7 billion per year (Colacicco et al, 1989). Although more than $500 billion has been spent on water pollution control since the implementation of the Clean Water Act in 1972, the quality of the nation's water still remains largely unknown (Akobundu and Riggs, 2000). The U.S. Environmental Protection Agency (EPA) is requiring the implementation of Total Maximum Daily Loads (TMDL's) by each individual state. The TMDL's of various pollutants are to be evaluated as to where they are coming from within agricultural watersheds and their impact on the health of the watershed.

The complexity and expensive nature of laboratory and field observation necessitate the use of mathematical models for evaluating the hydrologic and water quality response of a watershed to best management practices. An effective simulation tool will provide increased awareness to farmers and landowners and promote adoption of alternative farming systems. Ultimately, this will reduce adverse agricultural effects on water resources and ecological processes.

The Annualized Agricultural Non-Point Source Pollution model (AnnAGNPS) is an advanced technological watershed evaluation tool, which has been developed through a partnering project with the United States Department of Agriculture – Agriculture Research Service (USDA-ARS) and Natural Resources Conservation Service (NRCS) to aid in the evaluation of watershed response to agricultural management practices (Cronshey and Theurer, 1998). Through continuous simulation of surface runoff, sediment and chemical non-point source pollutant loading from watersheds, best management practices (BMP's) can be evaluated for risk and cost/benefit analyses.

AnnAGNPS has been developed as a direct replacement for the single event model, AGNPS 5.0, but retains many of the features of AGNPS 5.0. Many studies have been conducted using AGNPS and indicate that the simulated results for runoff and sediment from AGNPS compare favorably with observed data (Young et al., 1989a; Bingner et al., 1989). Young et al (1989b) also tested the chemical component of the model using three-year monitored data from seven different watersheds in Minnesota. They found that the simulated nitrogen and phosphorus concentrations agree reasonably well with measured concentrations. Mostaghimi et al. (1997) used AGNPS 5.0 to assess the impact of management practices on the water quality and quantity for Owl Run Watersheds in Virginia and concluded that the model is applicable for nonpoint source impact assessment.

AnnAGNPS is a continuous simulation, daily time step, pollutant loading model and includes significantly more advanced features than AGNPS

5.0. Daily climate information is needed to account for the temporal variation in the weather. The spatial variability within a watershed of soils, land use, and topography, is accounted for by dividing the watershed into many homogeneous drainage areas. These simulated drainage areas are then integrated together by simulated rivers and streams, which route the runoff and pollutants downstream. From individual fields, runoff can be produced from precipitation events that include rainfall, snowmelt and irrigation. A daily soil water balance is maintained, so runoff can be determined when a precipitation event occurs. Soil loss from each field is predicted based on the Revised Universal Soil Loss Equation (RUSLE) (Renard et al, 1997).

The Mississippi Delta Management Systems Evaluation Area project (MDMSEA) within the state of Mississippi has been developed as part of the national program "Agricultural Systems for Environmental Quality (ASEQ)" to reduce adverse agricultural impacts on water resources and ecology through developing alternative farming systems. Comprehensive data collection efforts have been ongoing for five years to monitor runoff, sediment and pollutant loadings into lakes from various farming practices (NSL, 2000).

The objectives of the MDMSEA project include evaluating the effect BMP's have on lake water quality. In order to accomplish this, application and modification of AnnAGNPS was performed to: include the capabilities needed to effectively simulate the processes within the MDMSEA watersheds; assemble all necessary data needed to estimate model parameters, verify model enhancements, and validate simulation results; use the simulation model to assess and evaluate the effects of alternative and innovative farming systems used for improved water quality and ecology in the Mississippi Delta.

The features and capabilities of AnnAGNPS are well suited to meet the modeling objectives of MDMSEA project. The main objective of this study was to evaluate the capability of AnnAGNPS to simulate runoff and sediment yield on a MDMSEA watershed using three years of field monitored data.

METHODS AND PROCEDURES

AnnAGNPS Model Description

AnnAGNPS is a distributed parameter model with the capabilities of dividing a watershed into amorphous, homogeneous areas with respect to soil type, land use and land management. Runoff, sediment, nutrients and pesticides leaving the homogeneous areas and their transport through the watershed can be simulated. The model can be used to examine the effects of implementing various conservation alternatives within a watershed. The model can be used to study the effects of alternative cropping and tillage systems including the effects of fertilizer, pesticide, irrigation application rate as well as point source yields and feedlot management (Bosch et al., 1998).

Required input parameters for application of the model include climate data, watershed physical information and management information. Physical information includes watershed delineation, cell boundary, land slope, slope direction and reach information which can be generated by the AGNPS 98 data preparation tools (TOPAGNPS and AGFLOW). Management information can be developed using the AnnAGNPS Input Editor, a graphical user interface developed to aid users in the selection of appropriate input parameters. Additional input information includes land characteristics, crop characteristics, field operation data, chemical operation data, feedlots, and soil information. Much of this information can be obtained from databases imported from RUSLE or from NRCS sources. Climate data can be generated using the climate data generator (GEM) based on the location of watershed and climate stations around the watershed.

Output files can include runoff, sediment, nutrient and pesticide yields on daily, monthly or yearly basis according to user's specification. Output parameters can be specified for any desired watershed source location such as specific cells, reaches, feedlots, point sources, or gullies. More information can be found in Cronshey and Theurer (1998), Geter and Theurer (1998), and Theurer and Cronshey (1998).

Watershed Description

The watershed studied is the Deep Hollow watershed located in Leflore County, and is a part of the Mississippi Delta (Figure 1). Deep Hollow watershed is one of the watersheds studied in the MDMSEA project. The main crops in the Deep Hollow watershed are cotton and soybeans. Some of the BMP's used in Deep Hollow watershed consist of reduced-tillage cotton and no-tillage soybeans with winter wheat cover in order to reduce sediment and agrochemical yields to the Deep Hollow Lake. Winter wheat is aerially seeded in October or later after cotton and soybeans are harvested. Around April of the following year, winter wheat is chemically killed and residue of winter wheat is left in the field, then cotton or soybeans are planted.

In 1995-96, the U. S. Geological Survey (Jackson, MS district office) installed two runoff sampling stations (UL1 and UL2, see Figure 1) in the Deep Hollow watershed. The drainage area, or sub-watershed, for these sites as well as all channels entering Deep Hollow Lake were determined in order to quantify the runoff, sediment, and chemical yields to the lake and to validate the model. Runoff was monitored using a critical flow flume. Both discrete and composite samples were taken during runoff events for sediment and nutrient analyses. Rainfall was monitored at both sites using a tipping bucket rain gages. The drainage area for UL1 is 42.6 acres and 27.9 acres for UL2. Monitoring data from UL2 is used in this study.

The entire Deep Hollow watershed is about 500 acres and is very flat. In October of 1998, a detailed watershed elevation was obtained. The maximum elevation difference of 4 meters made the delineation of the watershed difficult. Deep Hollow Lake is adjacent to the Yazoo River. When the Yazoo River floods, the water level in Deep Hollow Lake can rise high enough to back water onto the fields upstream of UL1 and UL2, which influence runoff measurement. Soil information was obtained from the USDA-NRCS area office in Greenwood, Mississippi. Field operation information has been recorded since October 1996. The operation management of cotton and soybeans for 1999 is illustrated in Table 1.

Input file preparation

Based on the measured topography, watershed and sub-watershed boundaries were delineated using TOPAGNPS and AGFLOW. For each cell, physical information such as cell area, length and slopes were generated by AGFLOW. Soil and land use maps were used with the sub-watershed map to produce the predominant soil and land use assigned to each sub-watershed.

The SCS curve number (CN) is a key factor in obtaining accurate prediction of runoff and sediment yields. Curve numbers were selected based on the *National Engineering Handbook*, Section 4 (Soil Conservation Service (SCS), 1985). CN's used in the model simulation are listed in Table 2. The CN for row-crop-poor condition is used for cotton and soybeans when crops are growing; CN for fallow with residue is used when crop is harvested and winter wheat has not yet been planted; and CN for small grain is used during the winter wheat growing period.

Operation information is important to accurately determine sediment yield. Therefore, the operation management information was developed with as much detail as possible, especially concerning soil disturbance or land cover changes. Operation and operation reference information for the watershed were set up for each field based on RUSLE guidelines and databases.

The Greenwood climate station was the nearest climate station to the Deep Hollow Watershed and was used to generate the climate information with GEM. Generated precipitation was replaced by monitored precipitation at the rain gage in order to compare the simulated with observed runoff and sediment yield.

Monthly runoff and sediment yield listed in Table 3 do not include all runoff and sediment yield that occurred in the watershed. Although it was attempted to collect samples for every storm event, some storm events were not sampled due to unforeseen circumstances such as equipment malfunction. Therefore, a comparison between model prediction and observation was made only when monitoring data were available. Estimated runoff and sediment yield from the monitoring stations for non-sampled events were not used to enable a better analysis of the capabilities of the model simulations. Therefore, reported rainfall in Table 3 only reflects the amount of rainfall associated with monitored data. Input parameters used for the simulations were not calibrated for the watershed. For ungaged watersheds, there would normally not be data available to perform calibrations and this analysis reflects the capability of AnnAGNPS to perform under these conditions. AnnAGNPS has been developed to include processes that incorporate input parameters from databases developed by NRCS for any location in the U.S. This reduces the effort users would need to acquire the needed information to apply AnnAGNPS and reduces the need for calibration.

RESULTS AND DISCUSSION

Predicted versus observed runoff

Monthly rainfall, and predicted and observed runoff are shown in Table 3. AnnAGNPS predicted runoff over a three-year period (1997-1999) was 85% of the observed total runoff. Predicted and observed runoff events were plotted in Figure 2. The observed runoff for all of the largest four rainfall events (Figure 2) was greater than the predicted runoff. The monthly average rainfall, predicted runoff, and observed runoff for the 3-year period were plotted in Figure 3. The AnnAGNPS under predicted runoff every month but May, October and November. Except for times during April, May, October and November, fields were covered either by cotton (soybean) or winter wheat which reduce runoff and sediment yield.

Predicted versus observed sediment yield

The AnnAGNPS predicted sediment yield over a three-year period (1997-1999) was 116% of the observed total sediment yield (Table 3). AnnAGNPS prediction of sediment yield by events, Figure 4, showed that the measured sediment yield was overestimated for the four largest events. Because of the high sediment yield in winter, riser boards were put at the monitoring flume after the crop was harvested to enhance sediment deposition before the runoff entered the lake. This could account for less monitored sediment yield during that period.

The predicted and observed monthly average sediment yields plotted in Figure 5 revealed the variation of sediment loss throughout a year. Sediment yield is greater in December and January because of more rainfall in the winter months. In addition, some disturbance of soil due to subsoiling does occur in the fall in the cotton fields prior to the December through January rainfall. High sediment yield was both predicted and observed in May even though there was not as much runoff as in December and January (Figure 3). In May, there is some minimal disturbance of soil during planting in the cotton fields thus causing higher sediment yield (table 1).

The use of RUSLE and the parameters associated with determining soil loss are meant to be used as long-term estimates. For this reason, comparison of individual events may not agree as well as long-term annual values. Runoff amounts do not affect the soil loss results directly, since rainfall amounts are what are used in RUSLE to determine an erosion index value for each storm. This is because RUSLE uses this rainfall and runoff factor in the calculation of soil loss and is only determined when AnnAGNPS predicts runoff occurring for an event. Since RUSLE produces gross soil losses, AnnAGNPS contains processes to determine the amount of deposition in the field before entering a stream system, which provides the sediment yield leaving a field.

The accuracy of the model prediction depends on how well a user can describe the watershed characteristics. Runoff prediction is very sensitive to curve number selection; sediment prediction is sensitive to operation parameters such as tillage, residue and crop cover. Therefore, a significant effort is needed in input data collection and preparation. For model validation purposes, accurate monitoring data and their interpretation are essential in validating a model.

SUMMARY

The AnnAGNPS pollutant loading model was used in predicting runoff and sediment yield from a monitored sub-watershed of Deep Hollow Watershed. Predictions were compared with observations in order to test AnnAGNPS. Test results showed that AnnAGNPS adequately predicts long-term monthly and annual runoff and sediment yield and can show the impact of BMP's. The simulation of individual events did not produce results as good as annual values since many of the model's parameters were derived from long term average annual estimates. In evaluating the effects of BMP's within a watershed, long-term results are needed to determine the influence of the local climatic patterns.

The model tended to under-predict runoff. The model also tended to over predict sediment yield, which may be due in part to the effects of impoundments at the monitoring flume during the winter months, causing deposition. Without considering the impoundment effect on sediment, AnnAGNPS provides a conservative estimate of sediment yield.

For this study, input parameters were not calibrated for the watershed. Simulated results may be further improved by calibrating the input parameters. However, the model was suitable for evaluation of long-term monthly and annual runoff and sediment yield. Therefore, the model is recommended for ungaged watershed simulation of runoff and sediment yield.

ACKNOWLEDGEMENTS

The authors would like to acknowledge the contribution of the MDMSEA project committee in funding and data collection support. The authors also wish to thank Richard Rebich for his runoff and sediment monitoring information, Vance Justice for his help in model simulation, and Dr. Seth Dabney for his technical guidance on RUSLE parameter selection.

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Table 1. Operation sequence for cotton and soybean fields on Deep Hollow Watershed.

FIELD	DATE	ACTION	MATERIALS	AMOUNT
Cotton	4-1-99	Winter wheat Burndown (plane)	Roundup Ultra	1 qt/acre
	4-30-99	Fertilize	NSol	91.4 lbs/acre
	5-9-99	Do-all , plant, and chemical application (1/4 % surfactant). 20" band	BXN 47 Stoneville Gramaxone	11 lbs/acre 20 oz/acre
	6-11-99	Chemical application in middles (hooded sprayer)	Roundup Ultra	1 qt/acre
	7-1-99	Broadcast over top	Staple buctril	8 oz/acre 1 pt/acre
	9-20-99	Defoliation		
	10-15-99	Harvest		
	10-29-99	Wheat		100 lb/acre
Soybean	4-1-99	Winter wheat Burndown (plane)	Roundup Ultra	1 qt/acre
	5-28-99	Do-all , plant, and chemical application	Asgro RR Command	50 lbs/acre 1.33 pt/ acre
	7-1-99	Spray over top	Roundup Ultra	1.5 pt/acre
	9-28-99	Harvest		
	10-11-99	Wheat wheat		100 lb/acre

Table 2. Selected SCS curve numbers for Deep Hollow Watershed.

Land Cover Class	Curve Number			
	Hydrologic soil group			
	A	B	C	D
Cotton_Straight_Row_Poor	72	81	88	91
Soybean_Straight_Row_Poor	72	81	88	91
Small_Grain_Straight_Row+Crop_Res._Poor	64	75	83	86
Fallow_+_Crop_Residue_Poor	76	85	90	93

Table 3. Monthly observed rainfall and predicted and observed runoff and sediment yield.

Year	Month	Rainfall (mm)	Runoff (mm)		Sediment Yield (Tons/ha)	
			Predicted	Observed	Predicted	Observed
1996	October	63.8	25.6	4.8	0.2	0.0
	November	122.4	49.5	27.4	0.2	0.1
	December	127.5	71.2	70.6	0.2	0.1
1997	January	182.1	101.4	129.5	0.2	0.7
	February	81.8	45.8	70.4	0.1	0.2
	March	0.0	0.0	0.0	0.0	0.0
	April	102.9	26.3	30.9	0.1	0.2
	May	152.4	25.1	2.1	0.6	1.1
	June	130.3	31.4	37.6	0.4	1.2
	July	41.1	3.1	4.1	0.1	0.1
	August	0.0	0.0	0.0	0.0	0.0
	September	0.0	0.0	0.0	0.0	0.0
	October	85.6	12.2	5.5	0.2	0.1
	November	56.4	16.6	13.1	0.3	0.1
	December	133.3	43.9	56.8	0.4	0.7
1998	January	142.5	50.8	59.3	0.6	0.6
	February	97.5	15.7	36.5	0.2	0.5
	March	95.0	18.9	37.7	0.2	0.2
	April	130.8	48.9	72.6	0.5	0.5
	May	111.5	64.3	84.6	2.2	0.8
	June	31.0	7.8	12.3	0.3	0.3
	July	166.1	48.8	53.6	0.5	0.2
	August	0.0	0.0	0.0	0.0	0.0
	September	0.0	0.0	0.0	0.0	0.0
	October	27.2	0.0	0.0	0.0	0.0
	November	141.2	50.8	39.9	0.7	0.1
	December	205.2	134.4	155.0	1.6	0.5
1999	January	224.3	147.3	214.8	2.0	1.7
	February	50.0	8.1	7.2	0.0	0.0
	March	120.4	45.9	58.1	0.2	0.2
	April	110.0	47.5	65.4	0.3	0.2
	May	73.7	7.0	6.5	0.1	0.1
	June	29.8	2.2	0.0	0.0	0.0
	July	7.1	0.1	0.0	0.0	0.0
	August	0	0	0.0	0.0	0.0
	September	40.5	3.6	0.0	0.0	0.0
Three Year Total		3227.5	1172.9	1356.3	12.8	10.9
Regression			Y=1.2X	R^2=0.9	Y=0.62X R^2=0.4	

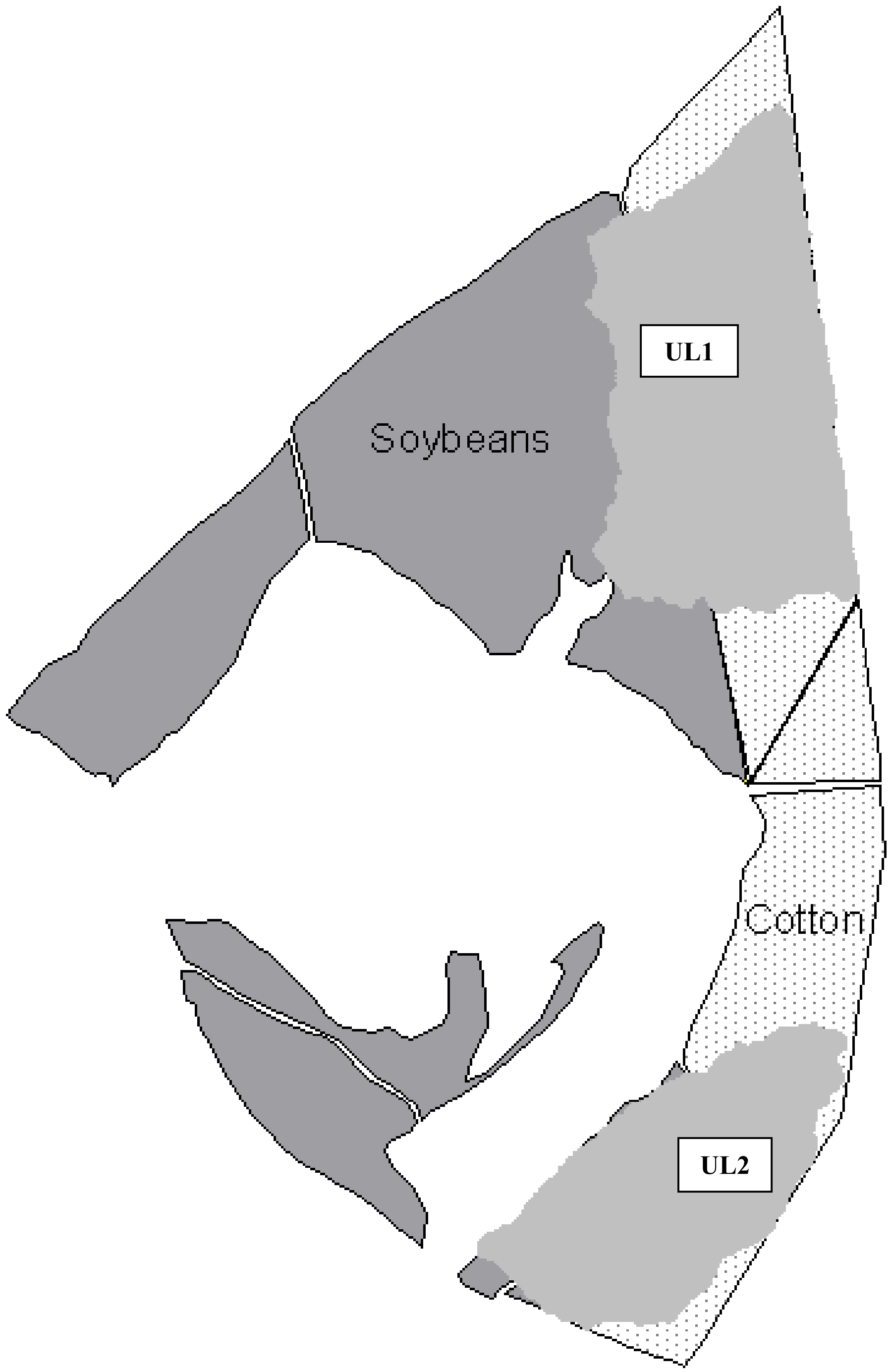

Figure 1. Deep Hollow watershed and monitoring flume drainage area's UL1 and UL2.

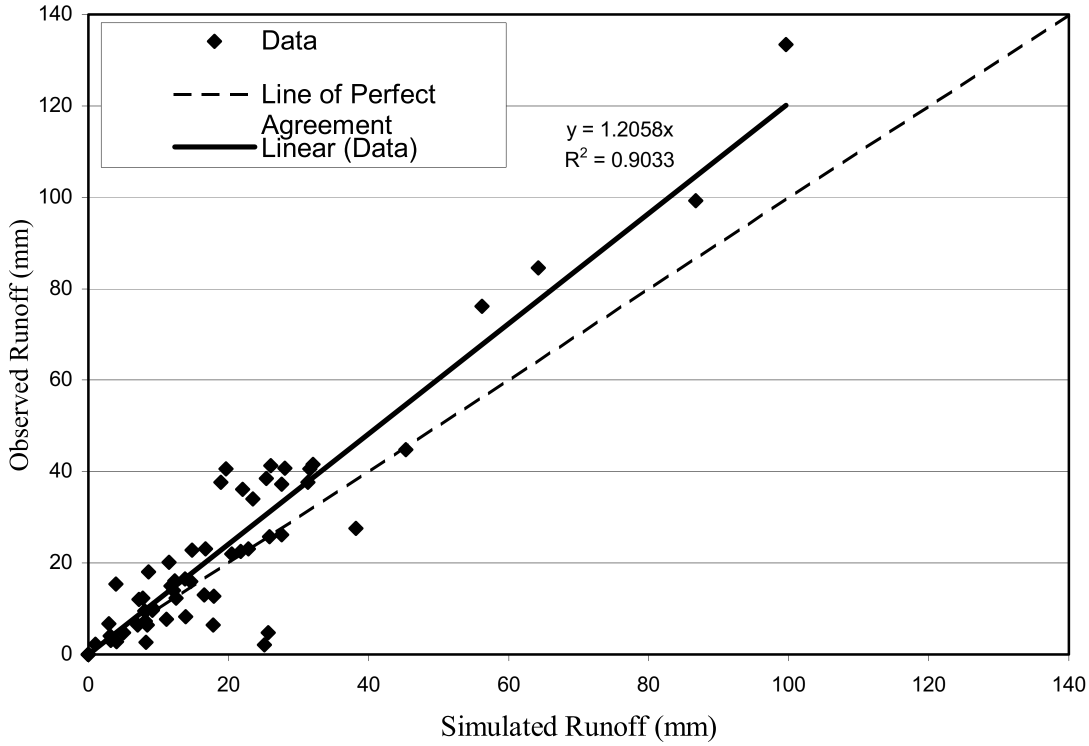

Figure 2. Comparison of observed and simulated runoff by event.

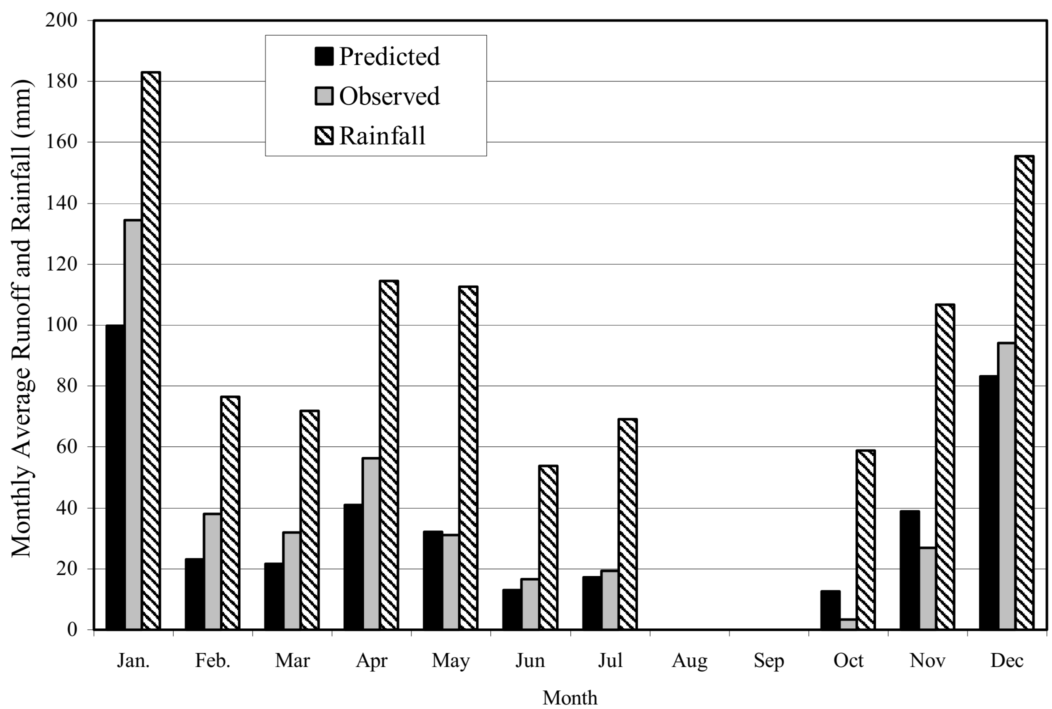

Figure 3. Comparison of monthly average predicted and observed runoff with associated rainfall.

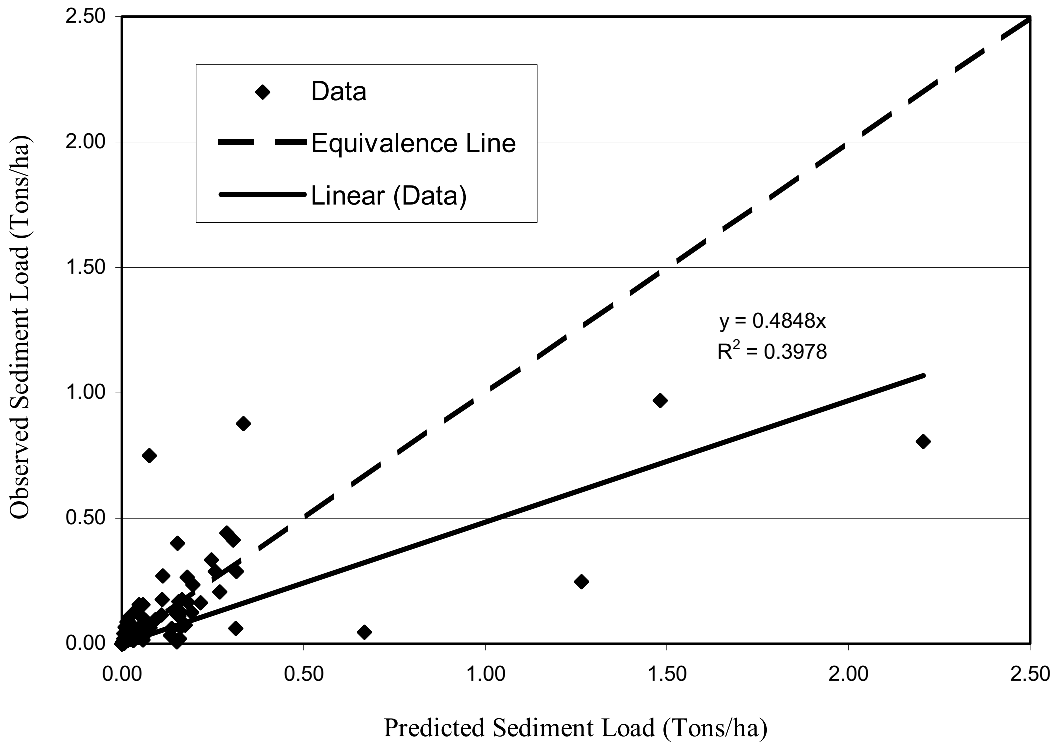

Figure 4. Comparison of observed and predicted sediment yield by event.

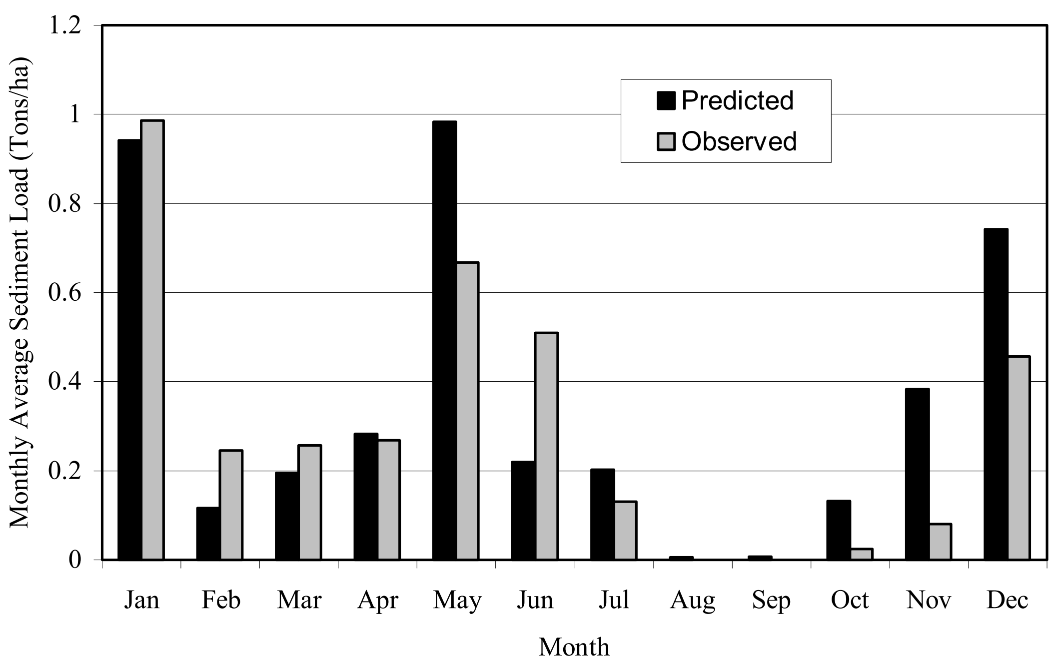

Figure 5. Comparison of predicted and observed monthly average sediment yield.

WEED SHIFTS IN DEEP HOLLOW WATERSHED, LEFLORE COUNTY, MS

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ABSTRACT

From 1995-1999, 467 plant species were detected in crop areas (cotton and soybean), grass filter strips, riparian areas, and in and around the oxbow lake at Deep Hollow (DH), Leflore County, MS. Of these, 195 species were present in cotton and soybean fields at DH, with 29 and 90 species in cotton and soybean exclusively, respectively. Weed shifts were detected in cotton and soybean over the four-year period. In reduced-till cotton and soybean where the hooded sensor-controlled sprayer was used, weed populations declined, with exception to several viney and woody species.

INTRODUCTION

About 8,000 species or 3% of all known plants are considered to be weeds in agriculture. Of these, about 200-250 species or less than 0.1% of the total, are recognized as major problems in world agriculture. Holm et al. (1977) estimated that about 200 species are involved worldwide in 95% of our agricultural weed problems. Of these, about 80 species are categorized as the primary or most troublesome species (Holmet al. 1977). In the U.S.A., about 70% of the most troublesome weeds of row crops originated somewhere else in the World (Bryson 1996).

Over 200 plant species have been recorded as weeds in cotton in the United States (Bryson et al. 1999). These cotton weeds belong to 43 plant families with 19% classified as monocots (Monocotyledonae) and 81% dicots (Dicotyledonae). Thirty to 40 species are important weeds throughout the U. S. Cotton Belt regardless of the tillage level (Bryson and Keeley 1992). The number of weedy species in soybean is slightly higher than in cotton. Soybeans are usually planted on a broader spectrum of soil types (e.g. sandy loam to heavier clay soils), with less seed bed preparation in the spring, and usually fewer tillage operations and herbicide applications (Bryson and Keeley 1992). Weed importance is not necessarily defined as to abundance within the crop and may vary with differing herbicide regimes (McWhorter and Bryson 1992). Some weeds may be very abundant in crops without causing interference, such as winter annuals that emerge, reproduce, and die too early to interfere with crop growth and yield. The most troublesome and important weeds are those that are difficult to control, compete effectively with crops for light, nutrients, water, and space (Radosevich and Holt 1984.), or interfere with harvest. Ultimately the most important weeds reduce economic returns to producers by interfering with crop growth, yield, harvest efficiency, and seed and fiber quality.

Research to develop new weed control technologies that reduce production costs and decrease environmental concerns is a high priority. Historically, postemergence weed control is applied over entire fields. One of the recent technology developments is a hooded sensor-controlled sprayer that can detect and spray weeds only where they occur between crop rows (Hanks and Beck 1998; Hanks and Bryson 1997; Hanks et al. 1998). Early research demonstrated that sensor sprayers were very effective in controlling weeds, thus eliminating the need for cultivation. Likewise, economic savings with the hooded sensor-controlled sprayer ranged from 63 to 85% when compared to conventional hooded spray systems with continuous application (Hanks and Beck 1998).

The Mississippi Delta Management Systems Evaluation Area (MSEA) is part of a national Agricultural Systems for Environmental Quality (ASEQ) program (Bryson and Hanks 1997; Locke 1997). ASEQ promotes cooperative research among federal, state, and local agencies to 1) develop alternative and innovative farming systems that improve water quality and ecology, 2) assess effects of management practices on soil and water quality, and 3) increase public awareness and promote adoption of these systems (Locke 1997).

The MSEA project was established in the fall of 1995 on three Mississippi Delta Region oxbow watersheds. These watersheds have varying degrees of crop management systems, ranging from conventional tillage production systems to reduced-tillage/cover crop systems with grass filter strips and slotted-board risers. One of these sites is Deep

Hollow (DH) northeast of Sidon, Leflore County, Mississippi. Of the three locations, DH watershed location receives the highest level of management, cultural, and structural practices.

The objective of our research was to establish a base-line list of plant species and weed populations levels at the initiation of the project and to determine weed shifts at DH as a result of the use of sensor-controlled hooded sprayer applications.

MATERIALS AND METHODS

Plant species data were determined by two methods. The first method of sampling was to record each species by habitat for crop areas (cotton and soybean), grass filter strips, riparian areas, and in and around the oxbow lake at DH. Plants were collected and vouchers were placed in the Southern Weed Science Research Unit Herbarium (SWSL) at Stoneville, MS. Data were recorded and updated following the addition of the discovery of species new to the area or within a given habitat.

In the second method, plants were counted in a 3 m long by 1 m wide area at geo-referenced points 62 m apart in reduced-tillage cotton (43 ha) and soybean (47 ha) fields in the DH watershed and in a conventional tillage cotton field (about 20 ha) adjacent to the DH watershed area. Base-line weed species data were gathered at grid points in 1996 on May 9, May 30-31, June 19, June 27, and July 12. In 1997-1999, data were gathered twice (mid to late June and early July) during each summer for each field, except on a third date in mid August, 1997 for one soybean field. In each year, data were gathered prior to canopy closure, thus the late sampling date in 1997 was due to late planted soybeans.

RESULTS AND DISCUSSION

From 1995 through 1999, 467 plant species were detected at DH, representing 94 families. These included six species of ferns (Pteridophyta); two species of conifers (Gymnospermae); and 461 species of flowering plants (Spermatophyta). Of flowering plants, 132 species in 14 families are monocots (including grasses, sedges, rushes, lilies, orchids, etc.); and 327 species in 74 families are dicots (broadleaf plants) (Figure 1).

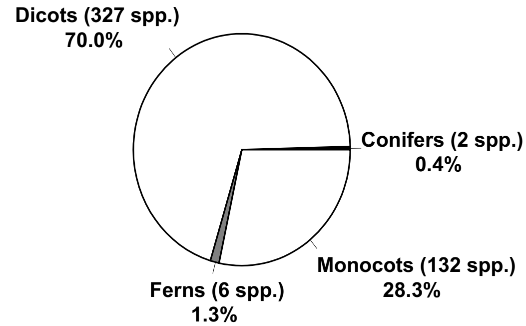

Figure 1. Plant species at the MSEA Deep Hollow, Leflore County, Mississippi separated by ferns (Pteridophyta), conifers (Gymnospermae); and flowering plants (Spermatophyta) (dicots and monocots).

A total of 195 species (58 monocots and 137 dicots) were present in cropland (cotton and soybean) at Deep Hollow (Figure 2); however, only 76 species (24 monocots and 52 dicots) were present in both cotton and soybean. In cropland areas, 29 species (2 monocots and 27 dicots) were detected in cotton exclusively, while 90 species (32 monocots and 58 dicots) were present in soybean exclusively. Thus, more plant species were detected in soybean (166 species) than in cotton (105 species). In cotton, 26 species were monocots and 79 were dicots, while in soybean, 56 species were monocots and 110 were dicots. Likewise, the number of species (25 including 9 monocots and 16 dicots) was greater on the edge of soybean fields than species (15 including 6 monocots and 9 dicots) on the edge of cotton fields. No conifers or fern species were found in crop areas.

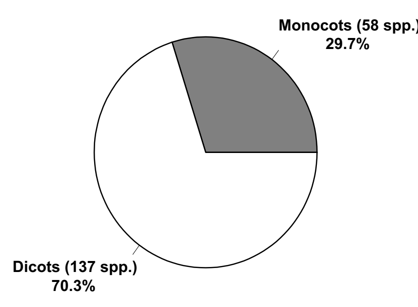

Figure 2. Plant species occurring in crops (cotton and soybean) at MSEA Deep Hollow, Leflore County, Mississippi.

Plants from the general surveys are classified into two distinct groups, 1) those that were weedy and 2) those that were of incidental occurrence. Sixty eight species or species groups (closely related species within the same genus) (17 monocots and 51 dicots or 52 annuals and 16 perennials) were present in at least one of the grid point sites in cropland areas (Figure 3).

Fewer plant species (annuals and perennials or monocots and dicots) and lower population levels by species were present in the conventional cotton than in reduced-tillage cotton and soybean areas. Six woody species were present in the reduced-tillage crop areas (cotton and/or soybean), but were absent from conventional tillage cotton (data not shown).

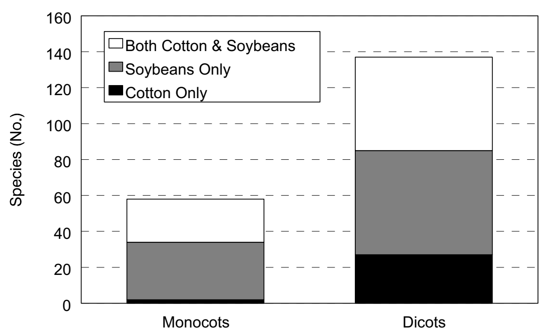

Figure 3. Plant species by monocots and dicots occuring in cotton, soybean, and both crops at MSEA Deep Hollow, Leflore County, Mississippi.

The 25 most common weeds (plants/ha) were as follows: southern crabgrass [*Digitaria ciliaris* (Retz.) Koel.], purple nutsedge (*Cyperus rotundus* L.), prickly sida (*Sida spinosa* L.), pitted morningglory (*Ipomoea lacunosa* L.), common chickweed [*Stellaria media* (L.) Vill.], cutleaf geranium (*Geranium disectum* L.), redvine [*Brunnichia ovata* (Walt.) Shinners], cutleaf eveningprimrose (*Oenothera laciniata* Hill), common purslane (*Portulaca oleracea* L.), curly dock (*Rumex crispus* L.), ivyleaf morningglory [*Ipomoea hederacea* (L.) Jacq.], carpetweed (*Mullogo verticillata* L.), horsenettle (*Solanum carolinense* L.), swinecress [*Coronopus didymus* (L.) Small], trumpetcreeper [*Campsis radicans* (L.) Seem. ex Bureau], spurges *Euphorbia* ssp. [including *E humistrata* Engelm. ex Gray, *E. hyssopifolia* L., *E. nutans* Lag., *E. maculata* L.], annual bluegrass (*Poa annua* L.), sibara [*Sibara virginica* (L.) Rollins], broadleaf signalgrass [*Brachiaria platyphylla* (Link.) A.S. Hitchc.], sicklepod *Senna obtusifolia* (L.) Irwin & Barneby (= *Cassia obtusifolia* L.), honeyvine milkweed [*Ampelamus albidus* (Nutt.) Britt.], and Johnsongrass [*Sorghum halepense* (L.) Pers.)].. Of the 25 most common species, six were perennials and 19 were annuals. Likewise, five species were monocots (three annuals and two perennial), while 20 species were dicots (17 annuals and 3 perennials). Four of the 20 species were winter annuals (one monocot and three dicots) that were detected prior to mid to late June in reduced-tillage areas. Winter annuals flowered, fruited, and died prior to mid season.

Weed population shifts were detected over the four-year period (1996-1999) within the DH watershed area. Total weed populations declined over the four-year period, regardless of the species group (Figure 4).

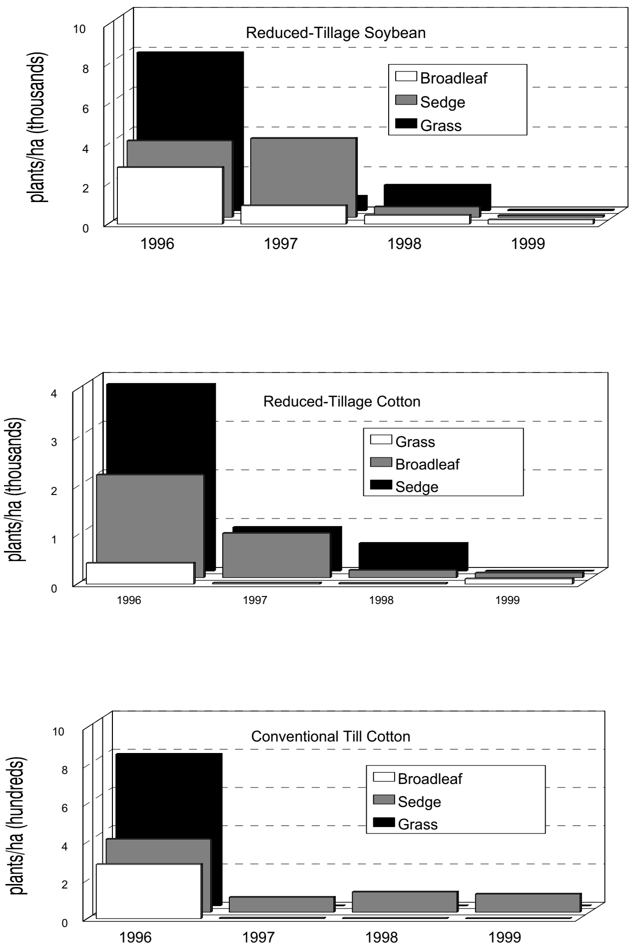

Figure 4. Weed population shifts (1996-1999) in reduced-till soybean, reduced-till cotton, and conventional till cotton at MSEA Deep Hollow, Leflore County, Mississippi.

Populations of most individual species declined over the four-year period (data not shown). Species groups presented herein are sedges and grasses (monocots) and broadleaf weeds (dicots). The reduction in the most troublesome weedy species such as crabgrass, bermudagrass, Johnsongrass, prickly sida, morningglory spp., nutsedge spp., etc. in reduced-tillage cotton and soybean over time may be due to the use of the hooded sensor-controlled sprayer.

One exception to reduction of weed populations was the appearance of several viney and woody species [e.g. poison ivy (*Rhus toxicodendron* L.), willow oak (*Quercus phellos* L.), sugarberry (Celtis laevigata Willd.), American sycamore (*Platanus occidentalis* L.), black willow (Salix nigra Marshall), persimmon (*Diospyros virginiana* L.), etc.] one to three years after initiation of reduced-tillage cropping systems in cotton and soybeans. Populations of each of these viney and woody species were greater in a no-till cotton area initiated in 1998 (data not shown). Additional data is needed to determine if this trend will continue over time and if several of the viney and/or woody species [e.g. redvine, trumpetcreeper, passionflower maypop (*Passiflora incarnata* L.) and those previously mentioned] will increase in the reduced-tillage crop areas at DH, regardless of the use of the hooded sensor-controlled sprayer.

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The authors would like to thank Mr. Philip Barbour for allowing the research to be conducted on his farm and Mr. Frank Gwin, Jr. for all of his support throughout this project and his dedication to MSEA. We also would like to express appreciation to Paige Goodlett, Terry Newton, Willie Reese, and Julia Rippee for their technical assistance and to John MacDonald and Randy Warren, graduate students at Mississippi State University, for their assistance in general field surveys.

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BT COTTON IN MISSISSIPPI DELTA MANAGEMENT SYSTEMS EVALUATION AREA INSECTICIDES IN RUNOFF, 1996-1999

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INTRODUCTION

Much attention has been given in the last decade to nonpoint source contamination of our Nation's water resources. Potential nonpoint source contaminants include sediment, nutrients, and pesticides in watersheds that drain from agricultural enterprises. Although impacts due to sediment and nutrients will probably outweigh impacts from pesticides, pesticides currently have been highly publicized. The concerns with pesticides have been on the potential impact to human health as well as the impact on aquatic and wildlife habitat.

Agricultural biotechnology, with its promise of high crop yields and dramatic reduction in pesticide use, has been touted as the way to feed the world's escalating population and reduce environmental damage from farming. Ever since the mid-1970s, when scientists found an easy way to copy genes and then transfer them to other species, the potential benefits to agriculture seemed extraordinary. It didn't take a visionary to see that corn engineered to produce more oil might have added value as animal feed or that soybeans packed with more protein might lead to a healthier human diet. Or that a cotton plant genetically engineered to produce its own pesticide could one day dramatically cut the volume of pesticides sprayed into the environment.

Patented by the U.S. company Monsanto, Bt (*Bacillus thuringiensis*) cotton is the first genetically modified plant for commercial release to resist tobacco budworms. Monsanto scientists discovered a way to insert an insecticidal protein derived from the bacterium *Bacillus thuringiensis*, into a cotton strain. The cotton industry believes the plant will help reduce pesticide use. Timely applications of pyrethroid pesticides to control the tobacco budworm would be adverted and eliminated with the Bt cotton. While there is some concern that worms will become resistant to Bt cotton, Monsanto is working on additional genetic alterations that will delay worm resistance. Moreover, producers now have another family of chemical insecticides, e.g. Tracer, which will provide another layer of protection against the worms. If the Bt cotton resulted in Bt-resistant worms, the crop could be sprayed with only one application of Tracer that would take out all of the Bt- resistant worms.

Current use insecticides account for 20 to 30 percent of all pesticides used in cotton. Most of the current-use insecticides include organophosphates (such as malathion, parathion, dimethoate) or carbamates (such as aldicarb and carbofuran). The newest group of insecticides, the synthetic pyrethroid compounds, includes such products as esfenvalerate, cyfluthrin, and cyhalothrin. Synthetic pyrethroids are only slightly toxic to birds and mammals, but are highly toxic to fish and other aquatic animals. The Bt cotton would require less of these chemicals for budworm control. Detection of these chemicals in runoff from the Bt cotton sites should be less frequent resulting in enhanced water quality entering adjacent streams and lakes.

One of the most intensive agricultural areas of the United States is the Mississippi River Alluvial Plain in northwestern Mississippi, a 18,130-square-km (7,000-square-mile) area. The hot, humid conditions during the long growing season in the Mississippi Delta increase the frequency and dependency of pesticide use, especially on cotton that is highly sensitive to intense insect and weed pressures. Concern exists for potential off-site movement of these compounds during runoff events, due to the amounts of pesticides used in the Mississippi Delta along with the fact that the region is characterized with high regional rainfall [about 1524 mm (60 inches) per year], low slopes, and slightly permeable soils.

The Delta Council, a regional economic development organization, in 1996 requested research of water quality from Bt cotton grown in the Mississippi Delta due to the Bt cotton initial commercial release. As part of an ongoing research and demonstration effort called the Mississippi Delta Management Systems Evaluation Areas (MDMSEA) begun in 1994 to address the concerns of agricultural nonpoint source pollution in the Delta (Rebich *et al.*, 1995), water quality from runoff from Bt-cotton sub-watersheds was analyzed and compared to other non-Bt cotton sub-watersheds in the area. Oxbow lakes within the MDMSEA accumulate all runoff from the surrounding agricultural sub-watersheds that provides an opportunity to understand the impacts of pesticides throughout the ecosystem of the whole oxbow lake watershed.

The U.S. Department of Agriculture (USDA), Agricultural Research Service (ARS), Water Quality and Ecological Processes Research Unit (WQEPRU) of the National Sedimentation Laboratory, in Oxford, MS began operating an automated acquisition system in June 1996 to sample and measure storm runoff from Bt cotton and non-Bt cotton watersheds. Also that year, the USGS began cooperating with the USDA-ARS Soil and Water Research Unit, in Baton Rouge, LA, to provide samples from their automated streamflow and water-quality sampling network (Rebich, 1997) for the purpose of insecticide analyses. In 1998, more emphasis was placed on low-level analyses of pyrethroid insecticides, and additional samplers were installed in cooperation with the pyrethroid manufacturing industry (Pyrethroid Working Group) to ensure that samples would be collected for as many runoff events as possible. The purpose of this paper is to present the insecticide concentration data for runoff samples from the Bt-cotton sub-watersheds and compare to concentration data from the non-Bt sites for the MDMSEA project from 1996 through 1999.

METHODS AND PROCEDURES

Study Sites

The study involved the fields in Beasley Lake watershed in Sunflower County, MS that were grown to Bt cotton and the fields in the Deep Hollow watershed in Leflore County, MS that were grown to non-Bt cotton. Runoff from these watersheds was gauged by USGS (Southwick *et al.*, 2000). Due to not knowing what each cotton grower would plant in this four-year period, additional sites located in the Beasley Lake watershed were gauged for runoff and water quality measurements.

In 1996, these additional two fields, 4 ha (10 acres) and 4.85 ha (12 acres) in size, were selected and planted to Bt cotton denoted as A1 and non-Bt cotton denoted as A2, respectively. Their respective owner managed each field. In each field, runoff was routed through a 61-cm (24-in) culvert. Attached to each culvert was a 0.6-m (2-ft) H flume. A bubbler flowmeter was attached to each flume for flow and flow rate determinations. A composite water sampler was wired into the flowmeter and activated based on flow proportion of every 0.25-mm (0.01-inch) of runoff.

After the first year, the owner of the non-Bt cotton field, site A2, converted to another cropping system other than cotton. Therefore, to compare the insecticides in runoff from the Bt cotton site to non-BT cotton sites, the insecticide data from the USGS water-quality sampling network (Southwick *et al.*, 2000) involving runoff from non-Bt cotton fields in the Deep Hollow Lake watershed labeled UL1 and UL2 were used. UL1 and UL2 were gauging sites located at edge of field. Meanwhile the cotton growers in the Beasley watershed were accepting Bt cotton and most of the cotton fields in that watershed were converted to Bt cotton in 1996. Therefore, the runoff from USGS sites labeled BL1, BL4a, and BL4b (Southwick *et al*., 2000) were analyzed as Bt cotton fields throughout the study. BL1 was an edge-of-field site located in an open-channel ditch that was grassed and drained a large area of conventional-till cotton. BL4a and BL4b were located at the entrance of the riparian zone of Beasley Lake. Most of the eastern part of the watershed, which had mixed crops of conventional-till cotton, soybeans, rice, and corn, drained through BL4a and BL4b.

The pyrethroid insecticides lambda-cyhalothrin, cypermethrin, cyfluthrin, and deltamethrin and the organophosphate insecticides methyl parathion and azinphosmethyl were selected for this study due to their popularity and use among MDMSEA farmers.

Sample Collection and Analyses

The samples collected for this project were all flow-weighted composite samples from automated samplers installed at each site. Each of the samplers are stage-activated and deposit aliquots of water into sample containers each time a pre-determined amount of volume has passed the sampling point. Thus, each sample represents an average concentration of insecticides in the runoff water per storm. None of the samples are filtered prior to shipment. Quality assurance / quality control (QA/QC) measures were adopted to avoid possible contamination to the samples.

The USDA-ARS WQEPRU of the National Sedimentation Laboratory in Oxford, MS analyzed runoff samples for pesticides from the two runoff sites of A1 and A2 collected from 1996 through 1999 using methods described elsewhere (Smith, 2000; Smith *et al.*, 2000). The USDA-ARS Soil and Water Research Unit, in Baton Rouge, LA, analyzed stream samples for pesticides from USGS streamflow sites BL1, BL4a, BL4b, UL1, and UL2 from 1996 through 1997. As stated earlier, additional samplers were installed in 1998 to ensure that enough samples were collected for insecticide analyses, specifically pyrethroids. The ARS lab in Baton Rouge continued with analyses for the organophosphates; however, a contract lab, PTRL East, Inc., in Richmond, Kentucky, was used for pyrethroid analyses. The method for analyses of these pesticides by ARS in Baton Rouge, LA and the contract lab are given in Southwick *et al.* (2000).

RESULTS

Pyrethroids

Table 1 is a listing of the various dates of application of pyrethroids to cotton fields upstream of the various sampling sites in the Beasley and Deep Hollow watersheds. Even though deltamethrin was used in the non-Bt cotton fields at Deep Hollow watershed, it was not applied in the Beasley Lake watershed. Also, no pyrethroids were applied to the Bt cotton at site A1 in the first two years (1996 and 1997) of the study. The Bt cotton at the A1 site had only two application dates of one pyrethroid insecticide (one in 1998 and the other in 1999) as compared to a minimum of 2 and a maximum of 7 application dates of two pyrethroid insecticides in 1997 and 1998, respectively, during the four years on the other Bt cotton sites at Beasley Lake watershed. The non-Bt sites (UL1 and UL2) required a minimum of 4 and a maximum of 7 application dates of at least one up to four different pyrethroid insecticides during the study. All four pyrethroid insecticides were applied in 1999 at recommended levels to control the tobacco budworm and bollworm at the non-Bt cotton sites. From these application dates data, less pyrethroid insecticides was being used in the Bt cotton sites that would lead to less insecticides entering runoff and eventually into streams from areas having the Bt cotton.

Table 2 is a listing of the pyrethroid concentrations in the sample water that were collected from the A1 Bt cotton site, the three USGS Bt cotton streamflow sites, and the two USGS non-Bt cotton streamflow sites. In 1996 and 1997, no runoff samples were collected and analyzed in the five USGS sites. During 1996 and 1997 no pyrethroid insecticides were used in the Bt cotton at site A1 to control the tobacco budworm or the bollworm, and thus the six runoff events in 1996, the five runoff events in 1997, and the first six runoff events of 1998 had no pyrethroid insecticides.

The Bt cotton field at A1 had 30 runoff events from 1996 through 1999. In this four year period, only two applications of a pyrethroid insecticide were applied to help in control of the bollworm, the first application being cyfluthrin on July 10, 1998 during the third season of Bt cotton and the second application being cypermethrin on May 3, 1999 during the fourth growing season. Cyfluthrin was found in one runoff event at 25 ppt four days after application in 1998. The three other runoff events of 1998 and the nine runoff events of 1999 resulted in non-detectable amounts of cyfluthrin. No detectable amounts of cypermethrin were found in the seven runoff events of the 1999 season.

At the other Bt cotton sites (BL sites) in 1998, 8 samples were collected from April 28 to December 11 ranging from 110 to 343 days after application. No 1998 runoff sample contained pyrethroids above the detection limit. Runoff that occurs within one month of application has the best opportunity to contain measurable pyrethroid content due to the half-life of these pyrethroids being 30 days. During this season, no runoff events occurred less than one month after application at these sites.

In 1999, 16 samples were collected from the BL sites with Bt cotton from January 8 to May 31 and ranged from 5 to 313 days after application. There were a total of 4 detects of pyrethroids within the 1999 sampling period. On May 4, five days after application, the concentration of cypermethrin was 100 ppt at BL4a, which is the entrance of a large riparian area. For that same runoff event, no cypermethrin was detected at the other side of the riparian zone above the entrance to Beasley Lake. A lambda cyhalothrin concentration of 30 ppt was observed at the entrance (BL4A), and a concentration of 20 ppt was observed at the exit for the May 4-5 event as well. According to farm records, however, lambda cyhalothrin had not been applied at these sites since the previous growing season. Possible explanations for these two lambda cyhalothrin detections include: (1) false positive analyses, (2) a non-recorded application within one month of the runoff event, or (3) a misapplication of the chemical. On May 31, 13 days after a known application, lambda cyhalothrin was detected again at BL4a at a concentration of 20 ppt. In all cases of detection, the concentrations were lower than toxic levels for aquatic species such as bluegill where the lethal concentration (LC_{50}) is 210 ppt (EXTOXNET, 1999). The fact that detections occurred at some sites and not others for runoff events shortly after application could verify the theory that sediment was elevated at some locations but not others. For instance, the detections that occurred in 1999 were at the BL4a site in the Beasley watershed that was located at the entrance of a riparian zone but drained a very large area of conventional-till row crops. This condition could result in high sediment-laden water entering the riparian area. Several other runoff events occurred in 1999 within one month of application that did not have detectable concentrations of pyrethroids. This supports the findings of others regarding the insecticide mitigating properties of riparian areas (Smith *et al.*, 2000). These non-detects occurred at locations such as the riparian exit in the Beasley watershed. Fairly low sediment loads could characterize the quality of the runoff water.

The non-Bt cotton sites also produced no detectable concentrations of pyrethroids even though more pyrethroid insecticides were applied as compared to the Bt-cotton sites. In 1997, the only runoff sample taken 3 days after application of cyfluthrin from the non-Bt cotton field at site UL1 had concentration less than the detection limit. In 1998, 20 samples were collected at the five USGS gauging sites previously described from April 27 to December 11 ranging from 8 to 343 days after application. No 1998 runoff sample from these USGS sites contained pyrethroids above the detection limit from either the Bt cotton nor the non-Bt cotton fields. Runoff that occurs within 1 month of application has the best opportunity to contain measurable pyrethroid content. During the 1998 season, there were only two runoff events that occurred less than one month after application. Both of these events were at the UL1 site, which has conservation tillage non-Bt cotton. The runoff event that occurred on May 28 was eight days after application of lambda cyhalothrin and 20 days after cypermethrin application. The June 15 runoff event occurred 26 days after application of lambda cyhalothrin and only 3 days after the second application of cypermethrin. Since pyrethroids exhibit low water solubility's [less than 0.01 mg L^{-1} (10 ppb)] and adhere to the soil particles, these compounds were expected to travel in runoff absorbed to suspended-sediment. The failure to detect the applied compounds within the first month, especially within the first 2 weeks of application, can imply that low levels of sediment characterized these runoff events. Other explanations for the lack of detection of these chemicals include higher than expected degradation rates and low application rates of approximately 42 gms per hectare (.037 lbs per acre) of each active ingredient.

<u>Organophosphates</u>
Table 1 is also a listing of the application dates of methyl parathion and azinphosmethyl in the Beasley and Deep Hollow watersheds for 1996 through 1999. Methyl parathion is used in both the Bt and non-Bt cotton fields to control the boll weevil, since the Bt cotton does not control the boll weevil. By eradicating the weevil from the area, no methyl parathion would be required. This would eliminate many application dates of this insecticide as seen in Table 1.

Table 3 is a listing of the concentrations of these two organophosphate insecticides in runoff samples collected during the study. Both application and runoff data were not available for the non-Bt cotton sites in 1999. Ten runoff events occurred after application of methyl parathion in 1996 ranging from 11 to 108 days after application. Six runoff events ranging from 3 to 275 days, 21 runoff events from 1 to 238 days, and nine runoff events ranging from 6 to 323 days after application of methyl parathion occurred during 1997, 1998, and 1999, respectively. In all cases except one, methyl parathion was insignificantly detected in extremely low amounts (<0.2 ppb). The one exception produced a detection of 2.671 ppb after 323 days of application. Possible explanations for this methyl parathion detection were false positive analyses, a non-recorded application within five days of the runoff event, or a misapplication of the chemical. The likely reason for no detection of methyl parathion in all runoff samples was probably due to the chemical's short soil half-life of 5 days and an even shorter half-life on cotton leaves of 0.1 day (Southwick *et al.*, 2000), thus degrading rapidly before being mobilized during a runoff event.

Five runoff events occurred after application of azinphosmethyl in 1998 ranging from 109 to 136 days after application and two runoff events ranging from 15 to 147 days application in 1999. There were no detections of azinphosmethyl in these samples from either Bt or non-Bt cotton sites. The soil half-life of azinphosmethyl is reported to be 10 days (Southwick *et al.*, 2000). Therefore, it is likely that azinphosmethyl degraded prior to these runoff events.

SUMMARY AND CONCLUSIONS

The U.S.D.A. Agricultural Research Service, Water Quality Ecology Research Unit of the National Sedimentation Laboratory, in Oxford, MS, at the request of the Delta Council in 1996 began operating an automated acquisition system to sample and measure insecticides in storm runoff from Bt (*Bacillus thuringiensis*) cotton and non-Bt cotton fields. Also in 1996, the USGS began cooperating with the USDA-ARS Soil and Water Research Unit, in Baton Rouge, LA, to provide samples from their automated streamflow and water-quality sampling network for the purpose of insecticide analyses. The insecticide analyses included pyrethroid and organophosphate insecticides based on the popularity and use of both throughout the Mississippi Delta in cotton-producing areas. In 1998, more emphasis was placed on low-level analyses of pyrethroid insecticides, and additional samplers were installed in cooperation with industry (Pyrethroid Working Group) to ensure that samples would be collected for as many runoff events as possible. The purpose of this paper was to present the insecticide concentration data for runoff samples from the Bt-cotton fields and compare to concentration data from non-Bt cotton sites within the Mississippi Delta Management Systems Evaluation project from 1996 through 1999.

Agricultural biotechnology, with its promise of high crop yields and dramatic reduction in pesticide use, has been touted as the way to feed the world's escalating population and reduce environmental damage from farming. The use of a cotton plant genetically engineered, called Bt cotton, to produce its own insecticide reduced the volume of pyrethroid insecticides sprayed into the environment at the Beasley Lake Watershed. The reduced application dates and pyrethroid types on the Bt cotton sites as compared to the multiple applications of multiple pyrethroid insecticides on the non-Bt cotton sites to control the tobacco budworm and bollworm resulted in dramatic reduction of pesticides released into the environment. Even though the non-Bt cotton sites resulted in little to no detects of the pyrethroid pesticides, the Bt cotton site had even lower concentrations in the runoff. Also, insignificant detects were found with the organophosphate insecticides from either Bt or non-Bt cotton sites. No detrimental environmental effect from the applied pyrethroid and organophosphate insecticides was found from water samples of runoff from all tested sites within the Beasley Lake and Deep Hollow watersheds during this four year study. Other than economics or costs of the Bt cottonseed and reduced applications of insecticide for budworm and bollworm control in heavily infected areas as compared to the costs of non-Bt cottonseed, the insecticides used for budworm and bollworm protection, and their multiple applications, there is little negative environment effect from either type of cottonseed.

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Table 1. Applications of pyrethroid in 1996-1999 and organophosphate in 1996-1998 at Beasley sites.
[------, no insecticides applied; *****, runoff samplers not installed]

	Pyrethroid				Organophosphate	
Site	**λ-Cyhalothrin**	**Cypermethrin**	**Cyfluthrin**	**Deltamethrin**	**Methyl Parathion**	**Azinphosmethyl**
			1996			
A1		------	------	------	Jun 3; Jul 25; Aug 3	------
BL1	Jun 12; Jul 11, 17, 25; Aug 17	------	------	------	Jun 5, 12; Jul 7, 11, 20; Aug 31	------
BL4a	*****	*****	*****	*****	*****	*****
BL4b	*****	*****	*****	*****	*****	*****
UL1	May 24; Jul 15	May 3	Jun 1	------	Jun 8; Jul 10, 15, 22	------
UL2	May 24; Jul 15	May 3	Jun 1	------	Jun 8; Jul 10, 15, 22	------
			1997			
A1	------	------	------	------	Jun 28; Jul 7, 10, 16, 22	------
BL1	Aug 21; Sep 1	------	Jun 17, 21, 24; Jul 2	------	Jun 4, 10; Jul 2, 15, 21; Aug 6; Sept 3, 12	------
BL4a	Jul 19	------	Jun 20	------	Jun 14, 16, 28; Jul 7, 10, 16, 22	------
BL4b	------	------	------	------	------	------
UL1	Aug 3,16	Jul 20	Jul 10	------	Jun 3, 11, 24	------
UL2	Aug 3,16	Jul 20	Jul 10	------	Jun 3, 11, 24	------
			1998			
A1	------	------	Jul 10	------	Jun 1, 3, 9, 12, 17, 26; Jul 30; Aug 3, 11	Jul 28
BL1	------	------	------	------	------	------
BL4a	Jun 17, 26	------	Jun 1; Jul 10, 15, 22, 27	------	Jun 1, 3, 9, 17, 26; Jul 30; Aug 3, 4, 10, 11	Jul 28
BL4b	------	------	------	------	------	------
UL1	May 20; Jul 1, 7	May 8; Jun 3; Aug 1	------	Aug 11	Sept 3	------
UL2	May 20; Jul 1, 7	May 8; Jun 8; Aug 1	------	Aug 11	Sept 3	------
			1999			
A1	------	May 3	------	------	Jul 5, 30	July 11, 26
BL1	Jul 8; Aug 13	May 9	------	------		
BL4a	May 18	Apr 29	------	------		
BL4b	May 13, 21; Jul 12	------	------	------		
UL1	May 30; Jun 15; Jul 31; Aug 14	May 11; Aug 14	Jun 9; Jul 17; Aug 14	Jul 24		
UL2	Jun 15; Jul 31; Aug 14	May 9; Aug 14	Jun 9; Jul 17; Aug 14	Jul 24		

The data for all BL and UL sites were taken from Southwick *et al*., 2000.

Table 2. Concentration of pyrethroids in runoff from Beasley watersheds, 1996-1999.
[ppt, parts per trillion; DAA, days after application; [a], USDA data; [b], PTRL East, Inc., data]

Site	Runoff event date	λ-Cyhalothrin ppt (DAA)	Cypermethrin ppt (DAA)	Cyfluthrin ppt (DAA)	Deltamethrin ppt (DAA)
		1996 [a]			
UL1	Aug 2		< 400 (91)	< 600 (30)	
UL2	Oct 25		< 400 (175)	< 600 (114)	
UL2	Nov 1		< 400 (182)	< 600 (121)	
UL2	Nov 7		< 400 (188)	< 600 (127)	
		1997 [a]			
UL1	Jul 13			< 600 (3)	
		1998 [b]			
A1	Jul 14			25 (4)	
A1	Jul 23			<10 (13)	
A1	Dec 18			<10 (161)	
A1	Dec 30			<10 (173)	
BL1	Apr 28	< 50 (240)		< 125 (300)	
BL4a	May 28	< 50 (313)		< 125 (342)	
BL4a	Nov 14	< 50 (141)		< 125 (110)	
BL4a	Nov 20	< 50 (147)		< 125 (116)	
BL4a	Dec 10	< 50 (167)		< 125 (136)	
BL4a	Dec 11	< 50 (168)		< 125 (137)	
UL1	Apr 27	< 50 (254	< 125 (281)	< 125 (291)	
UL1	May 28	< 50 (8)	< 125 (20)	< 125 (322)	
UL1	Jun 15	< 50 (26)	< 125 (12)	< 125 (340)	
UL1	Nov 14	< 50 (130)	< 125 (105)		< 125 (95)
UL1	Nov 20	< 50 (136)	< 125 (111)		< 125 (101)
UL1	Dec 7	< 50 (153)	< 125 (128)		< 125 (118)
UL1	Dec 10	< 50 (156)	< 125 (131)		< 125 (121)
UL1	Dec 11	< 50 (157)	< 125 (132)		< 125 (122)
UL2	Apr 28	< 50 (255)	< 125 (282)	< 125 (292)	
UL2	Apr 30	< 50 (257)	< 125 (284)	< 125 (294)	
UL2	Nov 14	< 50 (130)	< 125 (105)		< 125 (95)
UL2	Dec 7	< 50 (153)	< 125 (128)		< 125 (118)
UL2	Dec 11	< 50 (157)	< 125 (132)		< 125 (122)
		1999 [b]			
A1	May 11		< 10 (8)		
A1	June 1		< 10 (21)		
A1	June 16		< 10 (36)		
A1	June 30		< 10 (50)		
A1	Jul 12		< 10 (62)		
A1	Aug 10		< 10 (99)		
A1	Dec 20		< 10 (231)		
BL1	May 31		< 10 (22)		
BL1	Jun 2		< 10 (24)		
BL4a	Jan 8	< 50 (196)		< 125 (165)	
BL4a	Mar 2	< 10 (249)		< 10 (218)	
BL4a	Mar 13	< 10 (260)		< 10 (229)	
BL4a	Apr 3	< 10 (281)		< 10 (250)	

Table 2. Concentration of pyrethroids in runoff from Beasley watersheds, 1996-1999.
continued
[ppt, parts per trillion; DAA, days after application; [a] , USDA data; [b] , PTRL East, Inc., data]

Site	Runoff event date	λ-Cyhalothrin ppt (DAA)	Cypermethrin ppt (DAA)	Cyfluthrin ppt (DAA)	Deltamethrin ppt (DAA)
BL4a	Apr 5	< 10 (283)		< 10 (252)	
BL4a	Apr 14	< 10 (292)		< 10 (261)	
BL4a	May 4	30 (312)	100 (5)	< 10 (281)	
BL4a	May 31	20 (13)	< 10 (32)		
UL1	Jan 8	< 50 (185)	< 125 (160)		< 125 (150)
UL1	Mar 2	< 10 (238)	< 10 (213)		< 10 (203)
UL1	Mar 13	< 10 (249)	< 10 (224)		< 10 (214)
UL1	Apr 3	< 10 (270)	< 10 (245)		< 10 (235)
UL1	Apr 14	< 10 (281)	< 10 (256)		< 10 (246)
UL1	Jul 14	< 10 (29)	< 10 (65)	< 10 (26)	
UL1	Jul 21	< 10 (36)	< 10 (71)	< 10 (4)	
UL1	Aug 7	< 10 (7)	< 10 (88)	< 10 (21)	< 10 (14)
UL2	Jan 8	< 50 (185)	< 125 (160)		< 125 (150)
UL2	Mar 12	< 10 (248)	< 10 (223)		< 10 (213)
UL2	Apr 3	< 10 (270)	< 10 (245)		< 10 (235)
UL2	Apr 14	< 10 (281)	< 10 (256)		< 10 (246)
UL2	Jul 15	< 10 (30)	< 10 (66)	< 10 (27)	
UL2	Aug 7	< 10 (7)	< 10 (90)	< 10 (21)	< 10 (14)

The data for all BL and UL sites were taken from Southwick *et al*., 2000.

Table 3. Concentration of organophosphate insecticides in runoff from Beasley watershed, 1996-99

[ppb, parts per billion; DAA, days after application]

Site	Runoff event date	Methyl Parathion ppb (DAA)	Azinphosmethyl ppb (DAA)
		1996	
A1	15-Jul	<0.025 (42)	
A1	19-Jul	<0.025 (46)	
A1	17-Sep	<0.025 (45)	
A1	30-Sep	<0.025 (58)	
A1	24-Oct	<0.025 (81)	
A1	29-Oct	<0.025 (86)	
UL1	02-Aug	< 0.2 (11)	
UL2	25-Oct5	< 0.2 (95)	
UL2	01-Nov	< 0.2 (102)	
UL2	07-Nov	< 0.2 (108)	
		1997	
A1	23-Jan	<0.025 (173)	
A1	19-Mar	<0.025 (228)	
A1	05-May	<0.025 (275)	
A1	11-Aug	<0.025 (20)	
A1	17-Oct	<0.025 (87)	
BL1	09-Aug	< 0.2 (3)	

Table 3. Concentration of organophosphate insecticides in runoff from Beasley watershed, 1996-99. *continued*

[ppb, parts per billion; DAA, days after application]

Site	Runoff event date	Methyl Parathion ppb (DAA)	Azinphosmethyl ppb (DAA)
		1998	
A1	27-Feb	<0.025 (220)	
A1	10-Mar	<0.025 (231)	
A1	18-Mar	<0.025 (238)	
A1	02-Jun	<0.025 (1)	
A1	22-Jun	<0.025 (5)	
A1	06-Jul	0.083 (14)	
A1	14-Jul	0.029 (4)	
A1	23-Jul	0.074 (13)	
A1	18-Dec	<0.025 (129)	
A1	30-Dec	<0.025 (143)	
BL4a	14-Nov	< 0.2 (95)	< 0.5 (109)
BL4a	10-Dec	< 0.2 (121)	< 0.5 (135)
BL4a	11-Dec	< 0.2 (122)	< 0.5 (136)
UL1	14-Nov	< 0.2 (72)	
UL1	20-Nov	< 0.2 (78)	
UL1	07-Dec	< 0.2 (95)	
UL1	10-Dec	< 0.2 (98)	
UL1	11-Dec	< 0.2 (99)	
UL2	14-Nov	< 0.2 (72)	
UL2	07-Dec	< 0.2 (95)	
UL2	11-Dec	< 0.2 (99)	
		1999	
A1	6-Apr	<0.025 (238)	
A1	20-Apr	<0.025 (252)	
A1	11-May	<0.025 (273)	
A1	1-Jun	<0.025 (294)	
A1	16-Jun	<0.025 (309)	
A1	30-Jun	2.671 (323)	
A1	12-Jul	<0.025 (6)	
A1	10-Aug	<0.025 (11)	
A1	20-Dec	<0.025 (143)	

The data for all BL and UL sites were taken from Southwick *et al*., 2000.

SPATIAL RELATIONSHIPS AMONG SOIL PROPERTIES AND WEED POPULATIONS IN BEASLEY LAKE WATERSHED

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Detail of soil characteristics is essential in implementing precision farming technology. The objective of this study was to describe spatial variability of soil properties and weed populations in a 40 ha area in Beasley Lake watershed, part of the Mississippi Delta MSEA project. This will provide a database for use in precision application of agrichemicals. Surface soil samples were collected in a grid pattern prior to planting cotton (*Gossypium hirsutum*) in 1996. Soil was characterized for organic carbon (OC), pH, texture, and microbial activity. Herbicides fluometuron and metolachlor were banded over the crop row at planting. Weed counts were taken six weeks after herbicide application. Spatial variability of soil properties and weed populations was described using geostatistics. Total weeds, pH, OC and texture semivariograms were described well with linear and spherical models. Range of spatial dependence typically exceeded 120 m. Soil microbiological activity and weeds controlled by pre-emergence herbicides exhibited only limited spatial dependence. Weed densities were greater in areas with higher OC and finer texture. Areas of low OC and sandier soil often had fewer weeds. Thus, more uniform weed control might be achieved by varying preemergence herbicide application rate. Acceptable weed control might be achieved with lower herbicide application rates in certain areas.

INTRODUCTION

Precision agriculture is increasingly being utilized to reduce inputs of soil-applied agricultural chemicals, thereby lowering costs to producers and minimizing environmental impacts. These practices may require more detail and certainty about spatial variability of soils than currently provided by soil surveys. Although the Mississippi Delta is one of the most important agricultural regions of the country, data on the spatial variability of its soils are limited. As part of the Mississippi Delta Management Systems Evaluation Area (MD-MSEA) project, studies were conducted to characterize spatial distribution of soil properties in areas under cotton production. This paper describes a portion of those evaluations. More detailed consideration of results from this study are presented elsewhere (Gaston et al., 2000).

Our studies are the first to examine the field-scale spatial variability of these alluvial soils using geostatistical methods and to show that soil properties in the Mississippi Delta may be described in sufficient detail for use with simulation modeling or precision farming without prohibitive intensive sampling protocol. Objectives were to: (1) characterize spatial variability of soil properties that affect the fate of herbicides in the soil environment; and (2) determine relationships between the spatial variability of weed populations and soil properties.

MATERIALS AND METHODS

Study Site and Soil Sampling

One of three watershed sites included in the MDMSEA project is discussed in this paper – Beasley Lake. A 40-ha sub-area planted to cotton was assessed. Soil survey data (Soil Survey Staff, 1959) indicated that Dundee (fine-silty, mixed, thermic Typic Endoaqualfs), Forestdale (fine, smectitic, thermic Typic Endoaqualfs), Dowling (very-fine, smectitic, thermic Vertic Epiaquepts) and Alligator (very-fine, smectitic, thermic Alic Dystraquerts) are major soil series in the study sub-area. A 60 m by 60 m square grid was laid out, with column and row ends permanently marked and GPS coordinates recorded. Each grid node was the center of a 2 m x 2 m plot from which soil samples were taken from the upper 5 cm in April 1996.

Soil Analyses

Microbiological activity was measured by the rate of fluorescein diacetate hydrolysis (Schnüner and Rosswall, 1982) in field-moist samples. Soil pH (2:1, soil:0.01M $CaCl_2$), OC (Nelson and Sommers, 1982) and texture (hydrometer method; Gee and Bauder, 1986) were determined on air-dried, ground, sieved (< 2 mm) samples.

Agronomic Practices and Weed Counts

The Beasley site was conventionally tilled and irrigated. Weed management included initial burndown with glyphosate. Following re-bedding of rows, fluometuron and metolachlor were applied preemergence (1.7 and 1.1 kg ha^{-1}, respectively) in a 43 cm band at planting. Weed counts were taken six weeks following fluometuron and metolachlor application and prior to postemergence application of cyanazine and MSMA.

Weeds within a 1-m strip of the herbicide application band at the center of soil sampling areas were counted, identified and categorized as either controlled (good to excellent control; MCES, 1997) or not controlled (fair to no control) by fluometuron and metolachlor. Weed counts were taken in 1996 and 1997.

Statistical Analyses

Soil and weed data were analyzed by geostatistics and spatial variability quantified by linear or spherical semivariogram models (David, 1977). These models, together with experimental data, were used to estimate average values (David, 1977) for soil properties and weed densities in square 0.36 ha areas centered about each sampling grid node. Effects of soil properties on weed populations were examined with regressions and cross-semivariograms (David, 1977; Yeats and Warrick, 1987).

RESULTS AND DISCUSSION

Spatial Variability of Soil Properties

Means [variances] for soil properties are as follows: FDA activity 105 (44) nmol g^{-1} soil h^{-1}, pH 5.1 (1.7), OC 1.65% (0.34), clay 30% (16), sand 16% (10).

Except for FDA activity, semivariograms of soil properties showed spatial dependence that could best be described using spherical models. Zero-range (nugget) semivariances for pH and OC accounted for a large portion of maximum semivariance (sill). Thus, appreciable short-range variability could not be described at the sample spacing used. However, spatial dependence (sill minus nugget) extended to about 240 m. In contrast, there was little short-range variability for clay and sand. Spherical models for pH, OC, clay and sand semivariances were used to generate block-kriged maps of these properties. Kriged maps are shown in Figure 1.

Figure 1a shows a band of relatively high soil pH running diagonally across the study area, coincident with three long, broad depression areas. Relatively high clay (Fig. 1c) and low sand (Fig. 1d) contents occurred in the depressions. Highest sand content was found closest to Lake Beasley, on an old natural levee (Fig. 1d, top). OC distribution (Fig. 1b) does not follow topography as clearly as does pH (Fig. 1a), but comparison of areas high in OC to areas high in clay (Fig. 1c) shows the expected relationship.

Spatial Variability of Weed Populations

Weeds were grouped into those controlled by herbicide programs and those not controlled (MCES, 1997). Ten species were identified, and half of these were found in both years. Total weeds were greater in 1997 than in 1996, and densities of herbicide-controlled weeds were greater in 1997. Nevertheless, overall weed densities were low, reflecting adequate weed control by the grower.

Semivariograms for normalized weeds in 1996 and 1997 show large nugget semivariances and weak spatial structure that was adequately described by linear models. Figure 2 shows kriged estimates of total weeds in 1996 (1997 data not shown). Distribution of total weeds in 1996 shows good spatial relationships to both areas of higher pH (Fig. 1a) and clay content (Fig. 1c).

Relationships between Weed Populations and Soil Properties

The regressions of weed data on soil properties are given in Table 1. Populations of total and controlled weeds were positively correlated with clay and OC content in 1996. Controlled weeds were positively related to clay and OC in 1997.

A relationship between weeds susceptible to herbicide control and relatively high levels of OC in the soil may be expected. Efficacy of a pre-emergence herbicide requires plant uptake but potential uptake of most herbicides is reduced by sorption on organic matter (Locke et al., 1998). The basis for a positive relationship between total weeds and clay content lies in more available water and higher fertility associated with finer, compared to coarser, textured soil.

Weeds increased with increasing OC and clay (Fig. 3). The density of total and controlled weeds where clay was > 30 % was significantly greater ($p < 0.05$) than where clay was < 30 %. Similar trends were seen for OC.

Weed data may also be used to examine the potential for increased uniformity of control and / or reduced herbicide application if the application rates were varied with soil properties. Higher weed densities where clay and OC were high suggest that greater uniformity of weed control might be achieved by a higher rate of herbicide application. Average clay content where weeds occurred in both 1996 and 1997 was significantly greater than where weeds did not occur both years (39 % and 29 %, $p < 0.01$). OC was higher in areas where weeds reoccurred (1.96 % versus 1.63 %, $p < 0.01$). Thus, there was an apparent tendency for weeds to reoccur where clay or OC was relatively high, indicating localized weed persistence and the need for more aggressive control strategies.

Increased uniformity of weed control by using higher rates of herbicide increases production costs and the potential for off-site herbicide movement. Weed control at this study site was good and acceptable even where soil properties apparently limited herbicide efficacy. Therefore, if acceptable control was achieved at less than locally optimal application rates, then in locations where soil properties are less prone to limit herbicide efficacy, lower rates of application might achieve adequate weed control. More than 60 % of those areas were weed-free. Nearly 80 % of the areas contained only weeds that were tolerant to the herbicide application. Such a high level of complete weed control may not be economically justified. There was a nearly linear relationship between increasing frequency of weed-free plots and decreasing soil OC and clay. The average clay content of plots with no weeds in 1996 and 1997 was significantly less than that of plots with weeds at least one year (27 % and 34 %, $p < 0.01$). OC in the weed-free plots was also lower (1.57 % versus 1.77 %, $p < 0.05$).

CONCLUSIONS

Variability of pH, OC, clay, sand, and weeds in the Beasley watershed exhibited spatial dependence that could be well-described using semivariogram models. In general, OC and clay content were positively related to densities of total weeds. These relationships were less clear for weed species subject to herbicide control. However, weeds tended to reoccur in areas where clay and OC were relatively high, indicating persistence related to soil properties. On the other hand, relatively coarse textured areas were commonly weed-free for two years. These observations suggest that greater uniformity of weed control might be achieved by using a variable rate of herbicide application. Also, acceptable weed control might be achieved at a reduced rate of application in sandy, low OC areas.

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Table 1. R values for linear regression of total and controlled weeds on soil properties.

Weeds	Soil Property	1996	1997
Total	OC	0.28*	0.18
	Clay	0.49**	0.14
Controlled	OC	0.27*	0.26*
	Clay	0.43**	0.29*

*Denotes model significance at $p < 0.05$
**Denotes significance at $p < 0.01$.

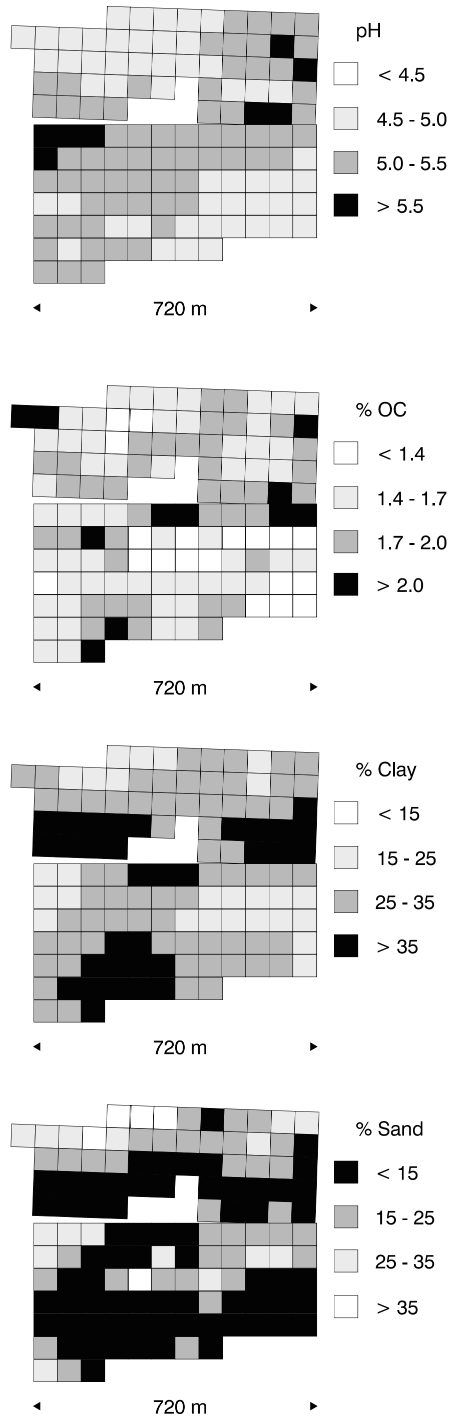

Figure 1. Block kriged estimates of (a) pH; (b) OC; (c) clay, and (d) sand (reprinted with permission of Soil Science Society of America Journal).

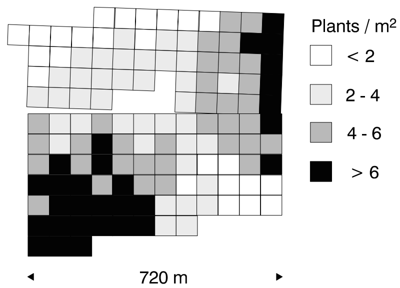

Figure 2. Block-kriged estimates of weed populations in 1996 (reprinted with permission of Soil Science Society of America Journal).

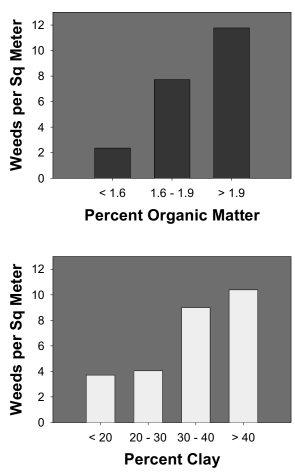

Figure 3. Effect of (a) organic carbon, and (b) clay on weed populations (reprinted with permission of Soil Science Society of America Journal).

SOCIOLOGICAL FACTORS INFLUENCING ADOPTION OF BEST MANAGEMENT PRACTICES IN THE MISSISSIPPI DELTA

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ABSTRACT

This study used a mail survey to collect information from Mississippi Delta farmers. Farmers indicated their use of best management practices (BMP's) in their farming operations and provided information about their farm operations and their opinions regarding various farm issues. The goal of the study was to find out what kinds of farm characteristics and farmer opinions were related to using BMP's. Among other findings, the results indicated that BMP's use was more likely to occur on larger farms and farms next to oxbow lakes. In addition, farmers who rely on agencies such as the Mississippi Cooperative Extension Service, Mississippi Soil and Water Conservation Commission, Natural Resource Conservation Service, YMD Joint Water Management District and local soil and water conservation districts used more BMP's. These agencies can play an important role in expanding the use of BMP's on Mississippi farms and thereby improving water quality.

INTRODUCTION

The Mississippi Delta Management Systems Evaluation Area (MDMSEA) is an area with water quality issues related to nonpoint-source pollution associated with intensive agricultural production (Cooper and Lipe 1992). Innovative practices in agricultural production can reduce nonpoint-source pollution. Interdisciplinary research has been initiated to identify and develop best management practices (BMP's) for agriculture to enhance the water quality of the Delta's numerous oxbow lakes. BMP's include practices such as reduced tillage and crop rotations as well as structural practices such as grade stabilization, sediment control basins and slotted board risers. Water quality can be improved in the region as more farmers commit to using BMP's.

Farm operator adoption of BMP's is essential to improving water quality throughout the region. Thus, there is a need to understand factors that might enhance the adoption process. Adoption and diffusion models are typically based on economic measures and traits, but, research suggests that other factors may influence the process, particularly when concerned with water quality issues (Rogers and Shoemaker 1971; Christensen and Norris 1983; van Es 1983; Heffernan 1984; Rikoon and Heffernan 1989; Bouwer 1990; Rikoon 1991; Vogel 1996). Although social scientists have included water quality issues as part of broader natural resource studies (e.g., Lovejoy and Napier 1986; Nowak 1984), there has been a lack of attention to social factors associated with adopting agricultural practices that improve water quality (Buttel and Swanson 1986; SCS 1989). This research examines sociological factors related to farm operators adopting new agricultural practices to improve water quality.

Factors related to BMP use are investigated by examining farmers and farm characteristics. Data include personal characteristics of farm operators, their attitudes, and their farm characteristics. Discussion of the findings is situated in a broader discussion of the social, cultural, political, and economic environment in which farmers operate.

METHODS

A sample frame of 2,509 individuals was created by aggregating a list of farm operators reported by each county agent in the Core Delta counties of Bolivar, Coahoma, Humphreys, Issaquena, Leflore, Quitman, Sharkey, Sunflower, Tallahatchie, Tunica, and Washington (Myles and Reinschmiedt, 1992). Data were obtained from a questionnaire mailed to a sample of farm operators in the Core Delta. A random sample of 950 individuals was selected, but 145 were deleted because the person had never farmed, were retired from farming or were deceased. The total number of completed surveys was 351 out of 805 (43.6%).

The survey was developed in consultation with members of The Delta Council, Mississippi Farm Bureau, Mississippi Cooperative Extension Service, the MDMSEA Technical Steering Committee and a small group of farmers. The survey contained the following sections: farm operation characteristics, awareness and use of BMP's, evaluation of information sources, attitudes, and socio-demographic characteristics.

ANALYSIS

The analytic framework was based on determining factors related to higher adoption rates of BMP's. An innovation index was developed to serve as the dependent variable. Independent variables were derived from the other sections of the survey.

The Index of Innovation

Level of innovation was measured by an index developed from a list of 25 BMP's (Table 1). For each BMP, farm operators indicated if they had ever used it (scored as 1 if yes and 0 if no). Because crop-specific questions were not applicable to all respondents, the use of "transgenic" crops were grouped to create a single item in the index. Respondents were assigned a value of 1 if they had used at least one type of transgenic crop and 0 if they had not used any. The index consisted of 22 items with a possible range of 0 to 22 and a reliability of .81.

Independent Variables

Independent variables included farm characteristics, farm operators' demographic characteristics, and social characteristics of farm operators. Farm characteristics included farm size, total farm sales, and adjacency of land to an oxbow lake, river, and/or stream. Farm size was measured in terms of total acres farmed while farm sales consisted of eight categories ranging from less than $5,000 to over $500,000. Adjacency of farmland to bodies of water was measured as yes (1) or no (0). Demographic characteristics included race, gender, education and marital status. Race was measured as white or nonwhite, gender was measured as male or female, and marital status was measured as married or non-married. Education was measured as an ordinal variable consisting of three categories: high school or less, some college, and college degree or more.

Attitude scales were constructed from a variety of items that covered topics such as influence of information, support for soil conservation, barriers to BMP adoption, attitudes toward government regulation of agrichemicals, environmental concern, and outdoor recreation behaviors. An influence of information scale measured the combined influence of eight sources of information concerning conservation practices. Sources consisted of farm consultants, farm magazines, other farmers, and various agencies involved with farm issues (e.g., Mississippi Cooperative Extension Service, Mississippi Soil and Water Conservation Commission). The score for each item ranged from 1 (no influence) to 4 (high influence) creating a scale range of 8 to 32. The Chronbach's alpha for scale reliability was .84. A soil conservation scale was constructed from eight items measuring how important various factors were in promoting conservation practices. Each item ranged from 1 (not at all important) to 9 (extremely important). The scale ranged from 8 to 72 and had a reliability of .93. A scale measuring attitudes toward BMP adoption was developed from nine items covering potential barriers to implementing practices. Items were measured from "strongly agree" to "strongly disagree" with higher scores indicating less perceived barriers. The range of the scale was 9 to 36 and the reliability was .91. Factor analysis was used to measure attitudes toward agrichemical regulation and concern for chemical use. Agrichemical regulation focused on views toward banning pesticides if government agencies find them contaminating drinking water or causing harm to humans. Higher factor scores indicated agreement that dangerous pesticides should be banned and the reliability of the scale was .70. Concern for chemical use focused on how serious a problem pesticide and fertilizer use was in Mississippi. Higher factor scores indicated greater concern for chemical use problems and the reliability of the scale was .83. Finally, an outdoor recreational activity scale was developed from of the summed scores of responses to four questions regarding participation in hunting and fishing activities in the Mississippi Delta. A score of 1 was assigned for each response of yes and a score of 0 was assigned for each response of no. The scale ranged from 0 to 4 with a Chronbach's alpha of .86.

STATISTICAL ANALYSIS

Initial analysis focused on the relationship between the innovation index and characteristics of farmers and their farms. Characteristics measured as dichotomous variables were testing by a Mann-Whitney U test. Results indicated that operators whose land was adjacent to bodies of water used significantly more innovations than operators whose land was not adjacent to water. Indeed, the highest mean score for innovation (11) was observed for farmers with land adjacent to oxbow lakes. Examination of the relationship between innovation and demographic characteristics indicated significantly higher levels of innovation for whites and males. However, the low number of non whites (16) and females (6) in the sample decreases the relevance of these characteristics in further analysis.

Characteristics of farmers and farms measured in a contiguous manner were analyzed with Pearson's Correlation Coefficient (Table 2). Results indicated that farm sales and farm size were most strongly correlated with innovativeness. These were followed by influence of information sources and education.

Regression Analysis

Drawing upon results of the non-parametric tests and correlation analysis, a series of regression models were developed to further investigate variables that were significantly related to the index of innovation. Models were developed for three sets of characteristics: farm; demographic; and social (Table 3). For each set, an initial model consisting of variables previously found to be statistically associated with the innovation index was run using the "enter" method. Variables found not to be significant in the initial model were dropped to create a reduced model.

Results indicated that farm characteristics accounted for almost 25% of the variance in the innovation index. Demographic characteristics explained about 10% and attitudinal characteristics explained approximately 20% of the variance. Important farm characteristic variables included adjacency of farmland to an oxbow lake and stream/creek, farm sales and farm size. Education was positively associated with innovation while age was negatively associated. Important social characteristics included influence of information, attitudes toward adoption of BMP's and toward government regulations and participation outdoor recreation activities. With the exception of attitudes toward government regulation, all social characteristics were positively associated with the innovation index.

The second step of regression analysis consisted of block regression (Table 4). Block regression indicates how much variance is explained by the addition of a set of variables to the overall regression equation. Beginning with the farm characteristic model that explained almost 25% of the variance, demographic variables were added (Model II). This resulted in an increase of 2% in the explained variance in the innovation index. Next, the social characteristics were added (Model III) resulting in a 6% increase in variance explained and an overall explanation of one-third of the variance in the innovation index. The addition of the blocks of variables caused some variables to lose their statistical significance. In particular, both demographic variables became insignificant as did farm size. A final reduced model was run to include those variables significant at the .10 level or less. The final model explained almost 33% of the variance.

DISCUSSION

Results of the analysis indicate that social characteristics play an important role in the adoption of best management practices in the Mississippi Delta. As a group, they explained almost 20% of the variance in level of innovation and contributed an additional 8% to the variance explained by farm characteristics. Of particular importance is the role of information sources. Agencies such as the Mississippi Cooperative Extension Service, Mississippi Soil and Water Conservation Commission, Natural Resource Conservation Service, YMD Joint Water Management District and local soil and water conservation districts have been successful in encouraging farm operators to adopt BMP's. However, these entities need to continue their efforts to expand adoption of BMP's. Positive attitudes toward BMP's are important for adopting BMP's and information source can play an important part in shaping these positive attitudes. At the same time, it is important to recognize that most MDMSEA farm operators are committed to using agrichemicals in their operations. There was a significant negative relationship between support for government bans of dangerous chemicals and use of BMP's. This may indicate that farm operators see agrichemicals as an integral part of their BMP program and/or they do not trust the federal government to make such decisions.

It is encouraging to observe that farmers with farmland adjacent to oxbow lakes and streams/creeks are using significantly more BMP's than those without similar land characteristics. However, since water quality problems continue to exist, more needs to be done to improve adoption of BMP's within entire watersheds. Certainly economic factors such as farm sales are important in this endeavor as BMP's often require significant capital investments. However, programs that build upon social as well as economic factors must be developed to improve success of BMP adoption and thereby improve water quality in the MDMSEA.

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Table 1: Mississippi Delta Farm Operators Who Have Ever Used Particular Best Management Practices

Practice	Used Practice	
	n	%
Cover Cropping	159	48%
Filter or Buffer Strips	70	21%
Slotted Board Risers	163	49%
Grass Waterways	65	20%
Sediment & Water Retention Basins	55	17%
Riparian/Wetland Zones	29	9%
Land Formed Fields	234	70%
Deep Tillage	276	84%
No Tillage	198	60%
Minimum Tillage Stale Seedbed	244	74%
Custom Application of Fertilizers	287	85%
Custom Application of Pesticides	288	86%
Custom Application of Lime	225	68%
Variable Rate Fertilization	72	22%
Variable Rate Liming	44	14%
Variable Rate Pesticide Application	65	20%
Yield Monitoring for Precision Agriculture	42	13%
Hooded Sprayers	76	23%
Integrated Pest Management	100	31%
Baculovirus	10	3%
Transgenic Cotton	153	47%
Transgenic Soybeans	141	43%
Transgenic Corn	13	4%
Transgenic Rice	10	3%
Low-Input Farming	68	22%

Table 2: Correlation Matrix*

	Innovation Scale	Farm Size	Farm Sales	Ed.	Age	Info Scal e	Soil Con.	Adopt Barrier	Chem. Concern	Gov. Reg.	Outdoor Rec. Scale
Innovation	— —	.344	.348	.290	-.220	.329	.151	.280	-.116	-.281	.231
Farm Size	.000	—	.418	.206	-.092	.210	.075	.149	-.104	-.131	.160
Farm Sales	..000	.000	—	.251	-.183	.136	.041	.084	-.216	-.207	.122
Education	.000	.000	.000	—	-.319	.216	.096	.281	-.068	-.309	.192
Age	.000	.087	.001	.000	—	-.194	-.095	-.186	.065	.180	-.398
Info Scale	.000	.000	.012	.000	.000	—	.560	.522	-.083	-.064	.252
Soil Con.	.004	.165	.446	.073	.077	.000	—	.463	-.035	.002	.225
Adoption Barriers	.000	.006	.120	.000	.000	.000	.000	—	-.083	-.124	.223
Chemical Concern	.029	.054	.000	.205	.221	.121	.516	.120	—	.290	-.093
Government Regulation	.000	.015	.000	.000	.001	.233	.970	.020	.000	—	-.130
Outdoor Rec. Scale	.000	.003	.023	.000	.000	.000	.000	.000	.081	.014	— —

- Numbers above the diagonal are correlation coefficients. Numbers below the diagonal are significance levels.

Table 3: Initial Regression Analysis of Variables Related to Adoption of Best Management Practices Among Mississippi Delta Farmers

	Model I		Reduced Model	
	Beta	Sig.	Beta	Sig.
Farm Characteristics				
Land adjacent to a stream or creek	.234	.000	.235	.000
Total farm sales	.224	.000	.223	.000
Land adjacent to an oxbow lake	.200	.000	.204	.000
Total acres farmed	.125	.000	.136	.012
Land adjacent to a river	.044	.374		
R^2	**.244**		**.244**	
Demographic Characteristics				
Education	.250	.000	.250	.000
Age	-.136	.010	-.136	.010
R^2	**.094**		**.094**	
Social Characteristics				
Influence of information sources	.260	.000	.227	.000
Attitudes toward government regulations	-.231	.000	-.239	.000
Attitudes toward adoption of BMP's	.125	.035	.114	.025
Outdoor recreation activities in MS Delta	.119	.020	.106	.063
Attitudes toward soil conservation	-.079	.192		
Concern about agrichemical use	-.009	.860		
R^2	**.188**		**.189**	

Table 4: Block Regression Analysis for Variables Related to Adoption of Best Management Practices Among Mississippi Delta Farmers.

Variables	Model I Beta	Model I Sig.	Model II Beta	Model II Sig.	Model III Beta	Model III Sig.	Reduced Model Beta	Reduced Model Sig.
Farm Characteristics								
Land adjacent to a stream or creek	.235	.000	.215	.000	.171	.000	.188	.000
Total farm sales	.223	.000	.189	.000	.178	.000	.211	.000
Land adjacent to an oxbow lake	.204	.000	.193	.000	.187	.000	.207	.000
Total acres farmed	.136	.012	.120	.026	.082	.116		
Demographic Characteristics								
Education			.121	.017	.053	.299		
Age			-.095	.050	-.024	.632		
Attitudinal Characteristics								
Influence of information sources					.137	.013	.154	.005
Attitudes toward government regulations					-.128	.008	-.147	.002
Attitudes toward adoption of BMP's					.116	.032	.121	.023
Outdoor recreation activities in MS Delta					.074	.134	.086	.067
R^2	**.244**		**.267**		**.328**		**.323**	

MISSISSIPPI DELTA MSEA PROJECT - PROJECT COORDINATOR OVERVIEW REPORT

Frank Gwin, MDMSEA Project Coordinator

This paper chronicles the history of the Mississippi Delta MSEA project. Watershed size, crops, agency and farmer involvement, and scientific research programs are listed.

INTRODUCTION

In the early 1990's the MSEA program was begun, primarily in the Mid-West. Originally there were seven studies. The plan was to study watersheds along streams and drainage basins in farming areas. USDA-ARS, USDI-USGS and MSWRRI saw the need for a study in the Mississippi Delta. They contacted the Mississippi Farm Bureau and the Delta Council for support.

The Delta is unique. Before the Mississippi River and its tributaries were contained within levees, in times of flood they meandered back and forth across the flood plain, leaving numerous oxbow lakes. These oxbow lakes have watersheds which drain into them that contain farmland and wooded areas ready-made for this type of study. There are more than 1500 of these lakes in the Mississippi Delta, varying in size anywhere from 15-20 acres to as much as 300 acres or more.

MDMSEA HISTORY

The plan for the Mississippi Delta MSEA project was to seek state and federal funding to study three of these lakes, their watersheds, and the farming practices used on them. One of the lakes would be studied allowing the farm owners to continue the same practices they were previously using. On the watershed of the second lake would be installed pipes, pads, and slotted-board risers, along with grass filter strips on the edge of the fields. It would be farmed with conventional tillage practices. The third lake's watershed would, in addition to edge-of-field practices, also have Best Management Practices (BMP's) installed on the farm land. The results could then be seen in what happened in the lakes themselves.

A proposal was written for funding by each of the three agencies. A committee was formed. The watersheds of 100 lakes were examined, and eventually three were chosen.

Two of the three agencies were funded. Without one-third of the funds needed for the project, other ways were sought to continue the study. A total of fifteen agencies agreed to help. A Project Coordinator was hired.

The first year of the five year time frame was taken up with the selection of the watersheds, planning, and the securing of permission of the eleven farmers to allow this study on their farms. The second year was consumed in the installation of the edge-of-field practices, the Best Management Practices in the fields, and the setting up of the many monitoring stations in the lakes, riparian zones and fields. Baseline data also had to be collected. Year three could be considered the shakedown year, with final decisions being made on plan design and methodology, as well as getting the equipment operational. By year four everything was in place, and mountains of data were collected in years four and five.

The farmers agreed to allow access to their records of cultural practices, nutrient requirements and applications, pesticide records (application rates, methods, and dates of application), custom applicator records, entomology reports, and yields. The keys to the success of the project were the unselfish cooperation and participation of the farmers whose land was in the watersheds, the cooperation of the agencies involved (private, local, state, and federal), and the interest and acceptance of the people who were made aware of MDMSEA.

Farming practices studied were conventional tillage, minimum tillage, conservation tillage and no-till, subsoiling, winter cover crops, transgenic crops, gypsum application, weevil eradication, GPS and satellite mapping, use of a hooded sprayer with weed sensors, weed mapping and yield monitors. New grasses were installed in concentrated flow areas of filter strips. New winter cover crop materials were studied. Forty overfall pipes and thirteen slotted-board risers were installed on two of the three watersheds, and fifty-one more are planned for the third lake. Seventeen acres of filter strips are in place on the two lakes.

Thighman Lake has a watershed of 3700 acres, the Beasley Lake watershed contains 2113 acres, and the Deep Hollow watershed consists of 500 acres. During the entire course of the study the Deep Hollow watershed has had 107 acres of cotton, 127 acres of soybeans, and 266 acres of woods. The crop acreage on the Beasley watershed has varied each year (table 1). The woodland area on the Beasley watershed has remained at 800 acres throughout the entire period. The Thighman Lake watershed crop acreage also changed from year to year (table 2). The catfish pond acreage at Thighman watershed remained constant throughout the period at 220 acres, as did the woodlands at 200 acres.

The agencies who cooperated in the MDMSEA study were:

Lead Agencies

- USDA ARS Oxford, Stoneville, and Baton Rouge
- USDI USGS Pearl
- MSWRRI Starkville

Other Agencies

- Delta Council
- Mississippi Farm Bureau
- Delta Wildlife Partners
- YMD Water Management District
- Mississippi Delta Experiment Station and Extension Dept. (MAFES)
- Mississippi Department of Environmental Quality
- Mississippi Department of Wildlife, Fisheries and Parks
- Mississippi Commissioner of Agriculture
- Mississippi State University
- University of Mississippi
- Delta State University
- USDA Wildlife Services
- US Fish and Wildlife
- Soil and Water Conservation Commission
- USDA NRCS
- USDA FSA
- US Army Corps of Engineers
- Pyrethroid Working Group
- John Deere Plow Co.
- Caterpillar Corporation

Studies conducted by the scientists involved included:

Farming Practices

- Tillage
- Nutrient Application
- Subsoiling
- Weed Populations and Mapping
- Herbicide Applications
- Transgenic Crops
- Insecticide Studies
- Weevil Eradication
- Row Direction
- Cover Crops
- GPS and Satellite Mapping
- Irrigation Wells and the Alluvial Aquifer

Edge-of-Field

- Storm Event Sampling
- Shallow Ground Water Wells
- Filter Strips
- Overfall Pipes and Pads
- Overfall Pipes with Slotted-Board Risers
- Ditches with and without Vegetation
- Wetland Areas
- Constructed Wetlands
- Beaver Control
- Weather Stations
- Flood Control
- Soil Loss

Riparian Zones

- Wildlife Enhancement
- Installation of Clemson's for Beaver Control
- Erosion Control
- Sediment Absorption of Pesticides and Nutrients
- Soil Absorption of Pesticides and Nutrients
- Water Absorption of Pesticides and Nutrients
- Vegetation Absorption of Pesticides and Nutrients

Lakes

- Fish
  - Renovation and Corrective Stocking
  - Spawning
  - Growth Rate
- Water Quality Monitoring
- Core Sampling of Lake Bottom
- Microbiological Populations
- Degradation of Pesticides
- Macro invertebrates
- Zooplankton
- Dye Studies

In addition, 32 tours have been arranged with 757 participants. Among these have been scientists from Japan and Holland, representatives of US. Senators and Congressmen, the U S. Deputy Under-Secretary of Agriculture for Environmental Concerns, the Washington staff of ARS and EPA, the staff of the Mississippi Department of Environmental Quality, the Commissioner and Board of the Mississippi Department of Agriculture and Commerce, state and local personnel of the NRCS, the US. Army Corps of Engineers, USDI-USGS regional personnel, the Water Management District Board, high school teachers and students, and area farmers and civic leaders.

Other activities include representation in the following venues:

- Radio and TV
- Video Documentaries
- Newspaper and Magazine Articles
- Presentations at Local, State, and National Meetings
- Scientific Papers and Publications
- Schools
- Teachers
- Classes
- Students
- STRIDE Program
- Social Science Survey
- Economic Cost Study
- Modeling

Changes in agriculture affecting this study include the Freedom to Farm Act, low commodity prices, changes in crops grown, inability to afford some BMP's, inability to update and purchase equipment, less cotton being planted, and less expensive crops.

The TMDL emphasis by the EPA will lead to less intensive farming practices and the future necessity of BMP's.

Table 1. Crop acreage at Beasley Lake watershed for the study period

Year	Cotton	Rice	Soybeans	Corn	Milo
1995	1052	0	261	0	0
1996	1052	0	261	0	0
1997	761	0	462	90	0
1998	593	40	242	438	0
1999	951	0	235	0	127

Table 2. Crop acreage at Thighman Lake watershed for study period

Year	Cotton	Rice	Soybeans	Corn
1995	1572	0	1708	0
1996	1572	0	1708	0
1997	356	0	996.5	1927.5
1998	270	219	744.5	2047.5
1999	395	659	1251.6	974.4

EVALUATION OF A SENSOR-CONTROLLED HOODED SPRAYER IN THE MISSISSIPPI DELTA MANAGEMENT SYSTEMS EVALUATION AREA

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ABSTRACT

Results of this study indicate significant reduction in herbicide usage can be achieved with new intermittent spray technology. Preliminary results from other studies conducted in cotton and soybeans indicate there was no yield difference using traditional cultivation or the sensor-controlled sprayer. The sensor-controlled hooded sprayer should allow producers to reduce tillage, by eliminating cultivation, which should significantly reduce soil erosion.

INTRODUCTION

Environmental concerns associated with pesticide applications have increased tremendously over the past years, with a major concern being related to water quality. These concerns have prompted investigations to help identify effects of current agricultural practices, develop more efficient crop production management practices, and develop environmentally sound methods of applying pesticides.

The Mississippi Delta Management Systems Evaluation Area (MDMSEA) was organized as a consortium of several federal, state, and local agencies. The purpose of the project was to evaluate the impact of agricultural production around oxbow lakes and develop best management practices (BMP's) to minimize adverse affects agricultural production may have on the ecology of the lakes. The MDMSEA project consisted of three oxbow lake watersheds with agricultural production immediately surrounding the lakes. Water quality monitoring stations were installed at various locations on each lake. Slotted board risers and grass buffer strips were installed at Beasley and Deep Hollow watersheds. Deep Hollow production practices were changed to conservation tillage with a winter cover crop and new application technology to reduce herbicide inputs was utilized. Thighman Lake watershed served as the control, therefore no BMP's were installed, only water monitoring stations.

Across the U.S. Cotton Belt, weeds in cotton cause annual losses of $188 million in yield reduction (Chandler and Cooke 1992). These significant losses in crop yield due to interference of weed have prompted producers to apply tremendous amounts of herbicide annually. Traditionally, herbicides are applied at a single rate over the entire field although weeds are normally not evenly distributed over an entire field but occur sporadically (Mortensen et al. 1993; Navas 1991; Thornton et al. 1990; Van Groenendael 1988). Although the concept of applying herbicide over an entire field has provided adequate weed control, significant amounts of herbicide are wasted and the excess herbicide increases the potential environmental contamination. Selectively applying herbicide only where weeds are present could result in significant reductions in herbicide usage and cost of production for the grower (Hanks and Beck 1998; Felton et al. 1991; Felton and McCloy 1992; Guyer et al. 1986; Haggar et al. 1983; Shearer and Jones 1991).

Studies presented herein were conducted in the Deep Hollow Lake watershed as part of the MDMSEA project to evaluate sensor-controlled intermittent spray technology as a method reducing herbicide usage for conservation-tillage production practices in the watershed.

MATERIALS AND METHODS

Studies were conducted during 1996, 1997 and 1998 to evaluate sensor-controlled spray technology on 43 ha of cotton and 47 ha of soybeans, producer grown in the Deep Hollow Lake watershed of the MDMSEA project. Crops were planted in rows spaced 1 m apart and grown under conservation tillage practices, with cultivation eliminated to minimize erosion and herbicide movement.

Figure 1. An 8-row sensor-controlled hooded sprayer applying herbicide only where weeds are present in soybeans.

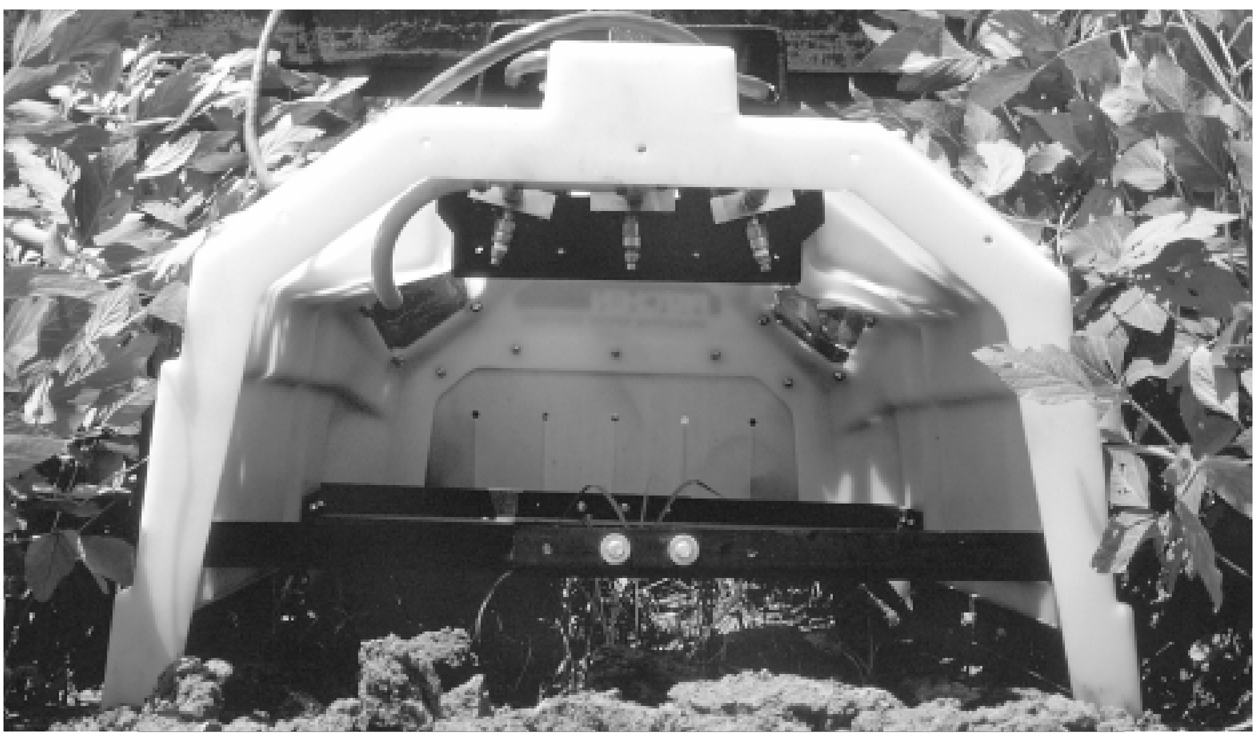

Figure 2. Sensor-controlled hooded sprayer in soybeans with three independently controlled weed detection sensor.

An 8-row hooded sprayer (Fig. 1) consisting of seven 0.7 m-wide hoods with three plant sensors and two 0.5 m-wide hoods with two plant sensors were used for weed control between the crop rows. During 1996 and 1997, WeedSeeker™ Model PhD 612 plant sensors were used, whereas in 1998 new experimental plant sensors were evaluated. The plant sensors utilize unique spectral differences in green living plants and bare soil to provide 'real-time' detection of weeds. Each sensor independently controls a solenoid valve that is actuated when a weed is detected; allowing herbicide to be dispensed (Fig. 2). Mounting the sensors in spray hoods provided an unobstructed view of the area between crop rows and removed crop from the area so that it would not be detected and sprayed (Fig. 3). The hoods also allowed non-selective herbicide to be applied without injury to the crop. The spray system was equipped with over-the-top and post-directed nozzles to allow banded applications between the hoods, but these applications were not considered part of this evaluation. Three tanks and pumping systems were used to allow simultaneous applications with hoods, over-the-top, and post-directed systems.

Figure 3. Plant detection sensors mounted in spray hoods.

The sensor system was calibrated for a spray volume of 94 L/ha at 11 km/h. Glyphosate was applied at a rate of 1.1 kg/ha in all applications with the sensor-controlled sprayer. Tanks used with the sensor were marked in 19L increments to provide more precise measurement of spray solution used. Total herbicide spray solution applied through the sensor system was recorded for each field. Area of each field was determined with a global positioning system (GPS) mounted on an all-terrain vehicle (Fig. 4) geographical information system (GIS). Savings were computed by comparing the actual amount of material applied with the sensor-controlled system to the theoretical amount required to spray the same area with a conventional hooded spray system without sensors. Herbicide applications, such as, preplant burndown, premergence, post-direct or banded applications over-the-top were not considered part of the study.

Figure 4. ATV with global positioning system.

The objective of this study was to evaluate savings potential of sensor-controlled hooded spray technology when compared to a hooded spray system without sensors.

RESULTS AND DISCUSSION

Cotton. The number of applications made with the sensor-controlled sprayer were four, one and two, respectively during the 1996, 1997 and 1998 crop production seasons. During 1996 season, savings for the four applications ranged from a low of 57% to 82% (Table 1). Resulting in a season-long average of 75%. Savings of 80% were recorded for the single application in 1997. The first and second applications of 1998 resulted in savings of 66% and 64%, respectively, for a season-long average of 65%. The sensor-controlled sprayer averaged 73% reduction in herbicide usage over the three years.

Soybeans. Soybeans were treated three times during the 1996 and 1997 seasons with only two applications being made in 1998 (Table 2). Herbicide reduction ranged from 43% to 79% and 33% to 44%, respectively for 1996 and 1997. Savings averaged 62% and 39%, respectively for the 1996 and 1997 crop production seasons. During

1998, the savings were 53% and 38%, respectively for the first and second applications. The season-long average for 1998 was 46%. The average savings in herbicide usage for the three-year period were 49% with the sensor-controlled sprayer.

General. Results of this study indicate significant reduction in herbicide usage can be achieved with new intermittent spray technology. Preliminary results from other studies conducted in cotton and soybeans indicate there was no yield difference using traditional cultivation or the sensor-controlled sprayer. The sensor-controlled hooded sprayer should allow producers to reduce tillage, by eliminating cultivation, which should significantly reduce soil erosion.

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Table 1. Herbicide reduction in cotton using a sensor-controlled hooded sprayer.

	Herbicide Reduction		
Application	**1996**	**1997**	**1998**
	%		
1	**82**	**80**	**66**
2	**81**	**-**	**64**
3	**57**	**-**	**-**
4	**80**	**-**	**-**
Season Avg.	**75**	**80**	**65**
3-Year Avg.		**73**	

Table 2. Herbicide reduction in soybeans using a sensor-controlled hooded sprayer.

	Herbicide Reduction		
Application	**1996**	**1997**	**1998**
	%		
1	**65**	**33**	**53**
2	**79**	**41**	**38**
3	**43**	**44**	**-**
Season Avg.	**62**	**39**	**46**
3-Year Avg.		**49**	

ECONOMIC ANALYSIS OF THE MISSISSIPPI DELTA MANAGEMENT SYSTEMS EVALUATION AREA

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ABSTRACT

The purpose of this analysis is to evaluate economic and environmental impacts of agricultural best management practices using a simulation model. Long-run biological and physical processes and their interaction with cropping systems and management practices are modeled. Model inputs include soil characteristics, terrain, and weather data. Under different assumptions on management practices, the model outputs crop yield and edge of field environmental information, (for example, amount of nitrogen runoff). Using the model output and farm budget data related to the MDMSEA watersheds, it is possible to estimate potential profitability and runoff reduction associated with various types of management practices.

INTRODUCTION

The primary goal set by the Mississippi Delta Management System Evaluation Area (MDMSEA) Modeling Subcommittee is to estimate the impacts agricultural best management practices (BMP's) will have on the environmental quality of watersheds where they are introduced. Although producers who feel morally obligated to protect the environment will adopt certain levels of BMP's, acceptance and optimal implementation of BMP's by farmers will ultimately depend on the effect of alternative cultural and structural practices on farm profits.

To evaluate the full scope of the economic effect of BMP's, impacts to agriculture at both the farm level and watershed level must be addressed. At the farm level, BMP's will allow farmers to reduce soil loss with accompanying nutrient and chemical losses, possibly providing benefits in the form of increased soil productivity. However, farmers may perceive that cultural and structural practices that prevent soil erosion would result in reduced crop yields. Thus, benefits from avoided soil loss might be countered by profit reductions, rendering BMP's unattractive to individual farmers. Furthermore, it must be recognized that BMP implementation in a watershed will require cooperative effort among farmers. As with any economic activity that requires a coordinated effort to be successful, proper incentives for participation—such as increased profits—must be considered.

Farm level economic impacts must be evaluated to understand the magnitude of gains and losses to individual farmers through use of BMP's. In our present research, we are developing bio-economic models to demonstrate novel ways farmers can use crop management practices to optimize profits as well as contribute to improvements in environmental quality. Since actual experience with BMP implementation will be correlated with exogenous factors, such as weather, a number of years' experience will be needed to demonstrate the expected outcome on farm profits and environmental quality. By using simulation models, we will be able to generate a large number of expected environmental and economic outcomes under various assumptions about structural and cultural BMP's.

BACKGROUND

The three experimental watersheds in MDMSEA will ultimately provide a laboratory for developing bio-economic models that combine biophysical models of soil erosion and water quality with economic optimization models. We use a bio-economic model to calculate the impacts of alternative management systems. The model merges physical data and biological data to model various management decisions and to determine optimal management in terms of profit and environmental quality. In the initial stages of the project, we are developing models of representative farms in the Mississippi Delta region as a baseline for testing bio-economic models specific to the three watershed test sites.

Farm level economic models assume that farmers' production decisions are constrained by various factors such as amount of land, labor and other available inputs, as well as by cost. An extension of the traditional economic model that we use in our analysis is a bio-economic model. In the model we develop here, environmental quality becomes an additional consideration, and BMP's are included as inputs into the production process.

Bio-economic models should ideally be developed at the watershed level, and we should be able to extrapolate model results over long periods of time. Such models require an underlying physical simulation model that can capture both short and long run weather patterns, nutrient uptake and the timing of planting and harvesting of crops, as well as the use of cultural and structural BMP's.

The economic analysis is in its initial stages, and thus the results presented here are limited to bio-economic models that use the Erosion/Productivity Impact Calculator. EPIC was developed by the US Department of Agriculture's Agricultural Research Service (ARS), Soil Conservation Service (SCS), and Economic Research Service (ERS) in the early 1980's (Sharply and Williams 1990 (a and b)). EPIC is designed to simulate biophysical processes and the interaction of cropping systems with management practices, soils and climates over a long period of time. EPIC can capture timing of planting and harvesting and use of cultural BMP's, but is limited to measuring environmental quality parameters at the edge of a field, and cannot measure downstream impacts.

Although EPIC is limited to edge of field impacts, it has become a widely accepted research tool for investigating environmental and economic impacts. For example Smith et al. (1998) use EPIC to demonstrate the reductions of edge of field runoff of nutrients and sediment and the expected changes in profit under conventional and no-till practices, and Forster et al. (1998) compared edge of field predictions from EPIC with actual water quality in two Lake Erie watersheds. Chapman (1998) uses data from the Ohio MSEA site near Piketon, Ohio and EPIC) to demonstrate the impact of nitrogen taxes, on the economic well being of farmers.

ANALYTICAL APPROACH

Our research program is focused on two modeling efforts. The first is an optimization model at the farm level that demonstrates ways in which farmers' expected profits may be impacted through BMP adoption, and the expected changes in key environmental parameters at the field level. In the second phase of research, we will develop a watershed level optimization model that accounts for externalities and offsite impacts within a watershed.

Development of both the farm and watershed level models follows the same general procedure. First, geophysical, and climatological data along with agricultural inputs are used to simulate runoff associated with various combinations of BMP's. Next, the runoff levels are incorporated into a farm profit maximization model that accounts for the differences in costs and revenues associated with various combinations of BMP's. For instance, certain BMP's require less labor than conventional farming practices, but may require increases in other inputs such as chemicals, or in higher fixed costs for special equipment.

FARM LEVEL PHYSICAL MODEL

We are currently developing a series of models using the Erosion/Productivity Impact Calculator (EPIC) in conjunction with farms representative of six different regions of Mississippi to simulate runoff at the level of individual fields. The purpose of this analysis is to demonstrate very basic environmental and economic impacts that may provide a baseline analysis against which models of the MDMSEA watersheds can be compared.

Preliminary Results

The results that are presented here are preliminary and are meant to illustrate the methodology that will eventually be applied to the MDMSEA site using site-specific inputs rather than the regional inputs we use in the present analysis.

Approximately twenty inputs into the EPIC program are necessary for each region in order to perform the necessary simulations. These include weather (as measured by the closest weather station to each county in a region), soil type, soil erodibility factors, topography (as measured by average slope length and steepness), average size of a watershed, average distance to a watercourse, crop rotation, tillage practices, and fertilizer and chemical usage. Each region is meant to represent an average farm within each of six areas of the state. For purposes of this report, we include only the two regions that represent the northern and southern Mississippi Delta. To this end, we use cropping practices typical of the Delta region. For the sake of simplicity, we report the combined output from the two Delta regions in aggregate.

In each of the two Delta regions, we have simulated five and twenty-five years on a representative farm using conventional tillage practices to determine a baseline for expected yields and expected environmental parameters as measured by soil sedimentation, phosphorous and nitrogen transported in sediment runoff and nitrogen in surface water runoff. These are then compared to expected values when no till practices are introduced. In particular we answer the following questions. 1) How does cultural BMP implementation affect the usage of production inputs—that is, can alternative and less expensive inputs be used, or can overall input usage be reduced to increase profits? 2) How does BMP implementation affect crop yields, that is, do yields suffer significantly or increase? Both of these questions address the basic economic question about the how BMP implementation can affect farm profits. In this early stage of the analysis, we present analysis of very simple scenarios to demonstrate the ways that expected profit may be impacted.

In Table 1, we present the results of our EPIC experiment on the four Delta soil types that comprise at least 80% of soils in the region. The soils used are Alligator, Dundee, Forestdale and Sharkey. The table reports the percentage change in yields, nutrient and sediment runoff, and expected profit per acre for no till on three major crops as compared to baseline conventional tillage practice. The crops investigated are continuous cotton, continuous soybean and continuous corn. Together, these three crops comprise more than 87% of planted acres in the Delta region in 1997.

The top set of numbers in Table 1 represents the five-year simulation experiment, and the bottom set of numbers represents simulation over 25 years. In each table, weighted average changes are reported for all of the model outputs; the weights applied represent the proportion of all soils in a region that a given soil type represents. For example, the weight for Alligator soil for cotton crops is given by the equation:

$$\frac{\text{acres of alligator soil}}{\text{acres of alligator} + \text{acres of dundee} + \text{acres of forestdale}}$$

The results presented here should be viewed with caution since the EPIC simulation model reflects edge of field measurement of environmental parameters. For instance, a large impact at the edge of field would not necessarily carry through downstream from the field due to factors such as residence time and settling of runoff. This may be a particularly important consideration in the Delta where the topography is quite flat.

Five Year Simulation Results. The results of the five year simulation show that switching from conventional to no till would have no Impact on cotton or corn yields, but would decrease soybean yields by 1.75%. On the other hand, profit per acre would increase by $12.75 for cotton and $24.70 for corn, but would decrease for soybeans by $4.53 per acre. Changes in profit reflect increased herbicide and other chemical costs, and cost savings from reduced field operations such as disking and subsoiling for no till. Table 2 shows the 1997 statistics for planted acreage of different crops in the Mississippi Delta. Even though soybeans comprise the largest planted acreage, expected net profit increases in the Delta are predicted to be in the order of $8.6 million (assuming that all planted acres are harvested). Estimated profits are calculated based using information about equipment costs and variable costs such as gasoline, herbicides, pesticides and fertilizer as well as yield changes. Thus, the increase in profit is driven by yield increases and by reduction in input usage.

The model results suggest that substantial environmental improvements in terms of nutrient and sediment runoff could be made by switching from conventional to no till cultural practices. Changes in sediment loss (% Change USLE) are particularly striking in this model, with a reduction in sedimentation of 61.63% annually. In addition, phosphorous loss in sediment drops by 23.25% and overall reductions in Nitrogen loss (weighted average of YNO3, or nitrogen in surface water, and YON, nitrogen transported in sediment) are 26.79%. Table 3 shows the basis for changes in environmental parameters reflecting the percentages of planted acres of corn, cotton and soybeans .

Twenty-five Year Simulation Results. The twenty five year simulation results show that no long term yield changes could be expected for cotton, but that soybean yields and corn yields would increase slightly with no till as compared with conventional tillage. Cotton profits in the twenty five year model are the same as in the five year model ($12.75 per acre), but average profit increases for soybeans are now positive at $4.03 per acre, and long run profits in corn remain close to the predicted level of the 5 year model ($24.72).

Of interest in the long run model is the predicted potential for no till to reduce agricultural runoff reported in Table 3. Reductions in phosphorous are 21.35%, reductions in total nitrogen are 23.84% and reductions in sediment are 62.18%, based on weighted acreage. Thus, our analysis suggests that switching from conventional to no till practices should have a positive environmental effect

FUTURE RESEARCH

Farm Level Model

We propose that an important task in this research will be to extend the existing EPIC program to incorporate experimental data gathered at the MDMSEA sites. From this data we will build models that represent 'typical' farms for each of the three watersheds. Thus, the next step will be to replicate the type of effort that was accomplished using the representative regional farm model, using site-specific data on soils, weather and other inputs from the MDMSEA sites. In addition, we will incorporate data on the effects that various non-cultural BMP's, such as grass strips and slotted-board risers have on reducing runoff.

We will continue analysis with our Delta region representative farms in order to estimate effects of cultural practices under a number of different scenarios. Modeling of cultural BMP's will be accomplished in a way similar to what we present in this paper; modeling of structural BMP's at the farm level will be achieved through use of the Agricultural Policy Environmental Extender (APEX; Blacklands Research XXXX) that allows incorporation of features such as filter strips. The advantage of these models is that they are capable of simulating agricultural yields and environmental parameters under various BMP scenarios. However, as previously noted, they cannot measure offsite water quality in streams, lakes, and groundwater.

Watershed Level Model

At the watershed level, we plan to use the Agricultural Non-Point Source Pollution Model (AGNPS) 98. This model uses the same inputs as the EPIC simulator, but has the capability to measure sediments downstream from the farm. By calibrating EPIC and AGNPS 98 at the field level, we will be able to make inferences about impacts of BMP's on yields, while accounting for offsite water quality. Methods for measuring the health of the MDMSEA watersheds were put in place by the US Geological Survey and the USDA-ARS Soil Sedimentation Laboratory during the first phase of the project. Water quality data specific to the project are therefore available for incorporation into the AGNPS 98 model.

AGNPS 98 will also allow us to investigate the impact of water quality standards from various monitoring points, not just at the edge of the field. For instance, AGNPS 98 will enable us to model runoff if a TMDL standard is set for an entire watershed by a single monitoring point in a lake, which is not possible with EPIC. In addition, this feature of the model may help lead to future research into determining optimal monitoring points in a watershed.

Integer Optimization Model

Since profit maximization is the primary concern of individual farmers, we will develop integer optimization models both at the farm level and at the watershed level. In the preliminary results section of this paper, we calculated profits based on simplifying assumptions that could not take into account the full effect of timing and other factors of the production process. Integer optimization models can incorporate a number of dimensions of a farm operation that we have not presented here.

The integer optimization model is a straightforward application of an economic profit maximization model in which a farmer maximizes the difference between revenues and costs of operations subject to constraints on input availability. Use of integer models explicitly recognizes that inputs and output may not necessarily be available in continuous units and that timing of inputs is crucial.

The optimization model has the advantage that, when properly formulated, timing as well as quantities of inputs into farm production can be explicitly accounted for. For example, the model can be set up to recognize different labor requirements for different times of year, and for different crop, machinery and cultural practice combinations.

The general setup of the integer model is as follows: the objective function is profit, which maximizes returns above total costs across tillage, rotation, and input levels; pounds of inputs per acre, such as nitrogen, phosphorus, and pesticides, are multiplied by their price per pound to find total input costs; miscellaneous costs, fertilizer costs, chemical costs, labor costs, machinery operating costs, and land rental costs, are all subtracted from crop revenue to calculate the return.

Crop revenue is calculated as the sum of all crops produced multiplied by the price of each. The fixed asset costs associated with different classes of cultural and structural practices will be explicitly calculated; since different farm implements are involved, fixed assets costs vary according to practice. Historical data on cost and yields that will be used as inputs in the model have been collected and developed in the form of farm budgets during the initial phase of the MSEA project. Standard farm budget data are also used in this model.

Constraints for the model include crop yields, nitrogen and phosphorous inputs, availability of labor, available machinery, acreage cultivated in various tillage practices, field time limitations, fixed costs, and sediments leaving the field and offsite. Crop yields and sediments that are inputs in the optimization model will be obtained as outputs from the physical models EPIC, APEX and AGNPS. Sediment levels will be varied based on different assumptions about monitoring points and TMDL standards.

CONCLUSIONS

We have demonstrated through a simple bio-economic modeling effort the types of impacts that cultural BMP's might have on expected profits and environmental quality in the Delta region of Mississippi. The simulations suggest that both improvements in profits as well as edge of field environmental quality parameters would be experienced in a change from conventional to no till cultural practices.

In addition, we have outlined the future direction that our analysis will take. We propose that of major concern in our future research are the externalities that are inherent in nonpoint source pollution (NPP). That is, what are the impacts at the individual farm level when adjacent farms change their cultural practices and increase TMDL's for an entire watershed. Such events could negatively impact individual farmers because they would have to then adjust their own practices in order to meet the compliance levels for the entire watershed. We thus further propose that the bio-economic models be used to help determine which BMP's will be most effectively used on different fields within a watershed, based on factors such as soil type and proximity to streams and lakes. At the same time, we will consider equity issues that may arise from differential implementation of practices by different farmers in order to increase acceptance of BMP'S. This will be the focus of our future research in which we will use bio-economic models to establish optimal distribution of BMP's within a watershed

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Table 1. Comparison of environmental and economic impacts conventional practices and no till, 5 and 25 year epic experiments

Delta Soils — 5 Year EPIC Experiment

Crop(s)	Soil Type	Soil Proportion	% Change Yields	% Change YP[a]	% Change YNO3[b]	% Change YON[c]	% Change YNO3 + YON	% Change USLE[d]	Change Profit ($/acre)
Cotton	Alligator	0.4090	0.00	-0.13	22.22	-7.67	-0.49	-42.88	12.75
	Dundee	0.2965	0.00	17.77	50.00	2.64	14.05	-50.05	12.75
	Forestdale	0.2945	0.00	-26.16	33.35	-30.73	-25.98	-52.44	12.75
Weighted Average		**1.0000**	**0.00**	**-2.49**	**33.74**	**-11.40**	**-3.69**	**-47.82**	**12.75**
Soybean	Alligator	0.2536	-6.90	-28.63	24.99	-44.36	-31.73	-56.99	-19.49
	Dundee	0.1839	0.00	-14.63	66.66	-48.79	-26.57	-72.29	0.39
	Sharkey	0.3798	0.00	-31.35	46.45	-45.48	-33.91	-61.71	0.39
	Forestdale	0.1827	0.00	-59.12	66.68	-66.67	-57.58	-74.85	0.39
Weighted Average		**1.0000**	**-1.75**	**-32.66**	**48.42**	**-49.67**	**-36.33**	**-64.86**	**-4.65**
Corn	Dundee	0.5017	0.00	4.04	39.98	-29.79	-15.35	-81.74	24.72
	Forestdale	0.4983	0.00	-54.02	33.35	-60.55	-53.42	-81.93	24.72
Weighted Average		**1.0000**	**0.00**	**-24.89**	**36.68**	**-45.12**	**-34.32**	**-81.84**	**24.72**

Delta Soils — 25 Year EPIC Experiment

Crop(s)	Soil Type	Soil Proportion	% Change Yields	% Change YP[a]	% Change YNO3[b]	% Change YON[c]	% Change YNO3 + YON	% Change USLE[d]	Change Profit ($/acre)
Cotton	Alligator	0.4090	0.00	12.63	11.54	-2.35	3.67	-45.51	12.75
	Dundee	0.2965	0.00	4.86	37.50	-16.54	1.55	-51.49	12.75
	Forestdale	0.2945	0.00	-26.11	66.68	-32.11	-23.49	-53.34	12.75
Weighted Average		**1.0000**	**0.00**	**-1.08**	**35.48**	**-15.32**	**-4.96**	**-49.59**	**12.75**
Soybean	Alligator	0.2536	0.00	-16.27	36.84	-42.06	-19.87	-62.80	0.39
	Dundee	0.1839	3.03	-9.78	71.42	-52.30	-22.42	-72.04	10.33
	Sharkey	0.3798	0.00	-23.38	57.12	-39.70	-23.32	-56.00	0.39
	Forestdale	0.1827	3.03	-64.98	50.00	-73.28	-62.98	-77.49	10.33
Weighted Average		**1.0000**	**1.11**	**-26.68**	**53.31**	**-48.75**	**-29.53**	**-64.60**	**4.03**
Corn	Dundee	0.5017	0.00	-25.96	33.32	-50.22	-24.48	-82.26	24.72
	Forestdale	0.4983	1.08	-67.57	66.68	-72.63	-61.69	-84.65	28.05
Weighted Average		**1.0000**	**0.54**	**-46.69**	**49.94**	**-61.39**	**-43.02**	**-83.45**	**26.38**

[a]YP = Phosphorus loss with sediment; [b]YNO3=Nitrogen loss in surface runoff;
[c]YON=Organic nitrogen loss with sediment; [d]USLE=Soil loss from water erosion using USLE

Table 2. Planted acreage in delta region, 1997

Crop	Planted Acreage	%
Corn	262,200	8.69
Cotton	753,900	24.98
Rice	231,450	7.67
Sorghum	15,300	0.51
Soybean	1,619,200	53.66
Wheat	135,400	4.49
Total	**3,017,450**	**100.00**

Source: National Agricultural Statistics Service

Table 3. Weighted average of environmental parameters in Delta region – 5 and 25 year epic experiments

		Planted Acreage	Weights	YP	YNO3 +YON	USLE
5 Year	**CORN**	262,200	0.10	-24.89	-34.32	-81.35
	COTTON	753,900	0.29	-2.49	-3.69	-47.82
	SOYBEAN	1,619,200	0.61	-32.66	-36.33	-64.86
Total/Weighted Average		**2,635,300**	**1.00**	**-23.26**	**-26.79**	**-61.63**
25 Year	**CORN**	262,200	0.10	-46.69	-43.02	-83.45
	COTTON	753,900	0.29	-1.08	-4.96	-49.59
	SOYBEAN	1,619,200	0.61	-26.68	-29.53	-64.60
Total/Weighted Average		**2,635,300**	**1.00**	**-21.35**	**-23.84**	**-62.18**

EFFECTS OF AGRICULTURAL SYSTEM PRACTICES ON MISSISSIPPI DELTA MSEA LAKE WATER QUALITY

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ABSTRACT

Over the course of the past century, aquatic habitats have declined worldwide. Much of this loss has been attributed to draining and clearing for agriculture as well as non-point source pollution associated with agricultural runoff. It is estimated that 60% of the approximately 3 billion tons of sediment per year deposited in the waterways originates from agricultural lands. In addition, these sediments are often accompanied by other contaminants such as pesticides and nutrients. The Mississippi Delta MSEA (Management Systems Evaluation Area) is a competitive agricultural systems-based research project designed to address the problems associated with these non-point source pollutants. The Mississippi Delta MSEA is unique among MSEA projects both because of its location in the Mississippi River alluvial plain and its strong ecological research component. Experimental design of the Mississippi Delta MSEA calls for the development of comprehensive land and cultural treatments targeted to reduce sediment and associated pollutants entering watershed ox-bow lakes. Changes in lake water quality are being used as one measure of management success. Analyses of water quality prior to the implementation of management practices indicate lakes that were stressed and ecologically damaged due to excessive in-flowing sediment. Significant improvements in water quality were realized through the use of cultural and structural best management practices. Sediments were decreased 34 to 59%, while Secchi visibility and chlorophyll generally increased. The most dramatic improvements in water quality occurred in Thighman and Deep Hollow which featured cultural practices and combinations of cultural and structural practices respectively. Reducing suspended sediment concentrations in these oxbow lakes resulted in conditions favorable for phytoplankton production. Increases in phytoplankton production resulted in increased chlorophyll concentrations and higher concentrations of dissolved oxygen, leading to improved secondary productivity (Knight et al., In Press). Land and farm management practices designed to control erosion and reduce transport of soil, organic matter and agricultural chemicals improve water quality and therefore ecological conditions.

INTRODUCTION

Water erosion removes 1.5 to 2 billion tons of U. S. topsoil each year and is a significant problem nationally. The Mississippi River alone carries 331 million tons of soil to the Gulf of Mexico annually (Brown, 1984). Fowler and Heady (1981) reported that in stream suspended sediments are, by volume, the largest pollutants in the United States). Much of the worldwide decline in aquatic habitats over the course of the past century can be attributed to draining and clearing of land for agriculture.

Delta lakes, long known for their productivity and recreational value (Cooper et. al., 1984) have not escaped the detrimental effects of soil erosion. Their popularity as recreational resources has decreased as water quality and fisheries have declined (Coleman, 1969). Cooper and Knight (1978) have attributed these declines, in part, to soil erosion and sedimentation. Detrimental impacts on stream and lake water quality due to erosion and sedimentation have been well documented (Knight et al. 1994, Waters 1995).

Oxbow lakes are remnants of meandering floodplain rivers that have been cut off and physically isolated from their respective main river channels. Because of this isolated condition, changes begin to occur in the physical and chemical characteristics of the lake basin and in the floral and faunal assemblages. Over time allochthonous organic materials derived from previous connections with the floodplain river ecosystem are processed and energetically depleted. Isolated oxbow lakes in agricultural regions tend to become less heterotrophic and more autotrophic, becoming closed entities within themselves, functioning similarly to farm ponds and other small impoundments.

If suspended sediment concentrations are low enough to provide suitable light penetration, oxbow lakes provide conditions conducive to photosynthesis, primarily via phytoplankton, and may support a sustainable sport fishery. However, agricultural practices often result in soil erosion that can lead to increased turbidity in the oxbow lakes and subsequent inhibition of photosynthesis. Turbidity in oxbow lakes can be persistent in areas having soils with high clay content. Although nutrients such as phosphorus are commonly associated with delta soils and isolated oxbow lakes tend to load nutrients, these systems may become energy starved and very unproductive due to lack of light penetration.

Best management practices (BMPs) designed to reduce sediment-laden runoff should reduce suspended sediment concentrations in the receiving waters of oxbow lakes. Although some reduction in nutrient in-flow may be realized most oxbow lakes should be eutrophic enough to boost primary productivity and consequently support a sustainable fishery. Research is needed to examine the impact of these management practices on the water quality and productivity of oxbow lakes receiving runoff from these managed watersheds.

The Mississippi Delta MSEA (Management Systems Evaluation Area) is a competitive agricultural systems-based research project designed to address the problems associated with these non-point source pollutants. The Mississippi Delta MSEA is unique among MSEA projects both because of its location in the Mississippi River alluvial plain and its strong ecological research component. Experimental design of the Mississippi Delta MSEA calls for the development of comprehensive land and cultural treatments targeted to reduce sediment and associated pollutants entering watershed ox-bow lakes. Major objectives of the MSEA project are: 1) to develop and evaluate alternative and innovative farming systems for improved water quality/ecology in the Mississippi Delta 2) to increase the knowledge to design and evaluate economical environmentally-sound best management practices (BMPs) as components of farming systems and 3) to increase awareness and adoption by farmers/landowners of alternative farming systems to reduce adverse agricultural impacts on water resources and ecological processes.

This study examines and documents pre-management water quality conditions on three oxbow lakes and resulting water quality improvements following the implementation of best management practices designed to control erosion and non-point source pollution.

MATERIALS AND METHODS

Study Site

Thighman and Beasley Lakes near Indianola, MS in Sunflower County and Deep Hollow Lake near Greenwood, MS in Leflore County are the three oxbow lake study sites. Thighman Lake has a watershed of approximately 3,700 acres and a surface area of 22 acres. Crop production is conventional cotton, rice, soybeans and corn. In addition to runoff from these crops Thighman Lake receives water discharged from catfish ponds. Beasley Lake is a 62 acre oxbow located in a 2,100 acre watershed. The watershed is primarily in conventional tillage cotton. It also contains a large wooded riparian zone. This watershed will be protected with such structural practices as slotted board risers, slotted pipes, grass filter strips, and riparian zones. Deep Hollow Lake has a surface area of 20 acres and a watershed size of 500 acres. This watershed is farmed in cotton and soybeans. Deep Hollow watershed will receive both structural and cultural management practices to reduce sediments and other non-point pollutants including: no-till cotton and soybeans with winter cover crop, hooded pesticide sprayers and weed sensor technology, slotted board risers, slotted pipes, grass filter strips, and riparian zones.

Data collection

Three sampling sites on each of the three lakes were selected for water quality monitoring. Yellow Springs Instruments (model provided for information purposes only and should not be taken as an endorsement of any particular brand or product) automated water quality monitoring equipment was used to obtain hour measurements of temperature, pH, dissolved oxygen and conductivity. Surface water quality was sampled biweekly for total, suspended, and dissolved solids, total phosphorus, filterable ortho-phosphate, ammonium nitrogen and nitrate nitrogen, chlorophyll, coliform and enterococci bacterial counts and secchi visibility.

Analytical and chemical methods were based on procedures from APHA (1992). Calculation of means and statistical analysis was completed using SAS statistical software (SAS Institute, inc. 1996). All parameters were tested for differences at the 5% level of significance.

RESULTS AND DISCUSSION

Mean physical and chemical water quality data for the three MSEA Lakes prior to establishment of erosion and pollution control structures and management practices may be found in tables 1 and 2. Water quality of all MSEA lakes were statistically similar to one another prior to implementation of BMPs (Table 3). Thighman Lake had significantly higher conductivity, and concentrations of dissolved solids and nitrate than either Deep Hollow or Beasley Lakes, while Beasley and Deep Hollow had higher concentrations of ortho-phosphate.

General Water Quality

Analyses of water quality prior to the implementation of management practices indicate lakes that were stressed and ecologically damaged due to excessive inflowing sediment. Mean total water column sediment concentrations ranged from 351 mg/L to 505 mg/L with maximum values reaching 2365 mg/L for Beasley Lake, 1094 mg/L for Thighman Lake and 804 mg/L for Deep Hollow Lake. High suspended solid concentrations on Thighman and Beasley Lakes corresponded to lower concentrations of chlorophyll and lower Secchi visibility. Deep Hollow Lake had the highest mean concentration of chlorophyll at 24.42 μg/L as well as the lowest mean concentration of suspended sediment (269 mg/L). Temperature, conductivity and pH values fell within ranges expected for the oxbow lakes in the Mississippi Delta. While all three lakes experienced occasional periods of low dissolved oxygen concentrations, average annual dissolved oxygen concentrations were adequate to maintain warm water fisheries.

Nitrogen

Atmospheric nitrogen is highly soluble in fresh water and only rarely a limiting factor in lake or pond productivity. All steps in the nitrogen cycle may occur in fresh water and are typically controlled by biological processes. Boyd (1979) reported that ammonium nitrogen and nitrate nitrogen concentrations of unfertilized woodland ponds were 0.052 mg/L and 0.075 mg/L respectively while catfish ponds had concentrations of 0.50 mg/L ammonium nitrogen and 0.25 mg/L nitrate nitrogen. Although the MSEA lakes exceeded these values, they never exceeded the 1 mg/L at pH 7 and 30 ^{o}C standard for ammonium nor the 0.02 mg/L standard for the highly toxic un-ionized form. MSEA lakes were also well below the 10 mg/L USEPA (1987) standard for water and fish ingestion. MSEA lakes had nitrate nitrogen concentrations that compared similarly to those values reported for Yazoo Basin lakes in 1969 (Table 4). Best Management Practices had little discernable effect on the concentration of nitrogen compounds in the MSEA lakes (Figure 1). Deep Hollow was the only lake to show a significant decrease in ammonium nitrogen (Table 5).

Phosphorus

Phosphorus plays a major role in biological metabolism and is typically the limiting factor in lake productivity and eurtrophication (Hutchinson 1957 and Lee 1970). Phosphate fertilizers are routinely added to ponds to increase primary productivity and fish growth (Mortimer, 1954; Hickling, 1962). Excessive amounts of phosphorus, however, may result in massive phytoplankton blooms and corresponding oxygen depletion. Boyd (1976) reported that fertilized farm ponds in Alabama averaged 0.17mg/L total phosphorus and 0.02 mg/L ortho-phosphate. USEPA (1987) stated that lake or reservoir waters should not exceed .025 mg/L total phosphorus in order to prevent nuisance growth of plants and eutrophication. Total phosphorus in the three MSEA lakes prior to BMPs ranged from and average of 0.437 to 0.522 mg/L (Table 2). Although these values are rather high, they are not unexpected give the relatively high phosphorus content of Mississippi Delta soils. Decreases in total phosphorus occurred in all MSEA lakes following implementation of BMPs (Figure 1). These decreases ranged from 31 to 55 % (Table 5). While total phosphorus decreased, filterable ortho phosphate significantly increased on all lakes from 53 to 144%.

Sediment and chlorophyll

Few studies have been conducted to determine the effects of clay turbidity on warmwater fishes. Wallen (1951) found that concentrations of suspended sediments as high as 100,000 mg/L were required for gills and opercular cavities to become clogged. However, stress related behaviors could be induced at concentrations as low as 20,000 mg/L. Wedemeyer et al. (1976) reported that concentrations of 80-100mg/L are considered to be the maximum that most species of fish can tolerate on a continual basis without causing gill damage. Long-term exposures (several months) to concentrations of 200-300 mg/L have caused bacterial tail and fin rot in salmonids, as well as pathological changes is gill structure (Herbert and Merkins 1961). While high concentrations of suspended solids rarely cause direct fish mortality relatively low concentrations can affect lake productivity (Murphy 1962). Waters (1995) detailed the sources, effects and control of sediment in streams and provided a summary of research on the effects of sediments on aquatic organisms.

Suspended and total solids concentrations prior to implementation of management practices were sufficiently high to consider the MSEA lakes sediment stressed systems (Figure 2). Suspended sediment concentrations exceed water quality standards established for Alaskan water reported by Lloyd (1987). The MSEA lakes also had suspended solids concentrations that were 84.2 % higher than that of Morris Pond, a 1.09 ha farm pond located in the hill lands of central Mississippi (Cooper and Knight 1990). Annual mean suspended solids concentration was 55.0 mg/L for Morris Pond compared to 405 mg/L, 429 mg/L, and 289 mg/L respectively for Thighman, Beasley and Deep Hollow. When compared to historical turbidity data (Table 4) collected from Yazoo Basin lakes from 1969, the three MSEA lakes exceeded estimated suspended solids concentrations of all lakes with the single exception of Arkabutla Reservoir (USCOE 1975). It should be noted that this 1969 data was collected prior to the increase of intensive cultivation of soybeans in the Mississippi Delta that occurred in the 1970's and is based on sediment-turbidity models developed by Sigler et al. (1984).

Cultural and structural management practices as well as combinations of the two reduced total and suspended sediments on all three MSEA lakes. The greatest percent reduction occurred in Deep Hollow Lake (76%), which features a combination approach to erosion control. This reduction in suspended sediment significantly improved Secchi visibility in two of the MSEA lakes. Prior to BMP establishment, Secchi visibility was exceptionally low averaging less than 17 cm and further supporting the contention that the MSEA lakes were sediment stressed. As a result of sediment reductions due to management practices, Secchi visibility increased to 25 cm on Deep Hollow Lake. This represents a 108% increase in water visibility. Secchi visibility also improved on Thighman, increasing by 36%.

Cooper and Bacon (1980) reported that primary productivity was adversely affected when suspended sediments exceeded 100mg/L. At this concentration of suspended sediments, chlorophyll concentration was reduced to less than 20 µg/L. Cooper et al. (1995) demonstrated that when suspended sediments were reduced through diversion of sediment laden runoff chlorophyll concentration doubled. Cooper and Bacon (1980) reported mean annual suspended sediment concentrations of 117, 198, and 262 for the years 1977, 1978 and 1979, which were lower than the means for the three MSEA lakes. While chlorophyll concentrations were also impacted by high suspended sediments in the MSEA lakes, reductions in sediments due to management practices contributed to corresponding increases in chlorophyll on all MSEA oxbows, ranging from 61 to 629% (Figure 2).

SUMMARY

This study examined and documented pre-management water quality conditions and resulting changes on three oxbow lakes prior to and following the implementation of Best Management Practices. Analyses of water quality prior to the implementation of management practices indicate lakes that were stressed and ecologically damaged due to excessive in-flowing sediment. Mean total suspended sediment concentrations for the three MSEA lakes exceeded concentrations estimated for regional lakes in 1969 as well as levels acceptable for fish growth and health. Because all MSEA lakes had low concentrations of chlorophyll despite relatively high concentrations of phosphorus it is reasonable to assume that high suspended solid concentrations likely suppressed phytoplankton production. This conclusion was further supported by the fact that Deep Hollow Lake had the highest mean concentration of chlorophyll of the three lakes as well as the lowest mean concentration of suspended sediment. Reducing suspended sediment concentrations through the use of best management practices produces conditions favorable for phytoplankton production as indicated by the increased water visibility and chlorophyll production. While all three lakes demonstrated improved water quality the most significant improvements occurred when cultural or combinations of cultural and structural practices were used. Land and farm management practices designed to control erosion and reduce transport of soil, organic matter and agricultural chemicals do indeed improve water quality and therefore ecological conditions.

ACKNOWLEDGEMENTS

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Table 1. Physical Data from MSEA Lakes Before implementation of Best Management Practices in September 1996.

Lake	Temp C	Conductivity µS/cm	Dissolved Oxygen mg/L	pH	Secchi cm	Total mg/L	Solids Dissolved mg/L	Suspended mg/L
T	29.80 (2.44)	0.309 (0.127)	5.06) (2.17)	7.21 (0.39)	11.5 (8.52)	505 (256)	115 (52)	405 (273)
B	25.61 (12.98)	0.072 (0.017)	6.38 (3.74)	7.00 (0.37)	16.6 (16.87)	482 (430)	58 (23)	429 (434)
DH	24.42 (6.52)	67.89 (46.21)	4.04 (1.59)	6.68 (0.75)	12.2 (9.37)	351 (224)	52 (22)	289 (237)

T= Thighman, B= Beasley, DH = Deep Hollow

Table 2. Chemical Data from MSEA Lakes Before implementation of Best Management Practices in September 1996.

Lake	Filterable ortho-PO_4 Mg/L	Total Phosphorus Mg/L	Coliform Count	Enterococci Count	NH_4 Mg/L	NO_3 Mg/L	Chlorophyll µg/L
T	0.018 (0.021)	0.437 (0.218)	4593 (5416)	27 (43)	0.168 (0.144)	1.157 (0.917)	9.89 (6.07)
B	0.032 (0.018)	0.496 (0.301)	86 (86)	7 (16)	0.123 (0.067)	0.534 (0.617)	16.56 (26.71)
DH	0.019 (0.062)	0.522 (0.256)	863 (958)	0 (0)	0.189 (0.144)	0.393 (0.375)	24.42 (34.70)

T= Thighman, B= Beasley, DH = Deep Hollow

Table 3. Water quality differences between MSEA Lakes before and after implementation of BMPs.

	Pre BMP Beasley	Pre BMP Deep Hollow	Pre BMP Thighman	Post BMP Beasley	Post BMP Deep Hollow	Post BMP Thighman
Secchi	A	A	A	B	A	B
Total Solids	A	A	A	B	A	C
Suspended Solids	A	A	A	C	A	C
Dissolved Solids	A	A	B	C	A	B
Nitrate N	A	A	B	C	A	B
Ammonium N	A	A	A	A	A	B
Total P	A	A	A	A	A	B
Filterable Ortho P	A	B	B	A	A	A
Chlorophyll	A	A	A	A	B	B

Different letters indicate significant differences between lakes within a pre or post category ($P < 0.05$)

Table 4 Mean water quality data from Yazoo Basin Lakes collected in 1969.[1]

Lake	Turbidity JTU	Suspended [2] Solids mg/L	NO3 mg/L	PO4 mg/L
Alligator Lake	25	25	0.43	0.54
Eagle Lake	25	25	0.11	0.08
Thompson Lake	25	25	0.00	0.00
Bear lake	25	25	0.39	0.02
Buzzard Bayou	109	115	0.00	0.66
Fish Lake	25	25	0.15	0.48
Old Orchard Lake	25	25	0.00	0.04
McIntyre Lake	42	45	0.55	0.42
Mathews Brake	25	25	0.29	0.05
Roebuck Lake	25	25	0.15	0.50
Twin Lake	222	240	1.08	0.73
Four Mile Lake	184	197	1.20	0.54
Sky lake	60	62	1.13	1.43
Goose Lake	25	25	0.00	0.08
Moon Lake	25	25	0.46	0.14
Lake Washington	77	80	0.00	0.44
Arkabutla Lake	280	305		
Sardis Lake	103	110		
Enid Lake	78	82		
Grenada lake	120	127		

[1] Source: USCOE 1975.
[2] Suspended sediment concentrations estimated from JTU data based on models published by Sigler et al. 1984.

Table 5. Pre- and post BMP comparisons of water quality for MSEA Lakes from 1996 through 1999.

	Beasley			Deep Hollow			Thighman		
Parameter	Pre	Post	Percent Change	Pre	Post	Percent Change	Pre	Post	Percent Change
Secchi (cm)	14	17	21	12	25	108*	11	15	36*
Total Solids (mg/L)	482	265	-45*	351	143	-59*	505	334	-34*
Suspended Solids (mg/L)	429	202	-53*	289	70	-76*	405	169	-58*
Dissolved Solids (mg/L)	58	65	12	52	75	44*	115	166	44*
Nitrate N (mg/L)	0.534	0.553	4	0.393	0.387	-2	1.157	0.85	-27
Ammonium N (mg/L)	0.123	0.139	13	0.189	0.116	-39*	0.168	0.224	33
Total P (mg/L)	0.496	0.344	-31*	0.522	0.233	-55*	0.437	0.299	-32*
Filterable Ortho P (mg/L)	0.032	0.049	53*	0.019	0.046	142*	0.018	0.044	144*
Chlorophyll (μg/L)	16.6	118.9	89*	24.4	61	150	9.9	72.2	629*

* Indicates a significant difference (Prob. < 0.05)
Note that negative percent change indicates a decrease from pre to post conditions

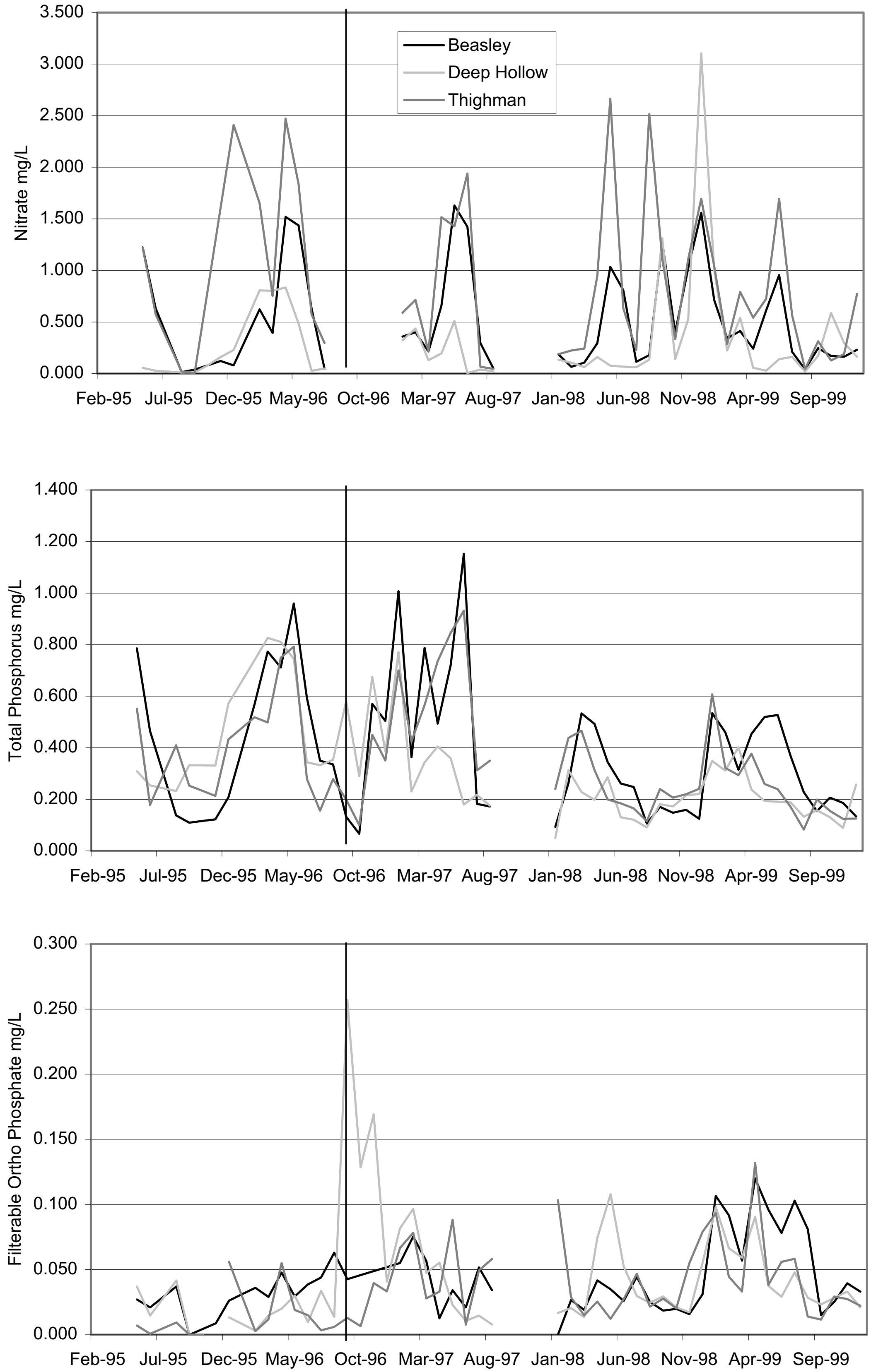

Figure 1. Monthly mean nitrate N, total P, and filterable ortho P for MSEA Lakes from 1996 though 1999. The vertical lines indicate implementation of BMPs.

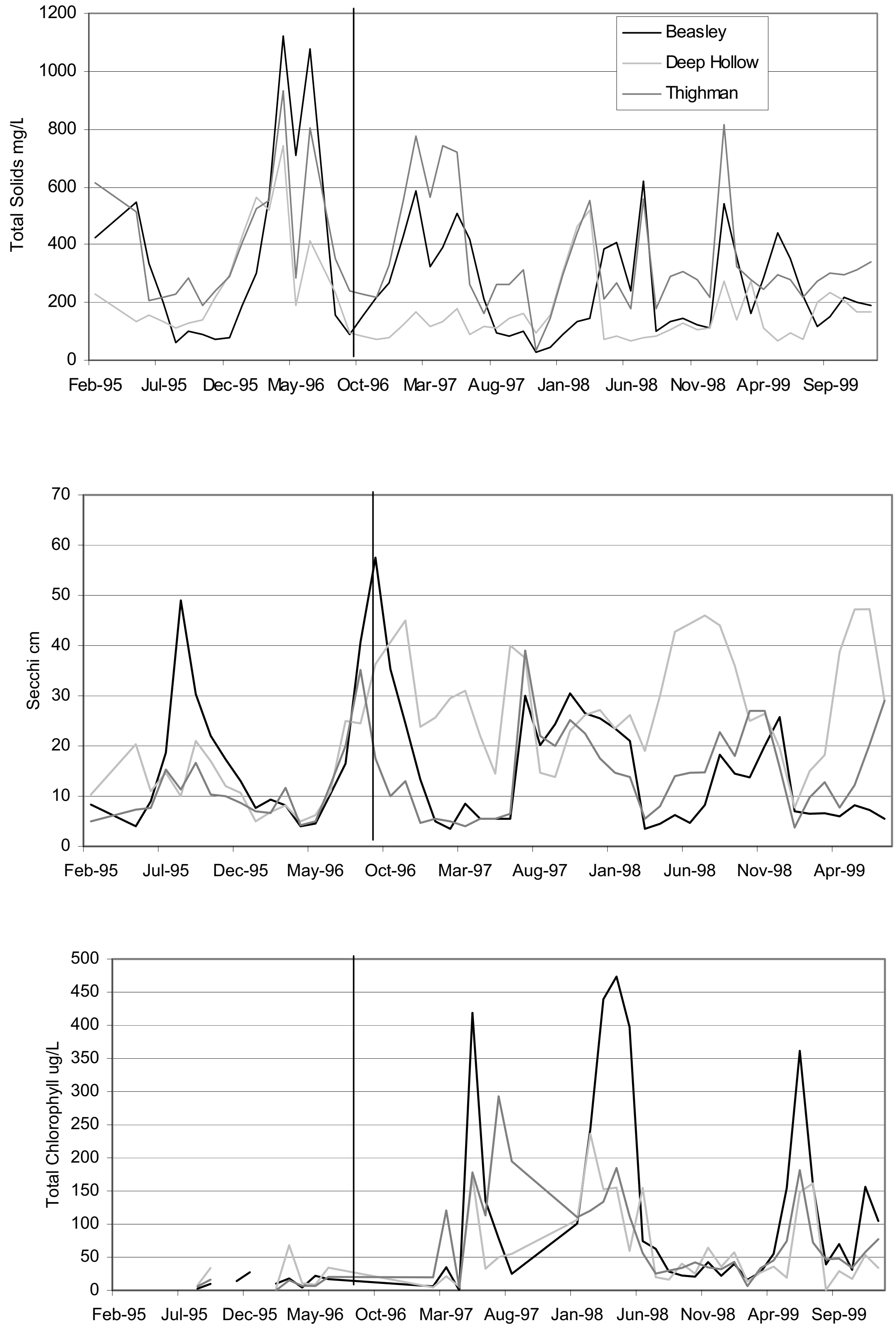

Figure 2. Monthly mean total solids, Secchi visibility, and total chlorophyll for MSEA Lakes from 1996 though 1999. The vertical lines indicate implementation of BMPs.

FISHERY EVALUATION OF MISSISSIPPI DELTA MANAGEMENT SYSTEMS EVALUATION AREA OXBOW LAKES

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INTRODUCTION

Water erosion removes 1.36 to 1.82 billion metric tons of U. S. topsoil each year and is a significant problem nationally. The Mississippi River alone transports 300 million metric tons of soil to the Gulf of Mexico annually (Brown, 1984). Fowler and Heady (1981) reported that in stream suspended sediments are, by volume, the largest pollutants in the United States. Much of the worldwide decline in aquatic habitats over the course of the past century can be attributed to draining and clearing of land for agriculture. It is estimated that 60% of the approximately 2.72 billion tons of sediment per year deposited in the waterways originates from agricultural lands. In addition, these sediments are often accompanied by other contaminants such as pesticides and nutrients. Lakes of the Mississippi alluvial plain, long known for their productivity and recreational value (Cooper et al., 1984) have not escaped the detrimental effects of soil erosion. Their popularity as recreational resources has decreased as water quality and fisheries have declined (Coleman, 1969). Cooper and Knight (1978) have attributed these declines, in part, to soil erosion and sedimentation. Detrimental impacts on stream and lake water quality due to erosion and sedimentation have been well documented (Knight et al. 1994, Waters 1995).

Oxbow lakes are remnants of meandering floodplain rivers that have been cut off and physically isolated from their respective main river channels. Because of this isolated condition, changes begin to occur in the physical and chemical characteristics of the lake basin and in the floral and faunal assemblages. Over time, as allochthonous organic materials derived from previous connections with the floodplain river ecosystem are processed and energetically depleted, isolated oxbow lakes in agricultural regions tend to become less heterotrophic and more autotrophic, becoming closed entities within themselves, functioning similarly to farm ponds and other small impoundments.

If suspended sediment concentrations are low enough to provide suitable light penetration, oxbow lakes provide conditions conducive to photosynthesis, primarily via phytoplankton, and may support a sustainable sport fishery. However, current established tillage practices in the Mississippi Delta region often result in excessive soil erosion that can lead to increased turbidity in the oxbow lakes and subsequent inhibition of photosynthesis. Turbidity in oxbow lakes can be persistent in areas having soils with high clay content. Although nutrients such as phosphorus are commonly associated with delta soils and isolated oxbow lakes tend to load nutrients, these systems may become energy starved and very unproductive due to lack of light penetration.

Best management practices (BMPs) designed to reduce sediment-laden runoff should reduce suspended sediment concentrations in the receiving waters of oxbow lakes. Although some reduction in nutrient in-flow may be realized most oxbow lakes should be sufficiently eutrophic to boost primary productivity and consequently support a sustainable fishery. The research presented here documents the impact of these management practices on the fisheries of oxbow lakes receiving runoff from these managed watersheds.

MATERIALS AND METHODS

Project Overview

The Mississippi Delta Management Systems Evaluation Area (MSEA) project was intended to demonstrate the effectiveness of farming systems designed to reduce nonpoint source pollution from agricultural runoff. These farming systems employed a variety of BMPs that fell into one of two categories, structural or cultural. Three oxbow lake watersheds were selected to receive management practices based on these different categories. One of the watersheds was protected solely with structural practices such as slotted pipes, slotted board inlets, grassed buffers and stiff grass hedges. Another watershed was protected with a combination of the afore mentioned structural practices as well as cultural methods including conservation tillage and winter cover crops. The third watershed was originally planned to be a "control" watershed that would demonstrate conventional tillage and typical farming practices of the region. While no structural or cultural practices were recommended or encouraged, the farmers within this watershed began adopting conservation tillage at about the same time that the various BMPs were initiated in the other two watersheds. This resulted in a study were one watershed was protected with cultural practices, one with structural practices and a third with a combination of both.

Study Site

The Mississippi Delta MSEA study sites included the three oxbow lakes of Thighman and Beasley Lakes near Indianola, MS in Sunflower County and Deep Hollow Lake near Greenwood, MS in Leflore County. Thighman Lake has a watershed of approximately 1,498 ha and a surface area of 9 ha. Crop production included cotton, rice, soybeans and corn. In addition to runoff from these crops, Thighman Lake receives water discharged from catfish ponds. Much of the land originally farmed in conventional tilled cotton was farmed in conservation tilled cotton and corn beginning in 1996. Beasley Lake is a 25 ha oxbow with a large wooded riparian zone located in a 850 ha watershed. Conventionally tilled cotton was principal crop in the watershed. Beasley Lake was managed with structural practices. Deep Hollow Lake has a surface area of 8 ha and a watershed size of 202 ha. This watershed was farmed in cotton and soybeans. Deep Hollow watershed will receive both structural and cultural management practices to reduce sediments and other non-point source pollutants.

Data collection

All three lakes were renovated using 5% rotenone solution. Pre-management standing stock and other fisheries characteristics were estimated for each oxbow by sub-sampling fish from approximately 0.56 hectares of block netted lake. Fish were weighed, measured for total length and identified to species.

Each lake was re-stocked with largemouth bass (*Micropterus salmoides*), a mix of bluegill (*Lepomis macrochirus*) and redear sunfish (*Lepomis microlophus*), and channel catfish (*Ictalurus punctatus*) at rates of 50, 500 and 150 per acre respectively. The bluegill - redear sunfish mix and channel catfish were introduced in the fall of 1996 followed by largemouth bass in the spring of 1997. Sampling was accomplished using a boat mounted Coffelt Model VVP-2C (model provided for information purposes only and should not be taken as an endorsement of any particular brand or product) electroshocker operating at 250 volts. Sampling effort was limited to one hour of electrofishing time per lake providing adequate survey coverage while minimizing damage to recovering populations. Captured fish were placed in holding tanks until they could be weighed, measured, and released. Capture mortality was generally limited to smaller individuals.

Calculation of means and statistical analysis was completed using SAS statistical software (SAS Institute, Inc. 1996).

RESULTS AND DISCUSSION

Renovation

Summary fishery characteristics prior to implementation of BMPs may be found in Table 1. Fish species identified in the rotenone sampling were typical of oxbow lake fauna. By number, gizzard shad (*Dorosoma cepedianum*), white crappie (*Pomoxis annularis*) and bluegill (*Lepomis macrochirus*) were the dominant species in Thighman Lake while white crappie, mosquito fish (*Gambusia affinis*) and gizzard shad where most abundant in Deep Hollow. White crappie, gizzard shad and madtom catfish (*Noturus gyrinus*) were numerically dominant species in Beasley Lake. Species richness was relatively low for all three MSEA lakes. Mississippi is home to over 300 species of freshwater fishes (Ross and Brenneman 1991).

Table 1. Fisheries Characteristics of MSEA lakes prior to implementation of Best Management Practices.

	Thighman	Deep Hollow	Beasley
Catch (kg)	157	163	85
Number	2139	1473	886
Number Of Species	17	21	15
Kg/ha	282	292	152

By weight, gar (*Lepisosteus sp*.), common carp (*Cyprinus carpio*), white crappie and paddlefish (*Polyodon spathula*) were important in all MSEA lakes. Deep Hollow Lake had the greatest standing stock at 292 kg/ha, followed by Thighman with 282 kg/ha and Beasley with 152 kg/ha. These standing stocks roughly fall within the ranges reported in the literature for various natural and unfertilized man-made lakes. Swingle and Smith (1938, and 1939) reported 168 to 337 kg/ha for bass bluegill ponds in Alabama. Carlander (1955) reported natural lakes ranging from 196 to 1010 kg/ha. Cooper et al. (1963) reported that standing stocks in natural lakes ranged from 56 to 168 kg/ha while artificial ponds ranged from 224 to 499 kg/ha. He attributed this difference in productivity to the low fertility of the natural glacial lakes and to nutrient rich runoff entering the artificial lakes from surrounding agricultural land. Ponds in Oklahoma ranged from 64 to 1045 kg/ha with a mean of 383 kg/ha (Jenkins 1958). Carlander and Moorman (1956) reported standing stocks of 1246 kg/ha in flood plain ponds in Illinois and 31 to 1386 kg/ha in Iowa. While the standing stock is in agreement with those reported in the literature much of the weight of fish from the MSEA lakes is made up of undesirable species such as gizzard shad, various species of gar (*Lepisosteus sp.*) and common carp.

Sports fishes were generally poorly represented with the exception of white crappie in all of the lakes and channel catfish (*Ictalurus punctatus*) in Thighman Lake. No largemouth bass were collected from Beasley or Thighman lakes. Catfish production ponds located nearby and draining into Thighman Lake may account for the healthy population of channel catfish found in that oxbow. While all three lakes support large numbers of the popular game fish, white crappie, these fish were typically small averaging 19 to 29 grams.

Electrofishing

First year fishery surveys evaluating BMPs for improving the water quality and fisheries of oxbow lakes indicate successful renovation of the two lakes with the greatest improvement in water quality. Monitoring of the three lakes shows little or no change in the water quality of Beasley Lake, but a marked improvement in Thighman and Deep Hollow. Fish numbers in Thighman Lake which was treated with cultural based BMPs and Deep Hollow Lake affected by comprehensive structural and cultural BMPs showed increasing populations (Fig. 1) and decreased diversity (Fig. 2) while the lake receiving only structural BMPs (Beasley) showed a decline in both populations and diversity (Figs. 1 and 2). Bass populations, lacking in all of the lakes prior renovation and restocking, demonstrated good survival in Deep Hollow and Thighman (Fig. 3). Increased diversity seen in Figure 2 for Thighman Lake may be from species introduction from other portions of the drainage, escapees from adjacent catfish ponds, or fish released by fishermen.

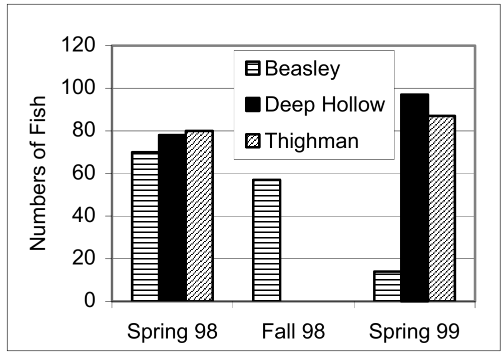

Figure 1. Electrofishing catch from MSEA lakes following lake renovation.

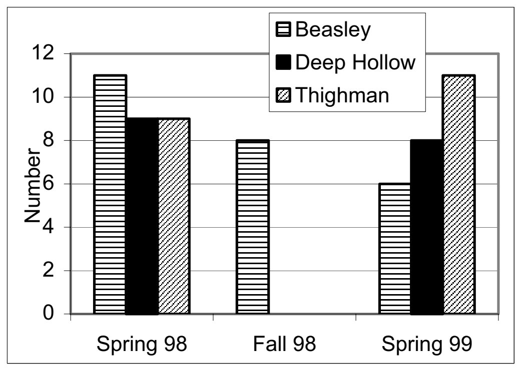

Figure 2. Number of species from Electrofishing catches from MSEA lakes following lake renovation.

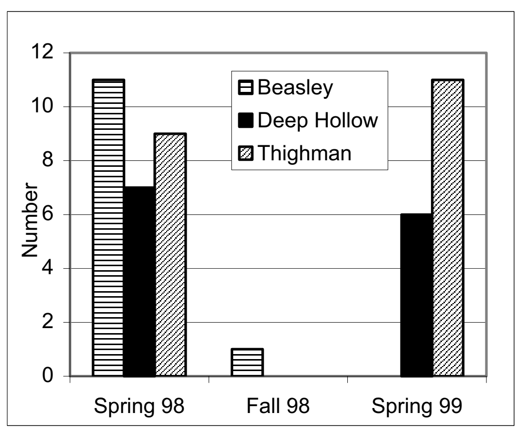

Figure 3. Number of largemouth bass *Micropterus salmoides* from Electrofishing catches from MSEA lakes following lake renovation.

SUMMARY

Fish species identified in the rotenone sampling were typical of oxbow lake fauna. Species richness was relatively low for all three MSEA lakes. Deep Hollow Lake had the greatest standing stock followed by Thighman and Beasley. Standing stocks roughly fell within the ranges reported in the literature for various natural and unfertilized man-made lakes. While the standing stock is in agreement with those reported in the literature much of the weight of fish from the MSEA lakes was made up of undesirable species such as gizzard shad, various species of gar (*Lepisosteus sp*.) and common carp.

Sports fishes were generally poorly represented with the exception of white crappie in all of the lakes and channel catfish (*Ictalurus punctatus*) in Thighman Lake. No largemouth bass were collected from Beasley or Thighman lakes.

Post BMP fishery surveys indicate successful renovation of lakes protected with cultural or structural and cultural practices. Water quality monitoring of the three lakes shows little or no improvement in the water quality of Beasley Lake, but a marked improvement in Deep Hollow and modest improvement in Thighman. Following renovation fish catches and diversity were highest in Thighman and Deep Hollow while Beasley showed a decline in both standing stock and diversity. Bass populations lacking in two of the lakes before renovation and restocking were successfully reestablished in Deep Hollow and Thighman. In all likelihood, restocking in Beasley Lake failed due to continuing poor water quality despite the presence of structural BMPs. Results indicate that cultural BMPs may play a more significant role in improving lake water quality and may be needed in addition to structural measures insure improve fisheries in oxbow lakes receiving agricultural runoff.

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The authors wish to thank personnel from Mississippi State University, the Mississippi Department of Wildlife Fisheries and Parks, the Mississippi Delta MSEA Technical Steering Committee, and cooperating agencies supporting the Mississippi Delta MSEA. In particular, we would like to thank Frank Gwin, Jr., Betty Hall, and Sam Testa III for providing technical support and assistance.

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NUTRIENT DISTRIBUTION IN REDUCED TILLAGE AND CONVENTIONAL TILLAGE COTTON SOILS

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Assessing plant nutrient status in soils is a critical component of reduced tillage management. This study characterizes spatial distribution of soil nutrients in two sub-areas of the Deep Hollow Lake watershed, one under crop residue management (CRM, wheat cover crop and reduced tillage) and the other receiving conventional tillage (CT). Objectives were to: (1) examine spatial relationships between soil nutrients and physical-chemical parameters; and 2) assess the influence of conservation practices on the spatial structure of soil properties. The two (approx. 2 ha each) sub-areas were laid out in a grid pattern, and soil was sampled in 1998 and 1999. Soils (0-5 cm depth) were characterized for organic matter (OM), texture, pH, phosphorus (P) and nitrate (NO_3). The spatial variability of soil properties was described using geostatistics. Crop residue management and landscape position were both important factors affecting the distribution of soil properties in this study. Lower levels of nitrate in the CRM (35 vs. 111 kg ha^{-1}) indicated that the plant residues were immobilizing soil nitrogen (N) or that less organic N was being mineralized. Higher P levels at the bottom of slopes may be attributed to movement in runoff as well as in association with higher levels of OM and clay.

INTRODUCTION

Long-term use of reduced tillage practices can significantly change the soil environment, particularly in the surface layer (Locke and Bryson, 1997). Plant residues not incorporated into the soil degrade slowly, and OM builds up in the surface over a number of years. These plant residues also serve as a mulch barrier to preserve soil moisture. If left undisturbed by tillage, a combination of enhanced OM and moist conditions provides an environment that is beneficial for microbial organisms. Microbial organisms and organic residues play an important role in the availability of plant nutrients in these soils (Locke and Hons, 1988). Residue management, especially with fall-seeded cereal cover crops, may "immobilize" soil nutrients during the winter, spring, and, depending on the growth stage at desiccation, during the early part of the following summer growing season (Dabney et al., 2001).

Crop residue management practices such as reduced tillage and use of cover crops require an intensive level of management input (Locke and Bryson, 1997). Accurate and detailed soil information is a critical element in managing plant nutritional needs. Precision farming technology is a tool to help farmers provide crops with a balanced supply of nutrients. Merging the management philosophy of reduced tillage with that of precision farming is a necessary objective for reducing fertilizer costs and potential environmental contamination by balancing chemical inputs with usage (uptake by plants) in sensitive areas. Achieving this goal requires information obtained by long-term studies of the effects of management on the spatial distribution of soil characteristics.

This study characterizes the spatial distribution of soil nutrients in two areas, one under crop residue management (CRM: cover crops and reduced tillage) and the other receiving conventional tillage (CT). Objectives of this study were to (1) examine spatial relationships among soil nutrients, specifically, soil NO_3, and P, and physical-chemical parameters; and (2) assess the influence of conservation practices on the spatial structure of soil properties. Additional information concerning this study is described in Staddon et al. (1999a, 1999b).

MATERIALS AND METHODS

Study Site and Soil Sampling

Two areas (each approx. 2 ha) under cotton (*Gossypium hirsutum*) production and located adjacent to Deep Hollow lake were studied for spatial distribution of various soil properties (OM, texture). The tops of slopes for each area were Dubbs very sandy loam, mid-slopes were Dundee loam, while the bottoms of slopes were Tensas silty clay loam. Slopes for both areas were less than 1%. One area was under crop residue management (CRM) since 1995. This management system included reduced tillage (annual subsoiling in fall and hipping up rows in spring) and a winter wheat (*Triticum aestivum*) cover crop desiccated in late winter. The last subsoiling and disking, as well as application of lime, occurred in Fall, 1997, so in 1998 and 1999, the CRM area was considered to be no-tillage with a wheat cover crop. The second area was under conventional tillage management (CT), which involved annual disking and bed preparation. Each year, fertilizer was applied in the spring before bed preparation (100 kg N ha^{-1} as urea or NH_3; 100 kg (30%) phosphate ha^{-1}).

A sampling grid was established using an equilateral triangle pattern with a distance between sampling points of 12.2 m. Initial sampling of the CRM soil was done in Fall, 1997, where sample cores were taken at depth increments of 0-5, 5-15, 15-25, 25-41, and 41-56 cm. Sampling for soil nutrients (CT and CRM) was performed during the second week of June in 1998 and 1999. Soil samples (upper 5 cm) were collected from within the cotton rows (top of row).

GPS (Pathfinder ProXR, Trimble Navigation, Ltd., Sunnyvale, CA) coordinates were recorded at each node so that this grid could be reestablished in subsequent years.

Soil Analyses

Soil pH (2:1, soil:0.01 M $CaCl_2$), OM (modified Mebius method; Nelson and Sommers, 1982) and texture (hydrometer method; Gee and Bauder, 1986) were determined using air-dried, ground, sieved (< 2 mm) samples. Nutrient analysis was performed at the Soil Testing and Research Laboratory, University of Arkansas (Marianna, AR). Soil NO_3 was extracted using ammonium sulfate. Soil P was extracted using the Mehlich III method.

Statistical Analyses

Geostatistical analysis (GS+, Gamma Design Software, Plainwell, MI) was used to determine the presence of spatial structure in the residuals. At least six points were included in each model. Correlation and regression analyses (SAS, 1986) were used to examine possible relationships between nutrient distribution and soil properties.

RESULTS AND DISCUSSION

Spatial Variability of Soil Properties and Nutrients

Geostatistical analysis showed that several soil parameters (P, OM, and clay) had significant spatial structure. This implies that over certain distances (a range) from a sampling point, the measure of a particular soil characteristic can be regarded as related and/or similar (i.e., they are spatially dependent). At locations further than that distance, the values for a particular soil characteristic are independent. Knowing the value of the range allows more efficient sampling for precision application of varying fertilizer rates. These geostatistical analyses can be used to construct contour maps of the distribution of relevant soil characteristics such as OM, clay texture, and soil P (Fig. 1 and 2). No spatial structure was observed for soil nitrate, indicating that samples were independent and equally variable.

The geostatistical analyses also indicated that trends in the spatial structure for each measured soil characteristic generally followed the topography of the areas (Fig. 1b and 2b). For example, the average clay content increases toward the lower slope positions (CT increases from 10 to 20 %, CRM 13 to 27%). Clay accumulation at the bottom of the slope and sand deposition higher up slope likely occurred over a long period of time during development of this alluvial soil. When the area was first farmed and cultivation began, processes of erosion and deposition by surface runoff accelerated. Changes resulting from these erosion processes can be demonstrated by looking at clay content at various soil depths in the CRM area (Fig. 3). At the bottom of the slope, clay content at deeper soil depths (e.g., 41-56 cm) is high (average 45%) compared to shallower depths (e.g., average 28% at 0-5 cm). The lower clay content in the shallow soil depths likely resulted from sand being deposited from runoff from the sandier upslope.

Unlike soil texture, soil characteristics such as OM and nutrient content can be influenced in a relatively short time by management. Soil P content increased with location toward the bottom of the slope (range from top of slope to bottom in 1998, CT 55 to 95 kg ha^{-1}, CRM 93 to 142 kg ha^{-1}) (Fig. 1c and 2c). The same trend observed for clay and P was also observed for soil OM, but was not as strong (Fig. 1a and 2a. The higher clay and OM in the lower slope area provide more P sorption capacity than did the sandier ridge soil. Phosphorus accumulated on organo-clay sorption sites would result in higher P levels in extracts from the downslope soil. The same rate of P fertilizer was applied over the entire area, so it can be inferred that the higher P levels in extracts from downhill soil resulted from P deposited during runoff from further up the slope.

Relationships Between Soil Properties and Residue Management

It is expected that under long term reduced tillage management, soil OM will increase (Locke and Bryson, 1997). The soil in the CRM area in this study was not disturbed for two years. An assessment over a longer term will be required to properly quantify changes in OM due to tillage, but several observations can be made after two years. Soil OM in CRM was greater than that in CT in both 1998 and 1999. The higher OM in CRM reflects the reduced tillage management of this area since 1995, even though the strict no-tillage management was initiated in 1997. There was also a slight increase in OM from 1998 to 1999 in CRM (Table 1). If this trend continues, the improvement to soil quality in CRM could be important in future years.

Little change in pH was observed from year to year (Table 1). Soil pH in the CRM area was higher than that in the CT area in both 1998 and 1999, reflecting lime applications.

Overall concentrations of phosphate were higher in CRM than in CT both years (Table 2). The surface soil was mixed during cultivation in CT, resulting in a redistribution of applied P over a greater depth and soil volume than in CRM. Phosphate was positively related to OM and clay and negatively related to sand content in both management areas (Table 3). As discussed previously, higher P levels were measured in areas at the bottom of the slope. Phosphorus is relatively immobile in soil, and significant movement by leaching is unlikely. However, the affinity of P for clay particles enhances its movement in runoff sediment.

Soil nitrate was higher in CT than in CRM both years (Table 2). The lower nitrate in CRM soil was attributed to immobilization of N in the organic residues accumulated at the surface. There was a weak positive correlation between nitrate and OM in CT (Table 3), but no such relationship existed between nitrate and OM in CRM. The variability in OM distribution at the surface of CRM soil likely contributed to this lack of trend. There was also a negative relationship between nitrate and pH for both CRM and CT (Table 3). The lower pH may have contributed to less optimum conditions for denitrification, resulting in higher nitrate levels (Focht and Verstraete, 1977).

CONCLUSIONS

This study indicates that soil fertility and nutrient availability in these Mississippi Delta soils are strongly influenced by soil properties, residue management, and landscape position. Development of site-specific nutrient management for these soils may be possible by gaining an understanding of the interactions among these three factors and their spatial distribution. In this study, soil OM and P were higher in the surface of CRM soil, while nitrate was 68% lower. This indicates that N may have been more limiting in CRM, perhaps caused by N immobilization in surface organic residues. A lack of tillage in CRM resulted in the P added in fertilizer remaining at the surface (125 kg ha^{-1}), while in CT, the P was mixed (81 kg ha^{-1}), likely making it more available to plant roots.

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Table 1. Various soil properties in 1998 and 1999 (0-5 cm depth), Deep Hollow Lake watershed, Mississippi.

Sub-Area	Property	Mean (s.e.)*	Mean (s.e.)*
		1998	1999
Conventional Tillage	pH	5.7 (0.02)	5.3 (0.02)
	OM	0.96 (0.03)	1.04 (0.03)
	Clay	15.7 (0.52)	-
Crop Residue Management	pH	6.9 (0.04)	6.7 (0.04)
	OM	1.02 (0.02)	1.21 (0.03)
	Clay	17.9 (0.73)	-

*s.e. = standard error

Table 2. Soil nitrate and phosphate in 1998 and 1999 (0-5 cm depth), Deep Hollow Lake watershed, Mississippi.

Sub-Area	Nutrient	Mean (s.e.)* kg ha^{-1}	
		1998	1999
Conventional Tillage	NO_3-N	102 (6.8)	120 (8.4)
	P	73 (2.0)	88 (2.1)
Crop Residue Management	NO_3-N	37 (2.5)	34 (1.2)
	P	111 (2.8)	139 (2.9)

*s.e. = standard error

Table 3. Correlation (r) of soil properties with soil nitrate and phosphate (1998 and 1999 combined), Deep Hollow Lake watershed, Mississippi.

	Nitrate†		Phosphate †	
	CT	CRM	CT	CRM
PH	-0.33***	-0.30***	-0.14*	NS
OM	0.26***	NS	0.60***	0.57***
Sand	-0.24***	-0.18*	-0.53***	-0.54***
Clay	NS	0.25*	0.60***	0.52***

†Levels (α) of statistical significance are: * = 0.05, and *** = 0.001.

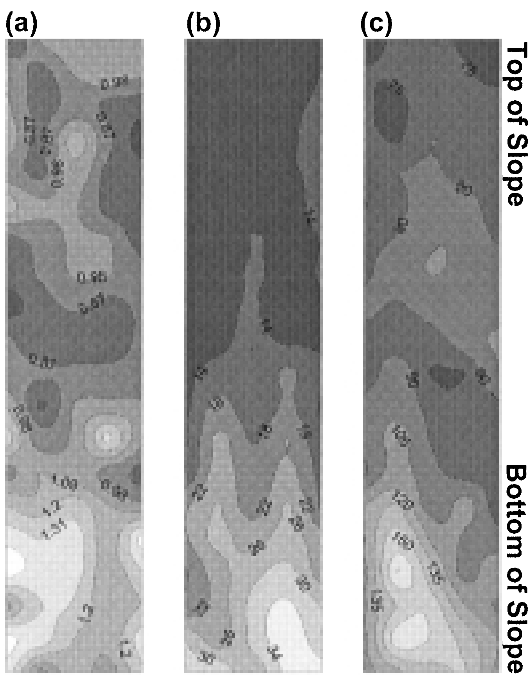

Figure 1. Soil characteristics in crop residue management area, 1999, Deep Hollow Lake watershed, Mississippi (a) % OM, (b) clay (kg ha^{-1}), (c) P (kg ha^{-1}).

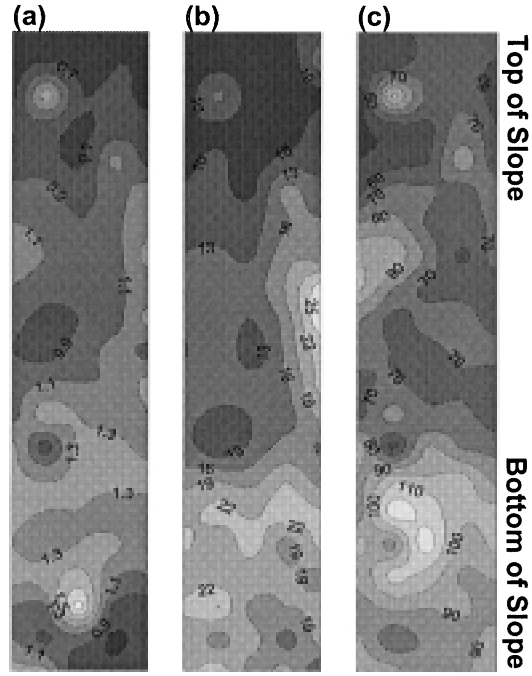

Figure 2. Soil characteristics in conventional tillage management area, 1999, Deep Hollow Lake watershed, Mississippi (a) % OM, (b) clay (kg ha^{-1}), (c) P (kg ha^{-1}).

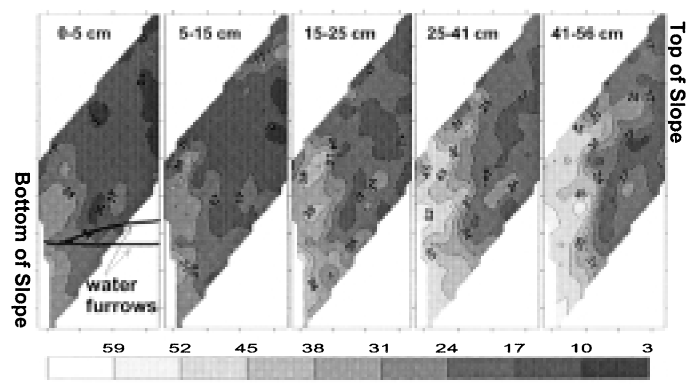

Figure 3. Clay content in several depth increments of the CRM soil area, Deep Hollow Lake watershed, Mississippi.

SELECTION AND PLANNING OF BEST MANAGEMENT PRACTICES ON THE MISSISSIPPI DELTA MSEA PROJECT

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ABSTRACT

The Mississippi Delta is one of the most intensively farmed areas in the United States. The alluvial soil materials are inherently rich in nutrients and rainfall is abundant; highly influencing the regions land users to produce row-crops on almost two million acres. Over fifty (50) percent of all row-cropped acreage in Mississippi lies in the Delta.

Surface water resources within the Delta region of Mississippi are extensive. There are over 100,000 acres of perennial streams and lakes (over 5 acres in surface area) in the Delta. Oxbow lakes, created from past stream and river meandering, are prevalent throughout the region. These lakes serve as water sources for irrigation and recreation and as natural filtering and flood control systems.

The soil textures range from clayey to sandy and land topography from nearly level to gently sloping. The potential for soil erosion that results in reduction of crop yields is low, but delivery of sediment to surface waters is high. Water quality impairment in the Mississippi Delta is of high concern due to sediment and the intensive use of nutrients and pesticides.

Research and studies conducted on small plots have proven the effectiveness of best management practices (BMP's). Research on a watershed size area is limited; however there are large scale research projects ongoing which demonstrate the performance of BMP's called Management System Evaluation Area (MSEA) studies. Funded through USDA-ARS, USDA-CSREES USGS and MDEQ the Delta area MSEA project was begun in 1994. Unlike the five ongoing projects located in the Midwest, the Delta MSEA project is based on three oxbow lake watersheds. Many other participating agencies and organizations are also involved. One of these agencies is USDA's - Natural Resources Conservation Service (NRCS).

The responsibility of the NRCS has been to develop the "Farm Plan" for each watershed. The "Farm Plan" includes the BMP's chosen for each watershed. The BMP's were initially recommended by a committee of scientists, agency field representatives and producers. Each watershed chosen was selected based upon a set of pre-determined requirements with each watershed receiving various degrees of treatment.

INTRODUCTION

The MSEA project includes the study of three watersheds that include oxbow lakes. The chosen lakes are: (1) Deep Hollow-Leflore County (2) Beasley Lake-Sunflower County and (3) Thigh-man Lake-Sunflower County.

One of the major goals of this project is to identify, implement and evaluate best management practices which have potential for use in the Mississippi Delta. A best management practice is the physical application of land and water management knowledge with the goal of protecting soil and water resources.

BEST MANAGEMENT PRACTICES

Selection Criteria

A multi-agency research project which evaluates and demonstrates best management practices on a watershed size area was begun in the Mississippi Delta in 1994. The Mississippi Delta Management System Evaluation Area (MSEA) was proposed due to high rainfall amounts and intensities falling on intensively cropped watersheds. Many of the storm events occur during times of the year when soils are most vulnerable to raindrop impacts and subsequent runoff (USDA Handbook 537).

The erosive nature of the soils combined with the highly refined drainage systems result in sediment yields which cause water quality impairment to the abundant surface water resources of the Delta. The sediment also serves as a carrier of other potential pollutants; specifically pesticides and nutrients. These non-point sources and their impact on the surface waters of the Mississippi Delta are the primary concerns of this project.

The Best management practices properly selected, designed and applied should control water movement and limit introduction of pollutants. Placing the

BMP'S into major headings leads to a clear and concise reasoning as to why practices were selected. The major practice types are:

* Runoff reducing, dispersing and filtering
* Erosion reducing
* Delivery ratio altering
* Pesticide and nutrient reducing

Eddie Taylor of Worton, Maryland probably says it best and simply by having stated that, "If you keep the soil where it belongs, nearly everything you apply to it stays put" (Progressive Farmer 1995). The first line of defense chosen to limit surface water pollution within the chosen watersheds (Deep Hollow, Beasley) was erosion reducing practices. These practices are designed to limit detachment and transport of soil particles. Soil detachment and movement are controlled by rainfall, soils, topography, cover conditions, and land use management.

Soils. The major land resource area (MLRA) known as the Southern Mississippi Valley Alluvium covers parts of five states. This area consists of 23 million acres of fertile, productive soils with fifty five (55) per cent being used for crop production (USDA-NRCS). The gently sloping to nearly level soils are deceiving to some degree in that erosion is considered relatively low. This is true when compared to the more steeply sloping, erodible soils to the east of the Mississippi Delta. Estimates based upon the USLE predict however that some of the Delta soils are eroding at levels greater than 10 tons per acre annually. This is twice tolerance and most often occurs on clean tilled cotton fields (USDA-NRCS-FOTG). Even though these levels have not yet impacted production, they are levels high enough to cause concern as related to water quality.

Rainfall. Rainfall dynamics has greatly aided our efforts in practice selection. Rainfall amounts, distribution and energy intensity are known to be greatest at crop stage periods when soils are most vulnerable to detachment and movement (USDA - HB 537). Almost seventy(70) per cent of Mississippi rainfall occurs during periods of crop production called the residue and seedbed preparation periods. The rainfall during these periods which coincide with the months of November through May also account for approximately fifty eight(58) per cent of the energy intensity associated with falling rainfall. Simply stated; the erosion of the soil is greatest during periods of higher rainfall associated with bare soils exposed to raindrops falling at speeds up to 30 feet per second (Meyer, DeCoursey and Romkens 1976).

Cover. The answer then seems simple! Delay tillage as long as practical to avoid the rainfall that is sure to come during the seedbed preparation period. Runoff and erosion plots at Holly Springs yielded 20 tons of soil per acre as the result of one rainfall event on May 31, 1982 . We cannot always count on long term predictions of storm distribution to design a cover management system. Our first line of defense is in field erosion control practices which are governed by rainfall dynamics and cover management techniques. The practices falling within these perimeters then become:

(1) CONSERVATION CROPPING SEQUENCE: A carefully devised crop production system which includes continuous row crop systems, crop rotations, tillage rotations and timing, use of close grown crops and narrow row technology. These are planned using the Universal Soil Loss Equation and the Revised Universal Soil Loss Equation.

(2) CROP RESIDUE USE: The maximum utilization of after harvest residues to cover soils during significant rainfall events. Residue amounts, distribution and persistence are considered in planning crop residue use.

(3) CONSERVATION TILLAGE SYSTEM: This is defined as any tillage system which leaves at least thirty(30) per cent of the soil surface covered after planting (USDA-NRCS-FOTG). This may be as complex as no-till cotton after a cover of vetch or as simple as reducing the number of tillage trips.

(4) COVER AND GREEN MANURE CROPS: The planting of a cover during the residue period of the cash crop. This is planned when the residue from the cash crop is not adequate or the cultural practices common to the cash crop call for destruction of the residues.

The cover management system chosen for the Deep Hollow Lake watershed is a combination of all of the above mentioned with an emphasis on cover crops and no-till crop production. Proper linking of soils with adaptable crops seems a simple and most often pre determined concern. Yet when looking at the impacts this simple decision has upon bio-mass production, canopy development, planting and harvest dates and soil stability; it becomes a major component of the cover management system.

Cotton grows best on well drained soils. To enhance the already efficient drainage systems, most cotton is planted on raised beds or hipped rows. Timely planting also enhances cotton production. This leads the Delta farmer to hip in the fall after harvest. Studies by ARS-Sedimentation Lab has shown much greater potential for higher erosion rates and off-field sediment movement due to these tillage systems (Meyer and Harmon 1978). Soil protection on fields hipped in the fall must be accomplished by planting a winter cover crop. Early planting and proper plant selection will result in a quicker cover and achieve a greater quantity of bio-mass production at an earlier date in the spring. Wheat was the choice on the Deep Hollow Lake watershed. Wheat is economical to plant, can be established easily, quickly covers the row side slopes and middles, can be eliminated with less cost and effort than some other cover crops and produces a stable cover that does not quickly decompose. Planting procedures and timely burndown will limit excess residue and properly selecting a planter will go a long way toward making the no-till cotton following wheat an acceptable and workable choice on the Deep Hollow site.

Reducing, dispersing and filtering runoff. Reducing runoff and dispersing the flow will limit transportability of sediment (Meyer, DeCoursey and Romkens 1976). Deposition occurs when transport capability of the runoff is reduced to the point that detached and transported soil material can no longer stay in suspension. Practices which allow more opportunities for deposition within field boundaries or prior to entering receiving waters comprise another component of any BMP system. These practices may be structural or vegetative and include:

(1) Grade Stabilization Structure: The grade stabilization structure is designed to control outlets of concentrated flow and slow runoff prior to exiting the field. Many variations exist and many have been planned and installed at the Deep Hollow and Beasley sites. Due to design limitations some of the structures have less ability to slow runoff to the point of dropping its' sediment load. However the structure may be controlling development of gullies at the outlet end of concentrated flow areas. Most however are designed to slow and release flow 24 hour storm events, thus causing some deposition to occur. The types that have been installed are: Flashboard risers, slotted inlet and the more typical cantilever overfall pipe. Where vegetative filter strip establishment and maintenance were suspect due to inundation caused by lake level fluctuations; the pipes were designed with extended levees.

Additional sites have been observed where flows are bringing excess sediment to field edges and the traditional pipe structure cannot be designed. These sites are being studied further for alternative methods of treatment. Such non-traditional methods as: toe wall structures, rock rip rap structures, vegetative flumes or grass hedges are being considered.

(2) Filter Strips: A grass strip 10 feet wide traps an estimated seventy(70) per cent of the soil leaving the field and twenty(20) to fifty(50) per cent of the chemicals (Kidwell 1995). Filter strips of tall fescue grass with widths of fifteen (15) feet have been strategically located at field edges and borders of surface ditches to filter runoff leaving the field in sheet flow. These vegetative measures serve as back up practices for the cover management practices. Tall fescue grass was chosen due to scheduling and installation restraints. Fescue is not as resistant to herbicides, traffic, nor as effective in trapping sediment as some other species. Spring seeding of switchgrass will be evaluated in the spring of 1996. Due to the erect, stiff-stemmed nature of switchgrass and the resistance it shows to herbicide injury, this species shows much promise in the State of Mississippi. It should also perform better where runoff flow is concentrated.

(3) Grass Hedge: Not yet an approved NRCS practice, the strips or hedges of tall, stiff-stemmed grasses planted across slopes of cropped fields are extremely effective in concentrated flow areas where runoff depths tend to bend traditional grass choices and where sediment levels have potential to cover lower growing grasses. Grass hedges of suitable vegetation also have the ability to re-grow after sediment accumulation (Meyer, Dabney, and Harmon 1995). The grass hedge is generally narrower than conventional filter strips and are more acceptable since they require less cropland for installation. Their efficiency at trapping fine silt and clay size particles is greatly diminished over their effectiveness in trapping sand size particles. This is also true for any of the grass filters. Switchgrass may become the grass of choice since the plant does not show the invader characteristics that some other species exhibit.

(4) Riparian Forest Buffer: The effect of riparian zones on agrichemical movement is not fully understood. It would be safe to say however that these naturally occurring barriers around most bodies of water in the Delta do have some ability to slow water movement and cause deposition. All of the selected watersheds have riparian zones which range in width from fifty (50) feet to as much as six hundred (600) feet from field edge to waterline of the oxbow lakes. Grassed filter strips were not planned where these riparian areas existed.

(5) Row Arrangement: Carefully arranged rows can result in adequate drainage and allow water movement to and sediment delivery to the field edge to be held to a minimum (Meyer 1981). This practice in many ways may be one of the most difficult to promote. Most Delta farmers have efficient drainage systems and arranging rows to move water as quickly from the field as possible is a major component of that system. Some common ground can be found however between the need for drainage and the need to control off site movement of sediment.

Pesticide and nutrient reducing. The Mississippi Delta is one of the major crop producing areas in the United States. Along with crop production goes the use of pesticides and nutrients and there is clear evidence that these have had an impact upon the water resources within the region. Limiting introduction and managing the use of these potential pollutants are the basis of the pest and nutrient management plan.

(1) Pest Management: Evaluating the need for applications by utilizing trained scouts and crop advisors is the primary component of an effective pest management program. The plan also calls for the use of and the following of all directions on pesticides labels. Proper storage and disposal of containers, careful mixing and loading, proper calibration of application equipment, timing of application in accordance with weather forecasts and the use of equipment which allows for reduced levels of application are other components of an effective pest management program. Most pesticides leave the field attached to soil or organic particles. By reducing runoff and associated sediment and trapping and filtering runoff with other best management practices the system becomes even more effective.

(2) Nutrient Management: Nutrients from agricultural non point sources have been identified as the main cause of cultural eutrophication in freshwater inland lakes of the United States with phosphorous being most often the nutrient of concern (Daniel, Sharpley, Edwards, Wedepohl and Lemunyon 1995). Nitrogen is the nutrient most subject to loss from the soil and much of this loss is due to leaching therefore, the greatest attention should be given to managing nitrogen(Stanford, England and Taylor 1970). Soil testing and application of nutrients based test results is the main component of the nutrient management plan. Fertilizer rates, formulation and method of application can influence loss as much as any of the cultural decisions made during crop production. Placement, timing , splitting of applications, and planting of cover crops that take up excess nutrients or provide organic forms of nitrogen are planned methods of controlling movement of nitrogen or phosphorous into the surface or ground water supplies. All of the noted methods and components are incorporated into the MSEA plans of Deep Hollow.

Social Considerations

Technically correct and well conceived best management practice systems will not always be implemented unless other considerations are reviewed and allowed to become a part of the planning activity. The questions asked of each component of the plan were:

(1) Is it implementable?
(2) Is it economical?
(3) Is it functional?
(4) Is it manageable?
(5) Is it acceptable?
(6) Does it fit the system?
(7) Is it flexible?

If the plan is technically correct and all of the above concerns and questions can be integrated into the plan, it then becomes a workable solution. This is what we believe we have achieved on the MSEA watersheds.

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QUALITY OF RUNOFF IN THE MISSISSIPPI DELTA MANAGEMENT SYSTEMS EVALUATION AREAS PROJECT, 1996-99

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INTRODUCTION

One of the most intensive agricultural areas of the United States is located in northwestern Mississippi, a 7,000-square-mile area locally referred to as the Delta. The fertile soils of the Mississippi Delta produce a variety of crops such as cotton, soybeans, corn, and rice. Similar to other areas of the Nation where agriculture is intense, water resources in the Mississippi Delta are vulnerable to potential adverse environmental effects caused by excessive sediment, nutrients, and pesticides transported from agricultural fields.

Suspended sediment—and turbid conditions caused by suspended sediment—is considered one of the primary water-quality concerns in the Mississippi Delta (State of Mississippi, 1999). Soil erosion and sedimentation have been well documented as causing declines in fisheries in Delta streams and oxbow lakes by limiting light penetration necessary for photosynthesis in aquatic plants (Cooper and Knight, 1978; Knight and others, 1994). The high erosion rates and off-field sediment movement could be linked to farming practices such as conventional tillage (Meyer and Harmon, 1978) where soil is disturbed frequently throughout the year, especially during winter and spring when rainfall is greatest. In addition, other contaminants such as nutrients and pesticides can attach to sediment and be transported during runoff events.

Excessive amounts of nutrients can lead to problems such as nuisance growth of aquatic plant material. Some of these problems are related directly to plant species; for example, certain varieties of algae (blue-green) can be toxic to fish. Other problems are the indirect result of excessive plant growth; depletion of oxygen as plants expire and decay can cause stress to fish and aquatic life. Nutrients are listed as a major impairment to Delta water bodies (State of Mississippi, 1999); however, none of the fish kills in the Delta have been directly linked to agricultural nonpoint sources of nutrients (State of Mississippi, 1999).

Pesticides are the most highly publicized pollutants in the Delta, as well as in the rest of Mississippi and the Nation. Numerous fish kills have been directly linked to agricultural nonpoint sources of pesticides. The largest fish kill documented in Mississippi occurred in the Delta in 1992 as a result of an insecticide transported in agricultural runoff (State of Mississippi, 1999). Another recent (1998) fish kill in the Delta was attributed to pesticides in runoff (State of Mississippi, 1999).

The Mississippi Delta Management Systems Evaluation Areas (MDMSEA) project began in 1995 to study agricultural nonpoint-source pollution of oxbow lake watersheds. Specifically, the two purposes of the MDMSEA project were to assess the effects of agriculture on water quality and to evaluate best management practices (BMP's) designed to improve water quality. As part of the MDMSEA project, the U.S. Geological Survey (USGS) began operating an automated streamflow and water-quality sampling network in April 1996 to assess the effects of an untreated system and BMP systems on edge-of-field runoff quality (Rebich, 1997). This report presents selected concentration and load data for sediment, nutrients, and pesticides from runoff samples collected from nine sites for the MDMSEA project from 1996 through 1999. The report also presents evaluations of the data to compare runoff quality from an untreated field to BMP-treated fields.

SITE LOCATIONS AND FIELD TREATMENTS

The three MDMSEA oxbow lake watersheds are located in Sunflower and Leflore Counties in northwestern Mississippi. Nine USGS streamflow and water-quality sampling sites were established in the MDMSEA watersheds to characterize the runoff from untreated and BMP-treated fields (streamflow and water-quality sampling sites are hereafter referred to as runoff sites). The watersheds and runoff sites are described in the following sections; however, due to space limitations, the locations of the watersheds in Mississippi and the runoff sites within each watershed are not shown.

A. Thighman Lake watershed (Sunflower County) - The total drainage area of this watershed, the largest of the three, is about 3,700 acres. Soils in the watershed vary from a loam to a very heavy clay. The Thighman watershed was selected as the control watershed with no BMP's planned by the MDMSEA project. Runoff quality in the Thighman watershed was expected to be the poorest of the three watersheds because conventional tillage was predominant at the beginning of the study. The primary row crops grown in 1995-96 at Thighman were cotton and soybeans, but producers grew a large amount of corn from 1997 to 1999 as a result of market changes (Gwin, 2001). In addition, producers in the upper Thighman drainage area began to utilize conservation tillage starting about 1997, possibly in an effort to reduce overhead costs and increase profit. Two runoff sites are located in the Thighman watershed:

- TL2 is on the primary inlet tributary of Thighman Lake and drains about 1,470 acres. Data collected from this site were used to document chemical and sediment loads entering the lake during runoff events.
- TL3 is an edge-of-field site located downstream of a cotton field that was in conventional tillage without BMP's for the entire study period. TL3 drains about 14 acres, and data collected at this untreated site were compared to data collected from the BMP sites.

B. Beasley Lake watershed (Sunflower County) - The total drainage area of this watershed is about 2,100 acres. Soils are generally a loam, and the primary crops include cotton and soybeans with some corn and rice. A large riparian area (about 800 acres) adjacent to the eastern side of the lake, in effect, serves as a natural filter. BMP's used in the Beasley watershed were primarily edge-of-field treatments and were either structural, such as slotted-board risers and slotted inlet pipes, or vegetative, such as grassed filter strips. These BMP's were considered to be more economical than other BMP's considered for the MDMSEA project. Although slotted-board risers have proven effective in reducing sediment-laden waters from entering receiving waters such as lakes (State of Mississippi, 1999), the BMP's used at Beasley were not expected to produce the highest level of improvement to runoff quality. Five runoff sites were installed in the Beasley watershed:

- BL1 drains about 100 acres of conventional-tillage cotton and is located in a grassed open-channel ditch. Filter strips and slotted-board risers were installed at strategic locations within the BL1 drainage area, but not directly upstream of the sampling point. Data from BL1 were used to evaluate the combined effectiveness of the grassed drainage ditch, slotted-board risers, and filter strips as a system of BMP's.
- BL3 drains about 18 acres of conventionally tilled crops. Cotton was grown every year at this site, except 1998 when corn was grown. A slotted-board riser was installed at the drainage outlet for this sub-watershed directly upstream of the sampling point. No other BMP's were used at this site, and the effectiveness of the slotted-board riser was evaluated individually. Typically, boards were placed in the riser in the fall shortly after harvest (late October) and then removed about one month before planting in the spring (late March) each year. However, boards were installed for only about 1 month in the fall of 1997 (no runoff events) at the request of the landowner in order to prepare fields prior to planting corn in the spring of 1998. Boards were not reinstalled at BL3 until October 1998.
- BL4, BL4A, and BL4B are located within the natural riparian area located directly east of Beasley Lake. Data from these three sites were used to assess the effects of the riparian area on runoff quality. BL4A and BL4B drain about 380 and 170 acres, respectively, and are located at separate drainage ditches on the east side of the undisturbed riparian area. Fields upstream (not directly) of BL4A and BL4B were primarily in conventional tillage. BL4 drains about 840 acres and is located on the west side of the riparian area near the outlet upstream of the lake entrance.

C. Unnamed Lake watershed (Leflore County) – This lake is not named on the USGS topographic map, but is locally and hereafter referred to as Deep Hollow Lake. The total drainage area of this watershed, the smallest of the three, is about 500 acres. Most of the watershed has loam soils that support cotton production (about two-thirds of the watershed), but heavier, clay soils also are present where soybeans are grown. This watershed received the most extensive BMP treatments and was expected to have the greatest improvements to runoff quality of the three watersheds. The same structural and vegetative edge-of-field treatments used in the Beasley watershed also were used in the Deep Hollow Lake watershed. In addition, residue-management practices, such as conservation tillage and winter cover, and new technologies, such as hooded sprayers with weed sensors, were used in this watershed. Two runoff sites were installed in the Deep Hollow Lake watershed:

- UL1 drains about 42 acres where cotton and soybeans were grown throughout the study period. Conservation-tillage cotton was grown in the upper elevations of the UL1 drainage area farthest from the sampling point, and no-till soybeans were grown in the lower elevations nearest the sampling point. Winter wheat was grown on the entire cropped area in the fall of each year with cover lasting from about late fall through late winter. This cover crop was chemically "burned down" or poisoned each year prior to planting in the early spring. In addition, a slotted-board riser was installed on the culvert entrance directly upstream of the sampling point at UL1.
- UL2 drains about 25 acres where cotton and soybeans were grown throughout the study period. Similar to UL1, conservation-tillage cotton was grown in the upper elevations and no-till soybeans were grown in the lower elevations of the UL2 drainage area. Winter wheat was grown on the entire cropped area in the fall of each year and burned down at UL2 at the same time each year as at UL1.

MATERIALS AND METHODS

Continuous streamflow records (or total-runoff volume) were collected at six of the nine runoff sites, the exception was the Beasley riparian area sites. Water-quality samples were collected at each runoff site. The samples were analyzed to determine sediment, nutrient, and selected pesticide concentrations, which were then used to calculate contaminant loads. The following sections describe sample collection procedures, sample analyses, and load calculations.

Sample Collection

The samples were collected from automated samplers installed at each site. Quality assurance/quality control (QA/QC) measures were taken to avoid possible contamination to the samples and to assess bias and variability in the analyses (Rebich, 1997). Streamflow was measured at six sites by using flumes, weirs, or acoustic Doppler instrumentation. Streamflow was not measured at the riparian sites, BL4, BL4A, and BL4B, in the Beasley watershed.

Automated samplers were activated during runoff events when the water level in a flume or weir exceeded a specified elevation. Once activated, the samplers pumped runoff into sample bottles after a specified volume of water flowed past the sampling point. For example, at the UL2 site, after each 4,000-cubic-foot (ft^3) increment of water flowed past the sampling point, the sampler pumped runoff into a sample bottle. This technique is referred to as flow-proportional sampling.

Composite and discrete flow-proportional samples were collected. For composite sampling, each sample of runoff was pumped into a single sample bottle. For example, at the UL2 site, after each 4,000-ft^3 increment of water flowed past the sampling point, 100 milliliters (mL) of water was pumped into the single sample bottle. So, at the end of a storm that produced 40,000 ft^3 of runoff, a single sample bottle would contain 1,000 mL, or 1 liter (L), of runoff. Water from this single container would then be analyzed for sediment, nutrient, and pesticide concentrations. Therefore, a composite sample represents a "storm-averaged" concentration of contaminants in the runoff. All nine runoff sites were equipped with a sampler dedicated to composite sampling.

In contrast to composite sampling, each sample of runoff was pumped to a separate sample bottle for discrete sampling. For example, at UL2, after each 8,000-ft^3 increment of water flowed past the sampling point, 1 L of runoff water was pumped into an individual sample bottle. So, if a storm produced 80,000 ft^3 of runoff, ten 1-L containers were available and analyzed individually. Discrete samples were used to determine variation of contaminant concentration over time during each runoff event and to produce more accurate estimates of load. Three sites (TL3, BL3, and UL2) were equipped with samplers dedicated to discrete sampling.

Sample Analyses

Samples were shipped to three different USGS laboratories for sediment, nutrient, and pesticide analyses. About 2,300 samples were analyzed for suspended sediment by the USGS sediment laboratory in Baton Rouge, LA. About 730 samples were analyzed for selected nutrients by the USGS Quality of Water Service Unit in Ocala, FL; analyses included nitrogen species - dissolved nitrite plus nitrate, dissolved nitrite, dissolved ammonia, and total ammonia plus organic nitrogen; phosphorus species - dissolved ortho-phosphorus and total phosphorus; and total organic carbon (dissolved nitrate concentrations presented later in this report were calculated values based on the difference between dissolved nitrite plus nitrate and dissolved nitrite). About 600 samples were analyzed for pesticides (herbicides) by the USGS Organic Geochemistry Laboratory in Lawrence, KS. Herbicide analyses by gas chromatography/mass spectrometry (GC/MS) included the following parent compounds: acetochlor, alachlor, atrazine, cyanazine, fluometuron, metolachlor, metribuzin, molinate, norflurazon, prometryn, propanil, propazine, simazine, and trifluralin; and the following degradation products: cyanazine-amide, deethylatrazine, deisopropylatrazine, deisopropylprometryn, demethylfluometuron, demethylnorflurazon, 3,4-dichloroanaline, trifluromethyl analine (TFMA), and trifluromethyl phenyl urea (TFMPU). Herbicide analyses by immunoassay included fluometuron, atrazine, and metribuzin.

Load Calculations

For this report, flow data were available for only TL3, BL3, and UL2, therefore, load calculations were made only for those three sites. Loads were calculated by using discrete data where available and procedures described by Porterfield (1972). Loads also were calculated by using composite data for runoff events where discrete data were not available. Some loads were estimated by using regression techniques described by Porterfield (1972) for storms where neither discrete nor composite data were available. Finally, loads were normalized by dividing each individual storm load by the drainage basin size and were expressed as tons (or pounds) per acre.

RESULTS AND DISCUSSION

Concentration (composite samples) and load data from the untreated site, TL3, are presented in the first section of this report to establish a baseline of information for agricultural practices where no BMP's were used. Concentration and load data from the BMP sites then are compared to data from TL3 in the second section of this report to document potential improvements to runoff quality. Concentration data are compared to available aquatic life standards, criteria, or recommendations, and other relevant research findings in an effort to assess water-quality conditions. Available drinking water standards for nutrients and pesticides are also provided for perspective purposes only; because runoff and lake water are not considered drinking water sources in these watersheds, direct comparisons of nutrient and pesticide concentrations in runoff to drinking water standards are not applicable.

Runoff Quality from the Untreated Site

Sediment, nutrient, and pesticide concentration and load data from TL3 are discussed in the following paragraphs relative to their effect on runoff quality.

Sediment. In 1996, all three oxbow lakes were stressed due to sediment (Knight and others, 2001). Much of the effect of sediment on the lakes was likely the result of conventional tillage, which was predominant among all of the watersheds at the beginning of the study. In some watershed locations, fields were plowed nearly to the edges of the lakes. As previously noted, TL3 remained in conventional tillage without BMP's throughout the study period. The distribution of suspended-sediment concentrations for TL3 is presented in figure 1. The median suspended-sediment concentration was about 1,350 milligrams per liter (mg/L), and concentrations exceeded 4,000 mg/L in 10 percent of the samples.

Although no aquatic health standards currently exist for suspended-sediment concentrations for lakes, Cooper and Bacon (1980) stated that primary productivity (phytoplankton) was adversely affected when suspended-sediment concentrations exceeded 100 mg/L. All concentrations of suspended-sediment in the runoff from TL3 exceeded 100 mg/L. In addition, the average annual suspended-sediment load for TL3 was 4.9 tons per acre per year, which was the highest average of the three sites where loads were calculated (table 1).

Nutrients. None of the lakes seemed to be adversely affected prior to the study due to excessive nutrients or over-production of aquatic plants. However, nitrogen and phosphorus in the runoff were excessive at times, especially at TL3. The median nitrate concentration at TL3 was about 1.8 mg/L, and concentrations exceeded 6 mg/L in 10 percent of the samples (fig. 1). All of the nitrate concentrations at TL3 were less than the 10-mg/L drinking-water standard [United States Environmental Protection Agency (USEPA), 1986]. Although no current aquatic life criterion exists for nitrate, nutrient criteria are currently being developed by each State (USEPA, 1999). As a comparison to other aquatic systems, more than 90 percent of the nitrate concentrations at TL3 exceeded the nitrate values typical for woodland lakes and catfish ponds, 0.075 and 0.25 mg/L, respectively (Boyd, 1979). This comparison of nitrate (and subsequent comparisons of other nutrients later in this section) in runoff from TL3 to the values from Boyd (1979) is provided for perspective purposes only. It is expected that nitrate concentrations from edge-of-field runoff would be higher than concentrations of nitrate in lakes due to dilution and processing that occur in lake systems. The average annual nitrate load was 11 pounds per acre per year at TL3, which was the highest average of the three sites where loads were calculated (table 1).

Ammonia exists in two forms in natural water: as ammonium ion (NH_4) and as un-ionized ammonia (NH_3). Aquatic organisms are highly sensitive to the un-ionized form based on chronic and acute exposures. Typically in natural waters, both forms are in equilibrium, which is influenced by pH and temperature. Criteria for ammonia reflect the influence of pH and temperature; for natural waters ranging in pH from 6.5 to 9 and temperatures ranging from 0 to 30 °C, ammonia concentrations should not exceed about 2.1 mg/L (USEPA, 1986). The median dissolved ammonia concentration at TL3 was 0.05 mg/L, with no concentrations at TL3 exceeding the ammonia criterion (fig.1). The average annual ammonia load was 0.99 pounds per acre per year at TL3, which was the highest average of the three sites where loads were calculated (table 1).

No standards or criteria currently exist for ammonia plus organic nitrogen. Sources of ammonia plus organic nitrogen include fertilizers and the decay of organic material such as plant debris and animal wastes. Both ammonia and organic nitrogen are relatively immobile in soils and ground water because of adsorption on soil surfaces and particulate filtering; however, both are susceptible to nitrification under aerobic conditions (USGS, 2000). Thus, the measure of total ammonia plus organic nitrogen represents the amount of nitrogen available for oxidation and could be considered a sink of oxygen for the oxbow lakes. The median total ammonia plus organic nitrogen concentration was about 3.5 mg/L, and concentrations exceeded 6 mg/L in 10 percent of the samples (fig. 1). The average annual total ammonia plus organic nitrogen load was 22 pounds per acre per year at TL3, which was the highest average of the three sites where loads were calculated (table 1).

Currently, there are no aquatic life criteria for phosphorus in natural waters; however, for perspective purposes, the USEPA (1987) suggests that total phosphate levels (which include ortho-, pyro-, and poly-phosphate) should not exceed 0.05 mg/L for waters entering a lake in order to control eutrophication. The USEPA (1987) also recommends that total phosphorus should not exceed 0.1 mg/L for flowing waters that do not discharge directly into lakes or impoundments. The median dissolved ortho-phosphorus concentration at TL3 was about 0.09 mg/L, and concentrations exceeded 0.06 mg/L in 75 percent of the samples (fig. 1). The average annual dissolved ortho-phosphorus load at TL3 was 0.53 pound per acre per year (table 1). The median total phosphorus concentration at TL3 was about 0.8 mg/L; all concentrations of total phosphorus were above 0.1 mg/L (fig.1). The average annual total phosphorus load at TL3 was 4.6 pounds per acre per year (table 1).

The fertility status of phosphorus in Delta soils is fairly high, and additional applications of phosphorus are typically unnecessary (Smith and others, 2001). Since phosphorus binds fairly readily to soils, the high total phosphorus concentrations in runoff indicated excessive amounts of sediment in the runoff. Although phosphorus concentrations were excessive in runoff at TL3 and in Thighman Lake, no nuisance plant growth was evident in the lake during the study period even after conservation tillage was used more in the upper Thighman drainage and sediments were reduced in the lake (Knight and others, 2001).

Total organic carbon is a measure of the amount of suspended and dissolved organic material present in the runoff. Similar to the discussion about total ammonia plus organic nitrogen, total organic carbon represents a sink for dissolved oxygen in receiving waters because organic materials deplete oxygen upon decay. The median total organic carbon concentration at TL3 was about 7 mg/L, and concentrations exceeded 10 mg/L in 10 percent of the samples (fig. 1). The average annual total organic carbon load at TL3 was 42 pounds per acre per year, which was the highest average of the three sites where loads were calculated (table 1).

Pesticides. The concerns with pesticides focus not only on the potential impact to human health, but also on aquatic life and wildlife. Early in the project, emphasis was placed on sampling herbicides rather than insecticides in runoff. Typically, insecticides such as pyrethroids and organophosphates are not very water soluble, degrade fairly rapidly, and are not expected to be present at elevated levels in the runoff unless a runoff event occurs shortly after application. Insecticides were re-emphasized in the USGS sampling program after partnering with industry and with the United States Department of Agriculture, Agricultural Research Service, in 1998. The results of the insecticide sampling were published in Southwick and others (2000). Only a few detections of pyrethroids at or near the detection levels and no detections of organophosphates were found in the runoff from any of the sites.

Some herbicides are more water soluble and remain in the environment for longer periods of time than insecticides. The five herbicide compounds most frequently detected in all samples were fluometuron, atrazine, norflurazon, metolachlor, and cyanazine (table 2). Other herbicides and herbicide degradation products were detected, although less frequently than these five compounds (data not shown). Concentrations of fluometuron, norflurazon, and cyanazine were selected for comparison because these were the only three herbicides common among all nine sites. Loads were calculated only for fluometuron for the three sites where flow data were available.

Fluometuron is used primarily as a pre-emergent cotton herbicide applied at planting, and is fairly popular among cotton growers in the Mississippi Delta. Fluometuron was detected at concentrations at or above 0.05 micrograms per liter (µg/L) in 97 percent of the herbicide samples from TL3 (table 2). Only one sample at TL3 had a concentration of fluometuron higher than the drinking-water standard for fluometuron, which is 90 µg/L (table 2). Aquatic health criterion does not exist for fluometuron, so assessments of fluometuron effects to runoff quality could not be made at this time. About 7 percent of the fluometuron applied was present in the runoff from TL3 (table 3).

Norflurazon is a pre-emergent herbicide for cotton and soybeans. Norflurazon was detected at concentrations at or above 0.05 µg/L in 74 percent of the samples from TL3 (table 2). At TL3, the median concentration of norflurazon was 0.68 µg/L, and less than 10 percent of the samples exceeded 3.6 µg/L. No drinking-water standard or aquatic health criterion currently exist for norflurazon; therefore, no assessments could be made about the effects of norflurazon on runoff quality.

Cyanazine is used both as a pre- and post-emergent herbicide for cotton and corn. Cyanazine was detected at concentrations at or above 0.05 µg/L in 51 percent of the samples from TL3 (table 2). Cyanazine concentrations exceeded both the drinking-water standard (1 µg/L) and the aquatic health criterion (2 µg/L) in less than 25 percent of the samples. It is noteworthy that these high concentrations (greater than 1 or 2 µg/L) occurred in 1997 only; by 1999, concentrations of cyanazine were at or near the detection limits (data not shown). Based on information supplied by the grower in the drainage area of the Thighman runoff site in the 1996 and 1997 growing seasons, cyanazine was applied on cotton acreage at planting in the spring. Typically, there are several large runoff events that occur each year shortly after planting resulting in high concentrations of cyanazine in the runoff in 1996-1997. However, in the 1998 and 1999 growing seasons, the grower began to apply cyanazine only as a lay-by treatment, which typically occurs in the summer months during dry conditions. Thus, runoff events occurred infrequently and at longer periods of time after application resulting in low concentrations of cyanazine in the runoff.

Runoff Quality from BMP Sites

As noted previously, soils, crops, drainage basin size, and farming practices varied substantially among the runoff sites in the three MDMSEA watersheds. These variations could limit data interpretation, especially when comparing data from the untreated site, TL3, to data from the BMP sites. Although selected mathematical differences are cited in the following sections, these differences do not account for the site-to-site variations, and the reader is cautioned not to over-interpret the results.

Statistical tests for significance were used to compare concentrations from the eight BMP sites to concentrations from TL3, and to compare loads from BL3 and UL2 to loads from TL3 (Kruskal-Wallis test, Helsel and Hirsch, 1992). The entire data set of concentrations and loads for the study period from each site was used in the tests. Results of the tests indicated whether differences in data sets from the BMP sites were statistically significant when compared to data sets from TL3. Selected results from these tests are presented in the following sections, but the data are not shown.

Sediment. All of the median suspended-sediment concentrations at the eight BMP sites exceeded 100 mg/L (fig. 1). Although most of the suspended-sediment concentrations at the BMP sites did not drop below this "threshold" concentration, there were some fairly substantial differences between suspended-sediment concentrations (and loads) at selected BMP sites compared to concentrations (and loads) at TL3. These differences, along with dilution in the lakes, could lower the concentrations of sediment in the lakes to acceptable levels to sustain primary productivity.

- The differences in suspended-sediment concentrations were statistically significant when comparing concentrations at TL2 to concentrations at TL3. The median suspended-sediment concentration was about 72 percent lower at TL2 than at TL3 (fig. 1). These low concentrations at TL2 could reflect changes in farming practice from conventional tillage to more conservation tillage which began in 1997 in the Thighman watershed. In addition, the lower portion of the TL2 drainage area is considered to be a wetlands/riparian area historically affected by periodic backwater conditions from beaver dams, damaged culverts, and high lake levels. As runoff drains from the fields through the long channel, backwater conditions could cause the velocity of the water to slow and allow sediment to settle.
- The differences in suspended-sediment concentrations were not statistically significant when comparing concentrations at BL3 and BL1 to concentrations at TL3. The median suspended-sediment concentration was slightly lower at BL3

and was slightly higher at BL1 compared to TL3 (fig. 1). These data indicate that the edge-of-field structural and vegetative treatments had little effect in reducing suspended-sediment concentrations.

- The differences in suspended-sediment loads were not statistically significant when comparing loads at BL3 to TL3, although the average annual suspended-sediment load was 16 percent lower at BL3 than at TL3 (table 1). However, it should be noted that two boards were permanently installed at BL3 since 1996. Runoff samples were collected immediately after water passed over the boards, and heavier sediment (or bed load material) was not measured during the study period. Since 1996, about one foot of heavier sediment was trapped in front of the permanent boards. In addition, suspended-sediment loads were reduced about 30 percent (data not shown) when additional boards were installed on top of the permanent boards, which was typically during the non-growing season months (October through March) of each year.
- Suspended-sediment loads at BL3 sharply declined starting in 1998 and continued through 1999 (fig. 2). If concentrations of sediment at BL3 were not statistically different from concentrations at TL3, then the lower loads at BL3 were due to less runoff in 1998 and 1999 (table 1). Although slotted-board risers were designed to reduce runoff, the lower amounts of runoff at BL3 were not due to the slotted-board riser. A field road that bisects the BL3 drainage was altered substantially in 1998 when corn was planted. After the field road was altered, runoff drained only to the sampling site during large runoff events. Therefore, less runoff was observed at BL3 from 1998 to 1999 due to the drainage basin alterations rather than the slotted-board riser.
- Differences in suspended-sediment concentrations were statistically significant when comparing concentrations at BL4A, BL4B, and BL4 to concentrations at TL3. Median suspended-sediment concentrations were 70, 88, and 84 percent lower at BL4A, BL4B, and BL4, respectively, than at TL3 (fig. 1). The low concentrations at these sites reflected the ability of the drainage ditches and the undisturbed riparian area at Beasley to filter sediment from runoff.
- Differences in suspended-sediment concentrations were statistically significant when comparing concentrations at UL2 and UL1 to concentrations at TL3. Median suspended-sediment concentrations at UL2 and UL1 were 62 and 48 percent lower, respectively, than concentrations at TL3 (fig. 1). Differences in suspended-sediment loads were statistically significant when comparing loads at UL2 to loads at TL3. The average annual suspended-sediment load was 70 percent lower at UL2 than at TL3 (table 1).

Nutrients. Nitrogen and phosphorus application data were not available at the time of this report, thus ratios of nutrients applied to nutrients in the runoff could not be calculated. Statistically significant differences were observed primarily when comparing nitrate, total ammonia plus organic nitrogen, and total phosphorus data for the BMP sites to date from TL3. In contrast, site comparisons of ammonia, ortho-phosphorus, and total organic carbon data showed fewer statistically significant differences.

- Median nitrate concentrations at the BMP sites were all lower than the drinking-water standard of 10 mg/L, but exceeded the typical nitrate values for woodland lakes and catfish ponds (0.075 and 0.25 mg/L, respectively, fig. 1). Nearly all of the ammonia concentrations at the BMP sites were less than 2.1 mg/L (fig. 1).
- The differences in nitrate concentrations were not statistically significant when comparing concentrations at TL2 to concentrations at TL3; also, the median ammonia concentration was about 400 percent higher at TL2 than at TL3 (fig. 1). These data may reflect the higher application of nitrogen fertilizers in 1997-99, corresponding with the gradual crop changes from cotton and soybeans to corn in 1997 in the upper drainage of TL2.
- The differences in nitrate concentrations were statistically significant when comparing concentrations at BL1, BL4B, BL4, UL2, and UL1 to concentrations at TL3. Median nitrate concentrations were 58, 81, 81, 84, and 80 percent lower at BL1, BL4B, BL4, UL2, and UL1, respectively, than at TL3 (fig.1). These five sites were characterized by more vegetation in their drainage areas than the other four sites: the channel directly upstream of BL1 is grassed; BL4B and BL4 were located in the densely vegetated riparian area at Beasley; and residue from winter cover and conservation tillage was abundant upstream of UL2 and UL1. One explanation is that extra organic material promoted denitrification at these sites converting nitrate to nitrogen gas; however, this explanation requires further research.
- The differences in nitrate concentrations and loads were not statistically significant when comparing concentrations and loads at BL3 to those at TL3. The differences in nitrate loads were statistically significant when comparing loads at UL2 to loads at TL3. The average annual nitrate load was 74 percent lower at UL2 as compared to TL3 (table 1).

- Total ammonia plus organic nitrogen concentrations and loads at the BMP sites generally followed the same pattern of variation as values for suspended sediment. The differences in ammonia plus organic nitrogen were statistically significant when comparing concentrations at TL2, BL4A, BL4B, BL4, and UL2 to concentrations at TL3. Median ammonia plus organic nitrogen concentrations were 43, 54, 63, 47, and 40 percent lower at TL2, BL4A, BL4B, BL4, and UL2, respectively, than at TL3 (fig. 1). Differences in total ammonia plus organic nitrogen loads were not statistically significant when comparing loads at BL3 to loads at TL3, but were significant when comparing loads at UL2 to loads at TL3. The average annual total ammonia plus organic nitrogen load was 56 percent lower at UL2 than at TL3 (table 1).
- Nearly all of the ortho-phosphorus concentrations exceeded 0.05 mg/L, and all of the total phosphorus concentrations exceeded 0.1 mg/L at the BMP sites (fig. 1). The total phosphorus concentrations were lowest where sediment concentrations were lowest. Median total phosphorus concentrations were 52, 27, and 63 percent lower at TL2, BL4A, and BL4B, respectively, than at TL3 (fig. 1). Differences in total phosphorus loads were not statistically significant when comparing loads at BL3 to loads at TL3, but were statistically significant when comparing loads at UL2 to loads at TL3. The average annual total phosphorus load was 28 percent lower at UL2 than at TL3 (table 1).

Pesticides. Herbicide applications were not similar at any of the runoff sites in the MDMSEA study; therefore, accurate comparisons of herbicide data from the BMP sites to data from TL3 were virtually impossible. Only a few general statements are listed below.

- Fluometuron, norflurazon, and cyanazine were detected at or above 0.05 µg/L in 71, 38, and 33 percent of the samples from BL3, respectively. These three herbicides were detected in 79, 50, and 26 percent of the samples from UL2, respectively (table 2).
- Fluometuron concentrations exceeded the drinking-water standard less than 10 percent of the time at BL3. Cyanazine concentrations never exceeded the drinking-water standard or aquatic health criterion at BL3 (table 2).
- Fluometuron concentrations never exceeded the drinking-water standard at UL2; cyanazine concentrations exceeded the drinking-water standard and aquatic health criterion less than 10 percent of the time (table 2).
- Fluometuron concentrations were lower at UL2 than at TL3 or at BL3 (table 2). About 2 and 3 percent of the fluometuron that was applied at UL2 and BL3, respectively, was present in the runoff as compared to about 6 percent at TL3 (table 3).

SUMMARY

The quality of the runoff was considered to be the poorest at the untreated site, TL3. This statement is supported by the fact that some of the highest concentrations of sediment, nutrients, and pesticides were found in runoff samples from TL3. In addition, suspended-sediment, nitrate, ammonia, total ammonia plus organic nitrogen, and total organic carbon loads were the highest at TL3.

The edge-of-field structural and vegetative BMP's utilized at BL1 and BL3 did not improve runoff quality significantly. This statement is supported by the fact that median concentrations of sediment and nutrients at BL1 and BL3 were nearly identical or actually greater than median concentrations at TL3. In addition, the differences in suspended-sediment loads were not statistically significant when comparing loads at BL3 to loads at TL3. When suspended-sediment loads were analyzed individually at BL3 (and normalized for flow), however, the suspended-sediment loads were reduced about 30 percent with boards in place.

Sediment, nutrient, and pesticide concentrations and loads were significantly lower where cultural practices such as conservation tillage with winter cover were utilized (UL1 and UL2). This statement is supported by the fact that median suspended-sediment concentrations at UL1 and UL2 were about 48 and 62 percent lower, respectively, than the median concentration at TL3. The average annual suspended-sediment load was 70 percent lower at UL2 than at TL3. Median nitrate concentrations were about 80 percent lower at UL1 and UL2 than at TL3. The average annual nitrate load was 74 percent lower at UL2 than at TL3. The average annual total ammonia plus organic nitrogen and total phosphorus loads were lower at UL2 than at TL3. Only about 2 percent of the fluometuron applied was present in the runoff at UL2 as compared to about 6 percent at TL3.

Data from the Beasley riparian area sites characterized the efficiency of an undisturbed riparian area for removal of sediment and nutrients. Median concentrations of suspended sediment and nitrogen and phosphorus species at BL4A, BL4B, and BL4 were among the lowest median concentrations at any of the other runoff sites.

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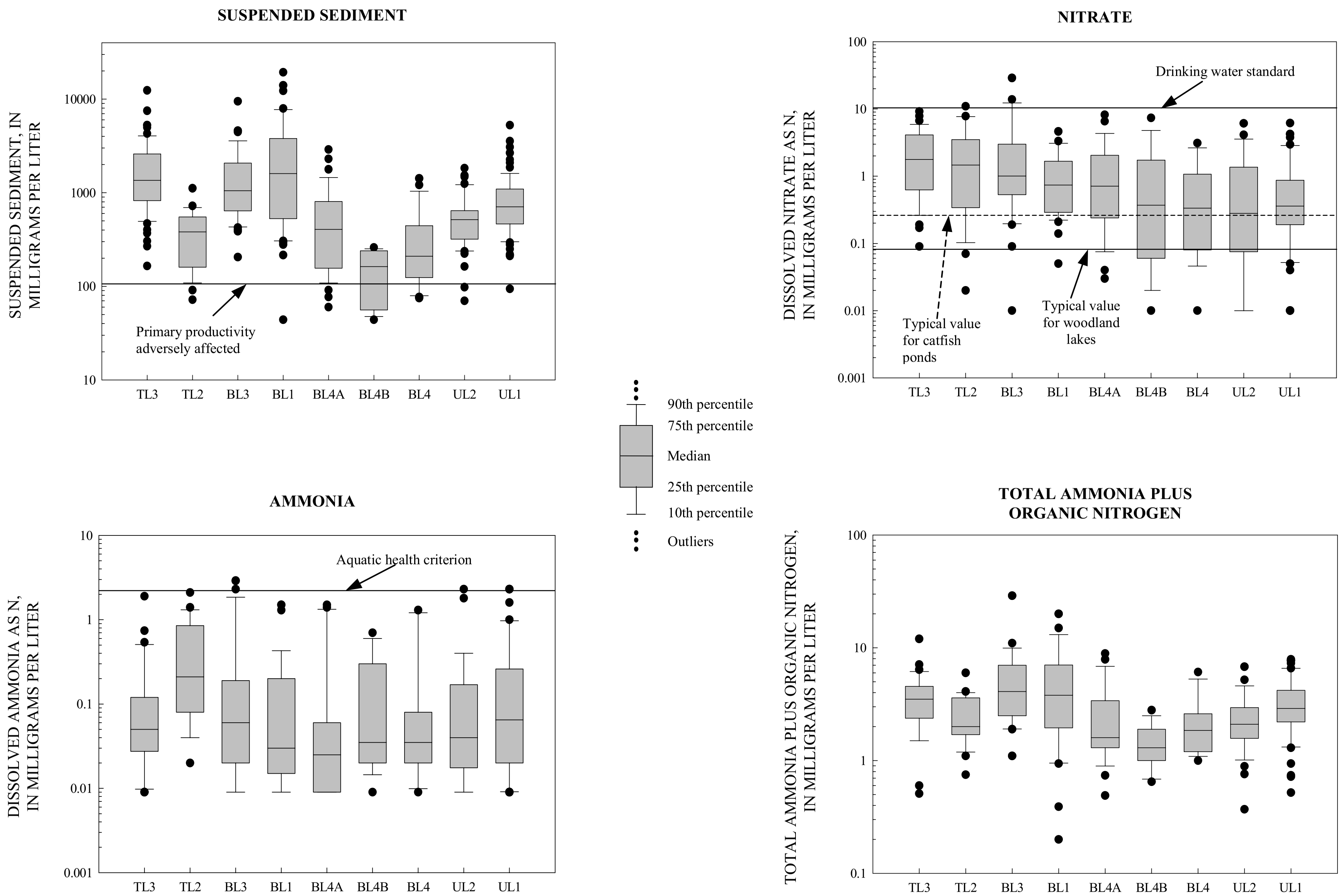

Figure 1. Distribution of sediment and nutrient concentrations from composite samples collected at MDMSEA runoff sites, 1996-99.

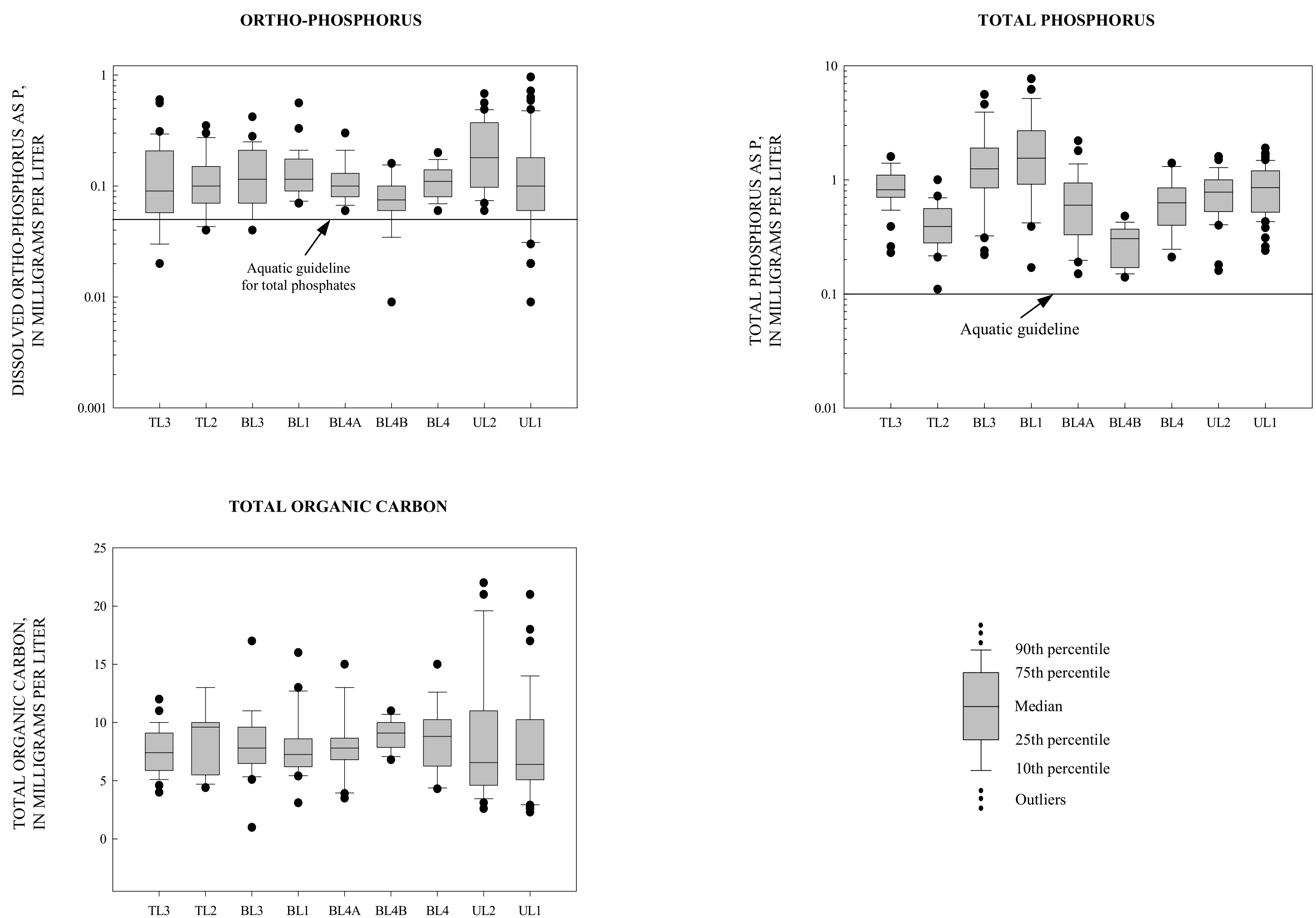

Figure 1. Distribution of sediment and nutrient concentrations from composite samples collected at MDMSEA runoff sites, 1996-99. *continued...*

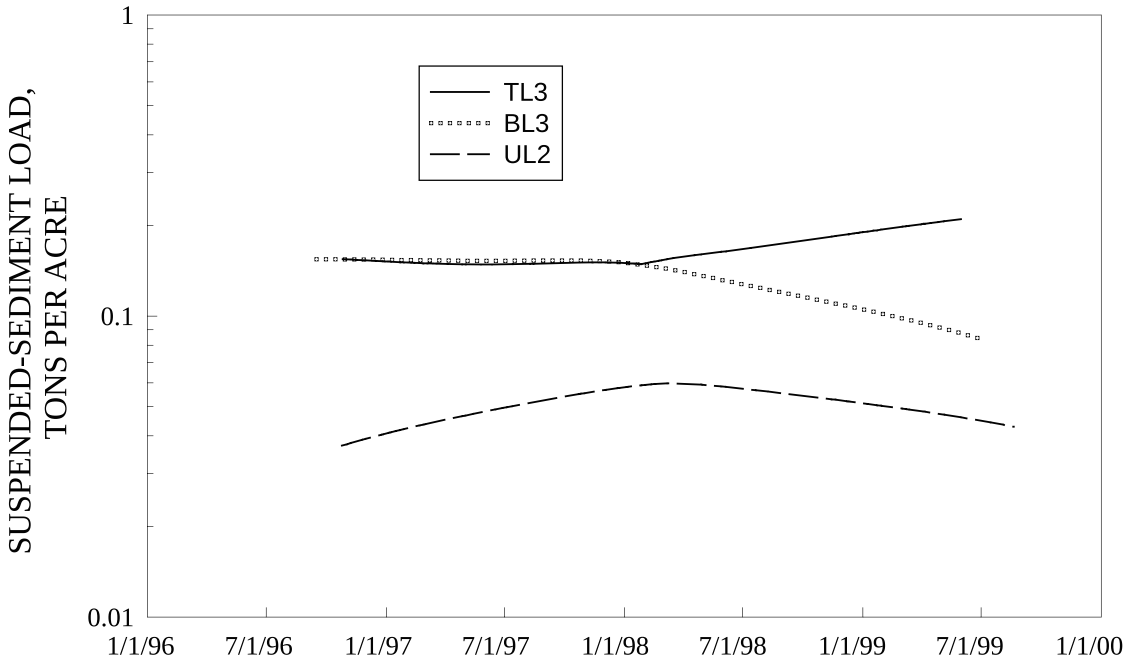

Figure 2. Locally-weighted scatterplot smoothes (LOWESS) for individual suspended-sediment loads for three MDMSEA runoff sites, 1996-99.

Table 1. Annual sediment and nutrient loads for three MDMSEA runoff sites, 1997-99

[Suspended-sediment load, tons per acre; all other loads, pounds per acre; N, nitrogen; avg., average; N/A, not available]

			Load							
Year	Rainfall (inches)	Runoff (inches)	Suspended sediment	Dissolved nitrate	Dissolved ammonia	Total ammonia plus organic-N	Dissolved ortho-phosphorus	Total phosphorus	Total organic carbon
					TL3					
1997	59.3	39.6	6.4	13	0.79	26	0.67	6.2	56
1998	35.3	25.4	3.8	6.8	1.8	19	0.45	3.8	38
1999	40.1	22.6	4.6	14	0.39	21	0.48	3.9	32
Avg.	**44.9**	**29.2**	**4.9**	**11**	**0.99**	**22**	**0.53**	**4.6**	**42**
					BL3					
1997	52.0	36.6	6.5	9.7	0.49	28	0.92	4.0	N/A
1998	40.3	15.1	3.5	7.9	1.0	23	0.47	5.4	30
1999	47.0	15.3	2.3	9.5	0.64	11	0.30	4.6	32
Avg.	**46.4**	**22.3**	**4.1**	**9.0**	**0.71**	**21**	**0.56**	**4.6**	**31**
					UL2					
1997	53.1	24.1	1.7	2.3	0.43	9.1	0.69	2.9	35
1998	45.8	19.4	1.6	2.7	0.39	8.7	0.53	2.9	28
1999	41.6	23.4	1.2	3.7	1.1	11	1.4	4.1	38
Avg.	**46.8**	**22.3**	**1.5**	**2.9**	**0.64**	**9.6**	**0.87**	**3.3**	**34**

Table 2. Statistical summary of selected herbicide concentrations in runoff for composite samples at the MDMSEA study sites, 1996-99

[Det. freq., detection frequency; all data are in micrograms per liter except for detection[1] frequencies, which are expressed as percent; <, less than; N/A, not available]

Pesticide	Det. freq.	Maxi-mum	Mini-mum	10th Percen-tile	25th Percen-tile	50th Percen-tile	75th Percen-tile	90th Percen-tile	Drinking water standard	Aquatic health criterion
					All Nine Sites					
Fluometuron	80	125	<0.05	<0.05	0.06	0.31	1.4	11.5	90	N/A
Norflurazon	46	7.3	<0.05	<0.05	<0.05	<0.05	0.21	0.72	N/A	N/A
Cyanazine	39	176	<0.05	<0.05	<0.05	<0.05	0.09	0.69	1	2
Atrazine	47	168	<0.05	<0.05	<0.05	<0.05	0.13	1	3	1.8
Metolachlor	40	376	<0.05	<0.05	<0.05	<0.05	0.12	1.5	70	7.8
					TL3					
Fluometuron	97	108	<0.05	0.32	0.49	1.6	6.1	11.1	90	N/A
Norflurazon	74	7.3	<0.05	<0.05	<0.05	0.68	1.6	3.6	N/A	N/A
Cyanazine	51	29	<0.05	<0.05	<0.05	<0.05	0.09	3.5	1	2
					BL3					
Fluometuron	71	125	<0.05	<0.05	0.05	0.17	0.63	19.5	90	N/A
Norflurazon	38	0.85	<0.05	<0.05	<0.05	<0.05	0.12	0.43	N/A	N/A
Cyanazine	33	0.47	<0.05	<0.05	<0.05	<0.05	0.07	0.09	1	2
					UL2					
Fluometuron	79	29	<0.05	<0.05	<0.05	0.1	0.7	2.7	90	N/A
Norflurazon	50	0.76	<0.05	<0.05	<0.05	<0.05	0.14	0.27	N/A	N/A
Cyanazine	26	4.9	<0.05	<0.05	<0.05	<0.05	0.05	0.17	1	2

[1] Detections are defined as concentrations above 0.05 μg/L.

Table 3. Amounts of fluometuron applied and in runoff for three MDMSEA sites, 1996-99

[N/A, not available]

Date applied	Amount applied (pounds)	Amount in runoff prior to next application (pounds)	Amount in runoff/ amount applied (percent)
		TL3	
05/04/1996	14.35	0.33*	N/A
05/1997**	14.35	1.05	7.3
05/05/1998	14.35	0.91	6.4
05/01/1999	7.17	N/A	N/A
		BL3	
05/1996**	8.89	0.03*	N/A
04/14/1997	8.89	0.27	3
04/29/1999**	12.44	N/A	N/A
		UL2	
05/03/1996	14.81	0.05*	N/A
05/17/1997	9.26	0.29	3.1
05/05/1998	12.3	0.11	1
05/09/1999	12.3	N/A	N/A

* incomplete period of record

** actual application date unknown

INSECTICIDES IN RUNOFF IN THE MISSISSIPPI DELTA MSEA PROJECT - SUMMARY OF DATA FOR 1996-99

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INTRODUCTION

One of the most intensive agricultural areas of the United States is the Mississippi River Alluvial Plain in northwestern Mississippi, a 7,000-square-mile area locally referred to as the "Delta." The rich, fertile soils of the Mississippi Delta produce a variety of crops such as cotton, soybeans, corn, and rice. The long growing season in the Mississippi Delta increases the dependency and frequency of pesticide use, especially on crops such as cotton that are highly sensitive to intense weed and insect pressures. Cotton grown in the Mississippi Delta receives about three to five times more applications of pesticides than does corn grown in the Midwest (Thurman and others, 1998). Because of the large amounts of pesticides used in the Mississippi Delta and the fact that the region is characterized with high regional rainfall (about 60 inches per year) and slightly permeable soils, there is concern for potential off-site movement of these compounds during runoff events.

The U.S. Geological Survey (USGS) began operating an automated streamflow and water-quality sampling network in the fall of 1995 as part of the Mississippi Delta Management Systems Evaluation Areas (MDMSEA) project (Rebich and others, 1995). The primary objectives of the network are to assess the effects of conventional and alternative agricultural practices on runoff water quality to oxbow lakes (Rebich 1997). Emphases of the USGS sampling program were placed on sediment, nutrient, and herbicide analyses. Additionally, in 1996, the USGS began providing samples to the U.S. Department of Agriculture, Agricultural Research Service (ARS), Soil and Water Research Unit, in Baton Rouge, LA, for insecticide analyses. From 1996 to 1997, the insecticide analyses included organophosphates and pyrethroids used throughout cotton-producing areas in the Mississippi Delta. However, very few samples for insecticide analyses were available in that time period due to infrequent storm events and low sample volumes. In 1998, more emphasis was placed on low-level analyses of pyrethroid insecticides, and additional samplers were installed in cooperation with industry to ensure that samples would be collected for as many runoff events as possible. The purpose of this paper is to present selected insecticide concentration data for runoff samples collected to date for the MDMSEA project from 1996 through 1999 and to estimate the impact of watershed-level best management practices (BMP's) on the occurrence of insecticides in storm runoff.

SITE LOCATIONS AND FIELD TREATMENTS

The three MDMSEA oxbow lake watersheds are in Sunflower and Leflore Counties in the west central part of Mississippi near Greenwood. Sampling sites are distributed among the three watersheds as follows (for this paper, site names are based on USGS topographic maps, and site numbers are based on USGS downstream ordering of tributaries):

A. Thighman Lake (TL) watershed -
    - Site TL2 is located on an inlet tributary of Thighman Lake. Data collected from this site will be used to compute chemical and sediment loads entering the lake during runoff events from a large area of mixed crops to the north.
    - Site TL3 is an edge-of-field site located downstream of a conventional tillage cotton field, which has no BMP's. Runoff data collected at this site will be compared to data collected from sites that have BMP's.

B. Beasley Lake (BL) watershed -
    - Site BL1 is an edge-of-field site that will be used to evaluate the combination of filter strips and slotted-board risers as BMP's. BL1 is located in an open-channel ditch that is grassed and drains a large area of conventional tillage cotton.
    - Site BL3 is an edge-of-field site that will be used to evaluate the performance of a slotted-board riser pipe, by itself, as a BMP. Cotton has been grown at this site every year except for 1998, in which corn was grown.
    - Sites BL4, BL4a, and BL4b will be used to assess the effects of a natural riparian

zone on the quality of surface-water runoff. BL4 is located at the outlet of the riparian zone upstream of the lake entrance. BL4a and BL4b are located at the entrance of the riparian zone. Most of the eastern part of the watershed, which has mixed crops of conventional cotton, soybeans, rice, and corn, drains through BL4a and BL4b and eventually through BL4.

C. Deep Hollow Lake watershed (UL stands for "unknown lake" because this particular lake is not named on the USGS topographic map) -
   - Site UL1 drains both soybean and cotton fields that will have the combination of conservation tillage and winter cover crops for BMP's. In addition, the culvert entrance at UL1 has a slotted-board riser.
   - Site UL2 also drains fields planted in both soybean and cotton and will have a combination of conservation tillage and winter cover crops as BMP's.

RESULTS AND DISCUSSION

Pyrethroids

Selected pyrethroid concentrations in runoff samples are listed in table 1. The table omits concentrations of pyrethroids for samples collected more than one year after application. Because the USGS sampling program prioritized the analyses of sediment, nutrients, and herbicides, there was only enough water available for seven runoff samples from three sites from 1996 to 1997 for pyrethroid analyses. In 1996, there were only six runoff samples collected between 30 and 188 days after application. Pyrethroid concentrations were all below the detection limits (400-600 parts per trillion, ppt). In 1997, only one runoff sample (from UL1) was collected, and it had pyrethroid concentrations below detection limits. Therefore, there were not enough data to adequately assess the effects of pyrethroid insecticides in the MDMSEA watersheds for the 1996-97 period.

No runoff sample collected during 1998 contained pyrethroids above the detection limits (50-125 ppt). Runoff that occurs within 1 month of application has the best opportunity to contain measurable pyrethroid content. During the 1998 season, there were only two runoff events that occurred less than 1 month after application. Both of these events were at the UL1 site, which has conservation tillage cotton and soybeans and a slotted-board riser as BMP's. The runoff event that occurred on May 28 was 8 days after application of lambda-cyhalothrin and 20 days after cypermethrin application. The June 15 runoff event occurred 26 days after application of lambda-cyhalothrin and only 3 days after the second application of cypermethrin. The failure to detect the applied compounds within the first month, especially within the first 2 weeks of application, can be explained by possible low sediment loads in the runoff, since the low pyrethroid water solubilities (less than 0.05 part per million, ppm; Hornsby and others, 1996; EXTOXNET-PIP, 1996) favor association of these insecticides with sediment in runoff. Other possible reasons for no detections are the low application rates (0.05 kg/ha), higher than expected degradation rates, high limits of detection, or false negative analyses (not detecting pyrethroids when present).

There were a total of 4 detects of pyrethroids within the 1999 sampling period (detection limit of 10 ppt). On May 4, 5 days after application, the concentration of cypermethrin was 100 ppt at BL4a, which is the entrance of the large riparian area at Beasley Lake. For that same runoff event, no cypermethrin was detected at the exit site BL4. A lambda-cyhalothrin concentration of 30 ppt was measured at the entrance (BL4a), and a concentration of 20 ppt was measured at the exit (BL4) for the May 4-5 event. According to farm records, however, lambda-cyhalothrin had not been applied at these sites since the previous growing season. Possible explanations for these two lambda-cyhalothrin detections include: (1) a non-recorded application within 1 month of the runoff event, (2) a misapplication of the chemical, or (3) false positive analyses, which is the detection of pyrethroids when none are present. On May 31, 10 days after a known application, lambda-cyhalothrin was detected at BL4a at a concentration of 20 ppt. In all cases of detection, the concentrations were lower than toxic levels for aquatic species (EXTOXNET-PIP, 1996) and were likely not bio-available in the water column.

The detections that occurred in 1999 were primarily at the BL4a site in the Beasley watershed, which is located at the entrance of the riparian zone and drains a large area of conventional tillage row crops. Such conditions could suggest that the quality of the water entering the riparian area is characterized by excessive sediment in the runoff. However, the median suspended-sediment concentration for BL4a for the period of record is 399 mg/L (milligrams per liter), which is low for runoff from a conventional tillage field. Therefore, it is unlikely that the detections of pyrethroids at BL4a in 1999 were due to excessive sediment.

There were numerous other samples collected during runoff events in 1999 that occurred within 1 month of application but did not have detectable concentrations of pyrethroids. One of these events occurred within 4 days after application of cyfluthrin. These non-detects occurred at locations such as the riparian exit in the Beasley watershed and at both sites in the Deep Hollow watershed, which contains conservation tillage. For these locations, the quality of the runoff water is characterized by fairly low sediment concentrations compared to sediment concentrations in runoff from conventional tillage. The median suspended-sediment concentration for the period of record at BL4 and UL1 is 201 and 748 mg/L, respectively, which is low compared to the median suspended-sediment concentration at TL3 of 1,317 mg/L. Because no pyrethroids were applied at the TL3 site in 1999, the ability of the BMP's to reduce pyrethroids with respect to sediment loads cannot be evaluated.

Organophosphates

Concentrations of methyl parathion and azinphosmethyl in runoff samples collected during 1996-1998 are listed in table 2. These two organophosphates were not applied in 1999. Concentrations of organophosphates for samples collected more than 1 year after application are not included in the table. Eight runoff events were sampled after application of methyl parathion in 1996. Five events were sampled after application of methyl parathion in 1997. Eleven runoff events were sampled after application of methyl parathion in 1998. Sufficient sample was available only for these few sampling events. In all cases, methyl parathion was not detected (limit of detection, 200 ppt), even in the samples collected from BL4 and BL1 in 1997 in which a runoff event occurred 1 and 3 days after application, respectively. The likely reason for most of the non-detects is that methyl parathion has short soil half-lives in soil and on leaves (about 5 days in soil; Hornsby and others, 1996; about 0.1 day on leaves; Willis and others, 1992), thus disappearing rapidly before being mobilized in a runoff event. The 1997 events 1 and 3 days after application should have been soon enough to observe methyl parathion in the runoff. In these cases, the non-detects could be the result of the locations of the sites in the watershed and their associated BMP's. BL4 is the exit site of the riparian zone as stated before, and BL1 has a long, grassed waterway prior to the sampling point. However, not enough data exist to evaluate the benefits of the BMP's in reducing methyl parathion concentrations in the runoff.

Three runoff events occurred after application of azinphosmethyl in 1998. There were no detections (detection limit, 500 ppt) of azinphosmethyl in these samples. The soil half-life of azinphosmethyl is about 10 days (Hornsby and others, 1996). Therefore, it is likely that azinphosmethyl degraded prior to these runoff events.

SUMMARY

For pyrethroid samples collected from 1996 to 1999, there were a total of four detects, which occurred in the 1999 sampling period. These detections occurred shortly after application; however, there were other samples collected shortly after application that had no detections. The fact that detections occurred at some sites and not others shortly after application could suggest that sediment concentrations were elevated at some locations but not others. However, no adequate conclusions could be drawn to evaluate the ability of the BMP's to reduce pyrethroids with respect to sediment loads. The failure to detect the applied compounds within the first month after application can also be explained by low application rates (less than 0.05 kg/ha), higher than expected degradation rates, high detection limits early in the study, or the possibility of false negative analyses. Not enough data exists to verify any of these conclusions.

Neither methyl parathion nor azinphosmethyl were detected in any of the samples from 1996 through 1998. The likely reason for the majority of the no detects is that both compounds have short soil and leaf surface half-lives. Insufficient data exists to evaluate the benefits of BMP's in reducing methyl parathion or azinphosmethyl concentrations in the runoff.

A more detailed report of these results has been published (Southwick and others, 2000).

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Table 1. Concentration of pyrethroids in runoff from MDMSEA watersheds, 1996-1999

[ppt, parts per trillion; DAA, days after application; [a], ARS data; [b], contract lab data]

Site	Runoff event date	Lambda-cyhalothrin ppt (DAA)	Cypermethrin ppt (DAA)	Cyfluthrin ppt (DAA)	Deltamethrin ppt (DAA)
			1996 [a]		
TL3	Oct 26			< 600 (63)	
TL3	Nov 7			< 600 (75)	
UL1	Aug 2		< 400 (91)	< 600 (30)	
UL2	Oct 25		< 400 (175)	< 600 (114)	
UL2	Nov 1		< 400 (182)	< 600 (121)	
UL2	Nov 7		< 400 (188)	< 600 (127)	
			1997 [a]		
UL1	Jul 13			< 600 (3)	
			1998 [b]		
TL2	Nov 14	< 50 (98)			
TL2	Dec 11	< 50 (125)			
BL1	Apr 28	< 50 (240)		< 125 (300)	
BL3	May 29			< 125 (339)	
BL4a	May 28	< 50 (313)		< 125 (342)	
BL4a	Nov 14	< 50 (141)		< 125 (110)	
BL4a	Nov 20	< 50 (147)		< 125 (116)	
BL4a	Dec 10	< 50 (167)		< 125 (136)	
BL4a	Dec 11	< 50 (168)		< 125 (137)	
BL4	May 29	< 50 (314)		< 125 (343)	
UL1	Apr 27	< 50 (254	< 125 (281)	< 125 (291)	
UL1	May 28	< 50 (8)	< 125 (20)	< 125 (322)	
UL1	Jun 15	< 50 (26)	< 125 (12)	< 125 (340)	
UL1	Nov 14	< 50 (130)	< 125 (105)		< 125 (95)
UL1	Nov 20	< 50 (136)	< 125 (111)		< 125 (101)
UL1	Dec 7	< 50 (153)	< 125 (128)		< 125 (118)
UL1	Dec 10	< 50 (156)	< 125 (131)		< 125 (121)
UL1	Dec 11	< 50 (157)	< 125 (132)		< 125 (122)
UL2	Apr 28	< 50 (255)	< 125 (282)	< 125 (292)	
UL2	Apr 30	< 50 (257)	< 125 (284)	< 125 (294)	
UL2	Nov 14	< 50 (130)	< 125 (105)		< 125 (95)
UL2	Dec 7	< 50 (153)	< 125 (128)		< 125 (118)
UL2	Dec 11	< 50 (157)	< 125 (132)		< 125 (122)

Table 1. Concentration of pyrethroids in runoff from MDMSEA watersheds, 1996-1999 … *continued*

[ppt, parts per trillion; DAA, days after application; [a] , ARS data; [b] , contract lab data]

Site	Runoff event date	Lambda-cyhalothrin ppt (DAA)	Cypermethrin ppt (DAA)	Cyfluthrin ppt (DAA)	Deltamethrin ppt (DAA)
			1999 [b]		
TL2	Jan 8	< 50 (153)			
TL3	Jan 8	< 50 (208)			
TL3	Apr 3	< 10 (293)			
TL3	Apr 14	< 10 (304)			
BL1	May 31		< 10 (22)		
BL1	Jun 2		< 10 (24)		
BL4a	Jan 8	< 50 (196)		< 125 (165)	
BL4a	Mar 2	< 10 (249)		< 10 (218)	
BL4a	Mar 13	< 10 (260)		< 10 (229)	
BL4a	Apr 3	< 10 (281)		< 10 (250)	
BL4a	Apr 5	< 10 (283)		< 10 (252)	
BL4a	Apr 14	< 10 (292)		< 10 (261)	
BL4a	May 4	30 (312)	100 (5)	< 10 (281)	
BL4a	May 31	20 (13)	< 10 (32)		
BL4a	Nov 2	< 10 (167)	< 10 (186)		
BL4a	Dec 12	< 10 (208)	< 10 (227)		
BL4b	Dec 12	< 10 (153)			
BL4	Jan 8	< 50 (196)		< 125 (165)	
BL4	Mar 13	< 10 (260)		< 10 (229)	
BL4	Apr 4	< 10 (282)		< 10 (251)	
BL4	Apr 6	< 10 (284)		< 10 (253)	
BL4	Apr 14	< 10 (292)		< 10 (261)	
BL4	May 5	20 (313)	< 10 (6)	< 10 (282)	
UL1	Jan 8	< 50 (185)	< 125 (160)		< 125 (150)
UL1	Mar 2	< 10 (238)	< 10 (213)		< 10 (203)
UL1	Mar 13	< 10 (249)	< 10 (224)		< 10 (214)
UL1	Apr 3	< 10 (270)	< 10 (245)		< 10 (235)
UL1	Apr 14	< 10 (281)	< 10 (256)		< 10 (246)
UL1	Jul 14	< 10 (29)	< 10 (65)	< 10 (26)	
UL1	Jul 21	< 10 (36)	< 10 (71)	< 10 (4)	
UL1	Aug 7	< 10 (7)	< 10 (88)	< 10 (21)	< 10 (14)
UL2	Jan 8	< 50 (185)	< 125 (160)		< 125 (150)
UL2	Mar 12	< 10 (248)	< 10 (223)		< 10 (213)
UL2	Apr 3	< 10 (270)	< 10 (245)		< 10 (235)
UL2	Apr 14	< 10 (281)	< 10 (256)		< 10 (246)
UL2	Jul 15	< 10 (30)	< 10 (66)	< 10 (27)	
UL2	Aug 7	< 10 (7)	< 10 (90)	< 10 (21)	< 10 (14)

Table 2. Concentration of organophosphate insecticides in runoff from MDMSEA watersheds, 1996-98 [ppt, parts per trillion; DAA, days after application]

Site	Runoff event date	Methyl Parathion ppt (DAA)	Azinphosmethyl ppt (DAA)
		1996	
TL3	Oct 26	< 200 (55)	
TL3	Nov 7	< 200 (67)	
BL3	Nov 1	< 200 (76)	
BL3	Nov 7	< 200 (82)	
UL1	Aug 2	< 200 (11)	
UL2	Oct 25	< 200 (95)	
UL2	Nov 1	< 200 (102)	
UL2	Nov 7	< 200 (108)	
		1997	
BL1	Aug 9	< 200 (3)	
BL4	Jul 8	< 200 (1)	
BL4	Aug 9	< 200 (18)	
BL4	Aug 14	< 200 (23)	
BL4	Aug 15	< 200 (24)	
		1998	
BL4a	Nov 14	< 200 (95)	< 500 (109)
BL4a	Dec 10	< 200 (121)	< 500 (135)
BL4a	Dec 11	< 200 (122)	< 500 (136)
UL1	Nov 14	< 200 (72)	
UL1	Nov 20	< 200 (78)	
UL1	Dec 7	< 200 (95)	
UL1	Dec 10	< 200 (98)	
UL1	Dec 11	< 200 (99)	
UL2	Nov 14	< 200 (72)	
UL2	Dec 7	< 200 (95)	
UL2	Dec 11	< 200 (99)	

ENVIRONMENTAL FATE OF FLUOMETURON IN SOIL INFLUENCED BY BEST MANAGEMENT PRACTICES (BMPs)

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INTRODUCTION

Fluometuron is an effective herbicide for annual grass and broadleaf weed control in cotton. Several fluometuron applications applied per growing season may include a preemergence, postemergence when cotton is 7.5 to 15 cm, and postemergence at lay-by (with the last cultivation). The mode of action is inhibition of photosynthetic electron transport by binding to the D1 protein of photosystem II and blocking electron transport from Q_A to Q_B (Ahrens, 1994). Fluometuron was labeled for use in 1965 (Timmons, 1970) and is one of several compounds that belong to the herbicide group known as the phenylureas or substituted ureas. These compounds have three hydrogen atoms of urea replaced or substituted with a variety of carbon chains and rings. Fluometuron is unique from other compounds in this group due to a trifluoromethyl group at the meta position of the phenyl ring (Rickard and Camper, 1978). Fluometuron is considered to be a nonionic molecule that does not ionize over a wide pH range (Patterson et al., 1982). Water solubility is 90 mg L^{-1} at 20 to 25 C and is categorized as moderately water soluble (Weber, 1972). Fluometuron was the herbicide of choice to evaluate because cooperating producers at all the MD-MSEA locations apply fluometuron, and detectable levels have been reported in surface water (Coupe et al., 1998; Pereira and Hostettler, 1993). Previous research suggests that herbicide and sediment in runoff is reduced as it moves through grass filter strips and riparian areas. Therefore, research objectives were: to characterize soil properties within different areas of a new (< 1 yr) grass filter strip, established (> 5 yr) grass filter, and a riparian forest to determine the impact of different BMPs on soil properties and the spatial distribution of soil particles within BMP areas; and determine fluometuron adsorption and degradation to these soils to assess the ability of soil from these BMPs to retain fluometuron.

MATERIALS AND METHODS

Soil Characterization

Research was conducted on a Dundee silt loam (fine silty, mixed, thermic, Aeric Ochraqualf) collected from a cropped area, adjacent tall fescue (*Festuca arundinacea* Schreb.) filter strip epipedons (0-2 cm depth); and a Dowling overwash phase (fine, montmorillonitic, thermic, Vertic Epiaquept) from a riparian forest epipedon. These BMP areas surround Beasley Lake in Sunflower Co., MS, in the Mississippi River alluvial floodplain. Samples were collected along a transect beginning at a mixing zone (1 m prior to the filter strip edge, but not in the crop area), the front edge of the filter strip, and at 1 and 2 m from the edge into the filter strip. Riparian forest sampling points were: riparian entrance from 0-25 m, and 50-200 and 400-800 m from the riparian entrance. Samples were analyzed for organic matter (OM) content by a colorimetric procedure (DeBolt, 1974), pH using a 1:2 soil to water suspension (McLean, 1982), and cation exchange capacity (CEC) by extraction and summation of exchangeable acids and bases (Rhoades, 1982). Particle size analyses were conducted using the hydrometer method (Gee and Bauder, 1986).

Fluometuron Adsorption

A batch equilibration method was used to determine fluometuron adsorption to soil collected from all areas described above. Technical grade fluometuron (96.8% chemical purity) was dissolved in 0.01 M $CaCl_2$ to achieve solution concentrations of 0.85, 4.7, 17.7, and 34.9 μmol L^{-1}. Fluometuron solutions contained 166.5 Bq ml^{-1} uniformly ring-labeled ^{14}C-fluometuron (specific activity 17.3 Bq g^{-1}, 99% radiochemical purity). The Langmuir model did not successfully describe the adsorption process for any of the soils evaluated and the Freundlich model only fit adsorption data for some of the soils. Consequently, fluometuron adsorption data were fit to simple quadratic regression equations computed as:

$$y = b_0 + b_1 x + b_2 x^2 \qquad [1]$$

where y (μmol kg^{-1}) is the amount of herbicide adsorbed at the equilibrium concentration x (μmol L^{-1}), and b_0, b_1, and b_2 (dimensionless) are quadratic coefficients. Estimated fluometuron adsorption from regression equations for different soils was compared at fluometuron equilibrium concentrations of 1 and 12 μmol L^{-1}. The 1 μmol L^{-1} concentration was chosen to describe adsorption of fluometuron to soils at the labeled field rate and 12 μmol L^{-1} was chosen to describe adsorption at a higher rate, approximately 8 times the recommended field rate, based on the concentration range at equilibrium relative to amount added.

Fluometuron Degradation

Soils were collected prior to initial fluometuron application in the spring of 1997. Grass filter strip soil sampling points were established 1 m into the strip every 20 m for a 60-m distance. Riparian area soil sampling points were divided into three areas designated as 0 to 25 m (entrance), 50 to 200 m, and 400 to 800 m. The experiment was initiated with the transfer of 40-g soil (oven-dry weight basis) into polypropylene wide-mouth bottles with screw-top caps and treated with an aqueous solution of technical grade fluometuron (96.8% chemical purity) at a rate of 1.75 μg g^{-1} soil. After herbicide amendment, soil moisture was brought to either field capacity (-33 kPa) or moderate to highly saturated conditions by the addition of 0.01 M $CaCl_2$ solution, as determined using a pressure plate apparatus (Cassel and Nielsen 1986). Soil moisture at field capacity resulted in 33%, 40%, 47% (by weight) moisture for cropped area, new filter strip, and established filter strip soils. Moderately saturated soil samples resulted in 64%, 74%, and 76% (by weight) moisture and highly saturated soil samples resulted in 84%, 100%, and 110% (by weight) moisture for soil collected from the riparian entrance, and 50 to 200 and 400 to 800 m from entrance. Samples were weighed and incubated in the dark at 28 C and 50% relative humidity. Samples were frozen at sampling points of 0, 7, 14, 21, 28, 56, and 112 d. Extractable-fluometuron concentration was determined by high performance liquid chromatography (HPLC). Data were fit to a first-order degradation model using the following integrated rate law:

$$\ln[C] = \ln[C]_0 + (-k)\,t \qquad [2]$$

where [C] (μg g^{-1}) is fluometuron concentration; $[C]_0$ (μg g^{-1}) is initial fluometuron concentration at time zero; k (day^{-1}) is the degradation rate coefficient; and t (day) is time.

The slope from equation [2], which is equal to (k), was used to calculate fluometuron half-life or 50% disappearance time (DT_{50}) in all soils from the equation:

$$DT_{50} = 0.693 / |\text{slope}| \qquad [3]$$

RESULTS AND DISCUSSION

Soil Characterization

Sand content was at least 38% in entrance areas for all BMPs, and 5% just prior to entrance into the lake (Table 1). Clay content ranged from 18 to 40% in BMP areas, compared to 13% in the cropped area. This suggests that runoff water kinetic energy decreased as it moved through BMPs, causing coarser fractions to settle out of suspension, and finer sediment to remain suspended before being deposited as distance increased through the BMPs. Gilliam et al. (1994) reported similar results where coarse sediment was deposited close to the field and sediment layers consisting of clay-sized materials developed with distance. The OM content and CEC were at least 3% and 23 cmol kg^{-1} in soil collected 50-200 and 400-800 m from the riparian entrance, respectively, which was higher than all other experimental soils (Table 1). The OM content and CEC ranged from 2.1 to 2.4% and 18.1 to 18.4 cmol kg^{-1}, respectively, in soil collected from the entrance of the riparian area and interior areas (1 and 2 m) of the established filter strip, which was lower compared to soil from other riparian areas. However, these two soil properties were lowest in soil collected from exterior areas (mixing zone and front edge of the strip) of the established filter strip, all areas of the new filter strip, and the cropped area. The partial decomposition of fescue grass in the established filter strip interior areas likely contributed to higher OM (Benoit et al., 1999). The higher OM content in soil from riparian areas was due to well-decomposed forest litter. Also, slow drainage of surface and subsurface water contributed to saturated conditions in the riparian areas, which can reduce OM decomposition (Lowrance et al., 1985). The higher CEC in these areas results from the combination of higher OM and clay content. Cation exchange capacity was correlated to OM (r = 0.61) and clay (r = 0.76), which emphases the importance of these two soil factors on the CEC (data not shown).

Fluometuron Adsorption

The quadratic parameter coefficients used to model fluometuron adsorption are given in Table 2. Concentrations of adsorbed fluometuron to soils at an equilibrium concentration of 1 μmol L^{-1} ranged from

0.9 to 4.2 μmol kg^{-1} (Table 2). Fluometuron concentration adsorbed to soil collected 400-800 m from the riparian entrance was 4.2 μmol kg^{-1} and greater than adsorbed concentrations to all other soils. Adsorption to soil collected 50-200 m from the riparian entrance was 1.3 μmol kg^{-1} less than to soil from the 400-800 m area, and not different than adsorption to soil collected from the riparian entrance and interior areas (1 and 2 m into strip) of the established filter strip. The concentration of adsorbed fluometuron to the riparian entrance and interior areas of the established strip was not different than the 1.6 μmol kg^{-1} adsorbed to cropped area soil. Fluometuron concentrations adsorbed to all areas of the new filter strip and exterior areas of the established filter strip were also not different than the amount adsorbed to cropped area soil. Therefore, retention of fluometuron to soil influenced by the riparian entrance and the new or established filter strip was equal to fluometuron retained in cropped area soil when fluometuron was applied at a labeled field rate.

Fluometuron concentration adsorbed to soils ranged from 5.6 to 49.1 μmol kg^{-1} at a higher equilibrium concentration of 12 μmol L^{-1} (Table 2). The concentrations adsorbed to soil collected from new filter strip areas ranged from 5.6 to 9.3 μmol kg^{-1} and were less than the 13.2 μmol kg^{-1} adsorbed to cropped area soil. Therefore, these areas had less adsorptive capacity than the cropped area at this equilibrium concentration. Decreased adsorption to new strip soil was probably due to decreased organic matter (Table 1). Results from other research emphasis a strong correlation of fluometuron adsorption with soil organic matter (Brown et al., 1994; Kozak and Weber, 1983; Mueller et al., 1992; Savage and Wauchope, 1974).

Fluometuron concentrations adsorbed to soil collected from established filter strip areas ranged from less than 14 μmol kg^{-1} in the strip exterior (mixing zone and front edge of strip) to at least 28 μmol kg^{-1} for strip interior when fluometuron equilibrium concentration was 12 μmol L^{-1} (Table 2). Adsorption to soil collected from established filter strip mixing zone was less than to cropped area soil and no different than to soil collected from all areas of the new filter strip. Adsorption to soil from the established filter strip edge was no different than to cropped area soil. However, adsorption to established strip interior was greater than to cropped area soil and at least two times higher than adsorption to soil from all other filter strip areas. Therefore, the potential capacity for retaining fluometuron to soil inside the established filter strip is greater than to soil in the cropped area and to soils associated with all other filter strip areas evaluated. In a similar experiment, Benoit et al. (1999) reported that adsorption of isoproturon, a phenylurea herbicide, to surface soil (0-2 cm) collected from a perennial ryegrass (Lolium perenne L.) filter strip was almost three times higher that to cropped area soil. They attributed higher adsorption to the high density of partially decomposed plant residues.

The concentration of fluometuron adsorbed to soil collected from riparian areas ranged from 25 to 49 μmol kg^{-1} (Table 2). Fluometuron adsorption to soil collected 400-800 m from the riparian entrance was greater than to all other soils in the experiment. Adsorption of fluometuron to soil collected 50-200 m from the riparian entrance was no different than to soil collected 1 m from established filter strip edge and soil from the riparian entrance was no different than to soil collected 2 m from the established filter strip edge. In general, the retention capacity for several soils influenced by BMPs at an equilibrium concentration of 12 μmol L^{-1} follows the order of magnitude: new strip area and established strip mixing zone $<$ cropped area = established strip edge $<$ established strip 2 m = riparian entrance $<$ established strip 1 m = riparian 50-200 m $<$ riparian 400-800 m (Table 2). There was a strong relationship between fluometuron adsorption and soil OM, clay content, and CEC, which had correlation coefficients of 0.95, 0.56, and 0.89, respectively (Table 3).

The OM content and CEC was highest in soil collected from the riparian area due to the accumulation of well-decomposed forest litter, which can increase herbicide adsorption and prolong herbicide residence time (Reddy et al., 1995). Adsorption increased with an increasing distance into the forest due to increased clay content and an increase in anaerobic conditions, which enhances organic residue preservation (Lowrance et al., 1985). As soil becomes saturated, gas exchange between soil and air is reduced, microbial populations change, soil Eh decreases, and pH changes, which affects enzymatic activity and organic matter decomposition (McLatchey and Reddy, 1998). Spatial differences in texture were due to coarse particle deposition near the forest entrance followed by fine particle deposition as runoff moved down slope. The OM content and fluometuron adsorption in established strip interior soil was greater than strip exterior due to the presence of partially decomposed grass residue. This resulted in an adsorptive capacity for the established strip interior that was comparable to the riparian forest entrance and 200-400 m from the entrance. Adsorption to soil from the new filter strip was lower compared to other BMPs due to the absence of OM accumulation. However, strip maturity should improve OM quality and composition if vegetation is maintained and decomposed plant residues remain on the filter strip (Locke and Bryson, 1997).

Results from this study indicate that fluometuron adsorption to soil from all areas influenced by a new or established filter was no different when applied fluometuron concentrations were within the range of a labeled field rate. Therefore, benefits from the retention of fluometuron should be immediate and only improve over time in a newly installed fescue filter strip if properly maintained. However, fluometuron retention to soil from established filter strip interior and riparian areas was greater than to soils from all other areas when fluometuron was applied to these soils at approximately 8 times the recommended field rate, which should only occur in an accidental spill situation. Therefore, installation of these BMPs promote soil properties such as OM, clay content, and consequent CEC that are proven to enhance the retention capacity of soil media, which should theoretically increase the potential affinity for fluometuron.

Fluometuron Degradation

Fluometuron half-lives in all soils influenced by a BMP, regardless of moisture conditions, were at least 49 d shorter than the 112-d half-life in the cropped area soil (Table 4). Lowest predicted fluometuron half-lives were 12, 14, 28, 35, and 38 d in soil collected 1 m from the established filter strip edge (field capacity), riparian entrance (moderately saturated), riparian 50 to 200 m (highly saturated), riparian 400 to 800 m (highly saturated), and riparian 400 to 800 m (moderately saturated), respectively, and different from all other soils. Half-lives of 55, 61, and 63 d for the new grass filter strip, riparian 50 to 200 m (highly saturated), and riparian entrance (highly saturated), respectively, were only lower than half-life in the cropped area soil. A fluometuron half-life of 12 d in established filter strip soil was the shortest among all soils (Table 4). Half-life in the new filter strip soil was 55 d. Along with the addition of plant residues, the rapid degradation in established versus new filter strip soil could be attributed in part to the growth of dense vegetation compared to the less dense new strip. Living vegetation not only contributes to degradation in soil by uptake and metabolism, but it can enhance microbial populations due to root exudates (Boyle and Shann 1998). Therefore, fluometuron degradation should increase with time in new filter strip soils as OM increases through additions of plant residue materials, which provide substrate for microbial activity and populations.

Higher fluometuron degradation by microorganisms in riparian area soils could be attributed to higher OM (Table 1) and soil moisture content compared to the cropped soil. This corresponds to other research that suggests higher moisture and labile organic carbon substrates in surface soil will promote both size and composition of microbial populations (Locke and Bryson 1997). Fluometuron degradation in soil from the riparian entrance occurred more rapidly in moderate (64% by weight) compared to highly (84% by weight) saturated moisture conditions based on half-lives of 14 and 63 d, respectively (Table 4). Wolt et al. (1992) found similar results for flumetsulam, where half-life was 40 and 183 d in aerobic and strongly anaerobic systems, respectively. In riparian soil collected 50 to 200 m from the entrance, predicted half-life was 33 d shorter in soil under moderate (74% by weight) compared to highly (100% by weight) saturated moisture conditions (Table 4). However, half-life in riparian soil collected 400 to 800 m from the entrance at both moisture contents was the same, and no different than riparian soil collected 50 to 200 m from the entrance under moderately saturated conditions (Table 4). The difference in fluometuron degradation rate in soil from different riparian areas may be due to a change in the composition of microorganisms that degrade fluometuron. A major influence on microbial type and population could be due to the spatial variation in soil moisture conditions influenced by the hydrologic regime in the riparian area. Riparian entrance soil is typically aerobic, but with increasing distance through the riparian area down to the lake, soil becomes wetter and anaerobic conditions occur more frequently. Therefore, the composition of microorganisms near the riparian entrance were likely aerobic in nature and capable of rapidly degrading fluometuron under moderate soil moisture conditions. However, when saturated conditions occur, microbial degradation processes are likely to decline in riparian entrance soil because of the more anaerobic conditions. Fluometuron degradation rate in soil collected 400 to 800 m from the entrance did not change when moisture conditions were changed because inherent microorganisms were likely more anaerobic in nature.

This study demonstrates that soil influenced by an established fescue filter strip and riparian forest can rapidly degrade fluometuron. Fluometuron degradation was more rapid in soil influenced by BMPs by at least 49 d compared to cropped area soil based on half-lives. Degradation in established filter strip soil was no different from riparian entrance soil, but was 43 d more rapid than in new filter strip soil. Half-life increased by 49 and 33 d in soil collected at the riparian entrance and 50 to 200 m from the entrance, respectively, as soil moisture increased from moderate to highly saturated soil moisture conditions. Soil moisture content was the only difference between riparian soil samples, which suggests that as the soil system approaches an anaerobic state, inherent degrading microbes become quiescent. Therefore, fluometuron degradation may decrease in soil at the entrance and 200 to 400 m from the entrance of the riparian area after a runoff event. However, once soil in these areas becomes more aerobic, quiescent microbes become more active and degradation processes increase. Fluometuron degradation in soil at 400 to 800 m from the riparian entrance should remain constant regardless of soil moisture conditions. Since soil in this area likely remains at or near a natural anaerobic state, microbial activity should not be affected by additional water following a runoff event because inherent microbial populations should be principally anaerobic in this area of the forest. In any case, soils influenced by these BMPs have the potential to rapidly degrade fluometuron; thus there should be a strong effort to establish and maintain BMPs.

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Table 1. Various chemical and physical properties of cropped, filter strip, and riparian soils located at Beasley Lake in Sunflower Co., MS.

Sampling Point	pH	CEC	OM	Sand	Silt	Clay
		cmol kg^{-1}	%			
Crop	4.7	11.7	0.7	28	59	13
New-strip mix	5.7	12.8	0.1	48	21	30
New-strip edge	6.0	13.6	0.1	33	48	19
New-strip 1 m	6.0	14.7	0.2	30	50	21
New-strip 2 m	6.4	14.0	0.5	24	51	25
Established-strip mix	5.9	12.2	0.4	46	36	18
Established-strip edge	6.0	14.4	0.9	40	39	21
Established-strip 1 m	6.3	18.2	2.1	21	58	22
Established-strip 2 m	6.0	18.1	2.4	31	46	23
Riparian 0-25m	6.8	18.4	2.3	38	40	22
Riparian 50-200m	6.4	23.3	3.1	7	62	26
Riparian 400-800m	5.8	31.7	4.5	5	55	40
LSD ($\alpha = 0.05$)	0.3	2.1	0.6	2	5	3

Table 2. Quadratic regression coefficients determined for fluometuron adsorption to soils collected at Beasley Lake in Sunflower Co., MS.

Sampling Point	Regression equation	R^2	Adsorption at equilibrium concentrations	
			1 μmol L^{-1}	12 μmol L^{-1}
			μmol kg^{-1}	
Crop	$Y = 0.8440 + 0.7762 X - 0.0214 X^2$	0.99	1.6 cdef	13.2 d
New-strip mix	$Y = 0.8110 + 0.0254 X - 0.0311 X^2$	0.98	0.9 f	5.6 h
New-strip edge	$Y = 0.5803 + 0.3055 X - 0.0199 X^2$	0.99	0.9 f	7.1 fg
New-strip 1 m	$Y = 1.23 + 0.1058 X - 0.0317 X^2$	0.98	1.2 ef	6.9 gh
New-strip 2 m	$Y = 1.24 + 0.1251 X - 0.0454 X^2$	0.98	1.4 def	9.3 e
Established-strip mix	$Y = 0.7426 + 0.2757 X - 0.0295 X^2$	0.98	1.1 f	8.3 ef
Established-strip edge	$Y = 0.7093 + 0.6827 X - 0.0297 X^2$	0.99	1.4 def	13.2 d
Established-strip 1 m	$Y = 0.2756 + 2.24 X - 0.0080 X^2$	0.99	2.5 bcd	28.3 b
Established-strip 2 m	$Y = 0.6299 + 1.61 X - 0.0325 X^2$	0.99	2.3 bcde	24.6 c
Riparian 0-25m	$Y = 1.09 + 1.51 X - 0.0408 X^2$	0.99	2.6 bc	25.1 c
Riparian 50-200m	$Y = 0.8227 + 2.09 X - 0.0134 X^2$	0.99	2.9 b	27.8 b
Riparian 400-800m	$Y = 0.9401 + 3.23 X - 0.0656 X^2$	0.99	4.2 a	49.1 a

Table 3. Correlation coefficients for soil properties with estimated fluometuron adsorption at 12 μmol L^{-1}.

Soil properties	Pearson correlation coefficients Across soil samples
pH	0.17
Cation exchange capacity	0.89
Sand	-0.72
Silt	0.48
Clay	0.56
Organic matter	0.95

Table 4. First-order rate and regression coefficients and predicted fluometuron half-lives.

Sampling Point[a]	Degradation rate	Coefficient of determination	Half life
	k	R^2	DT_{50}
Crop (FC)	0.0062	0.91	112
New tall fescue filter strip (FC)	0.0126	0.99	55
Established tall fescue filter strip (FC)	0.0577	0.98	12
Riparian entrance (MOD)	0.0495	0.94	14
Riparian entrance (HIGH)	0.0110	0.93	63
50-200 m from entrance (MOD)	0.0248	0.95	28
50-200 m from entrance (HIGH)	0.0114	0.80	61
400-800 m from entrance (MOD)	0.0182	0.91	38
400-800 m from entrance (HIGH)	0.0198	0.77	35
LSD (0.05)	0.0047	0.11	16

[a] Abbreviations: soil moisture content at field capacity (FC), moderately saturated conditions (MOD), and highly saturated conditions (HIGH).

SHALLOW GROUND WATER RESEARCH IN THE MISSISSIPPI DELTA MSEA

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BACKGROUND

One of the major objectives of the MDMSEA project is to develop alternative and innovative farming systems for improved water quality/ecology in the Mississippi Delta. Such farming systems are to be composed of economical, environmentally-sound best management practices (BMPs), which are likely to be adopted by farmers/landowners. Many of the MDMSEA project BMPs that have been implemented are designed to slow surface runoff and enhance agrichemical processing/retention. These include conservation tillage (no-till, reduced-till, etc.) grass filter strips/stiff grass hedges, grassed waterways (e.g. vegetated drainage ditches), and natural and constructed wetlands. The above practices tend to increase infiltration and the potential for dissolved agrichemicals (nutrients and pesticides) to leach into the soil profile (USDA, 1989; Leonard, 1988). To what extent this impairs shallow ground water quality is a regional as well a national concern. Just over a decade ago, pesticides were assumed not to leach to underlying groundwater (Bouwer, 1990). However, recent ground water surveys have revealed the contamination of some of the Nation's aquifers with agrichemicals and as better and more sensitive pesticide analytical methods were developed, the number and frequency of pesticide detections increased (Cohen et al., 1984; Cohen et al., 1986; Williams et al., 1988). The effects of conservation tillage on pesticide leaching to ground water has only recently come under investigation (Brinsfield et al., 1988; Ritter et al., 1991; Isensee et al., 1988; Smith et al., 1994; Smith et al., 1995). In Mississippi Delta flatland soils, the significance of agrichemical percolation to relatively shallow water tables, which are often hydraulically connected to nearby water bodies (e.g. oxbow lakes, rivers), is poorly understood. This paper reports the results of our efforts to determine and characterize pesticide movement in shallow ground water during three water years (1996-1998) of the 5-year project.

MATERIALS AND METHODS

Observation wells for sampling shallow ground water were installed in clusters of 3 (about 3 feet apart) at depths of 5, 10, and 15 feet in critical flow areas (i.e. in front of slotted-board risers and slotted-inlet pipes, in grass filter strips and riparian areas) in the watersheds (please refer to the MDMSEA web site at *www.sedlab.olemiss.edu/msea.html* for well site locations). A General 550 Dig-R-Mobile was used to drill a 3 5/8-inch diameter hole 3-6 inches deeper than the required well depth. The hole was backfilled with pea gravel to the required well depth and a commercially-available 2-inch diameter well (schedule 40 PVC with 1 foot of well screen), cut to a length of about 1 foot longer than the required depth, was inserted into the hole. The hole around the outside of the well was backfilled first with about 1 foot of pea gravel so as to encase the well screen in gravel. The rest of the hole around the outside of the well was then filled to the surface of the ground with commercially-available ¼ -inch diameter bentonite pellets. The pellets were packed every 2-3 feet using a piece of schedule 40 PVC pipe with an i. d. just large enough to fit over the well. Bentonite pellets were packed around the outside of the well at the surface of the ground, covered with soil, and packed again. This provided a watertight casing around the well to prevent surface water (possibly containing dissolved agrichemicals) from seeping down the outside of the well. (*Note: we have observed wells standing in surface water, but with no water in the wells.*)

The sampling of shallow ground water was similar to that previously reported (Smith et al., 1991). Usually within 24h of a rainfall event, a minimum 500mL sample was collected from each well (using a battery-operated ISCO AccuWell model 150 portable pump fitted with a teflon-lined intake line) in a 0.5-L amber bottle with teflon-lined screw cap. Each well was pumped dry and the excess well water was discarded. Shallow ground water samples were placed on ice immediately, transported to the National Sedimentation Laboratory, stored at 4°C (<48 h), and prepared for pesticide analyses via gas chromatography (GC).

The pesticides initially targeted for analysis, along with their GC retention times, are shown in Table 1. 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 were in current use in the MDMSEA watersheds in 1995. *Note: tralomethrin is the precursor to deltamethrin and is detected by GC as deltamethrin.* Analysis of ground water samples was similar to the method of Smith et al. (1995), with modifications. Ground 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, and discarding the water phase. 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 from shallow ground water.

Initially, the gas chromatographs were Tracor model 540s equipped with Dynatech Precision GC-411V auto-samplers to facilitate unattended injection of samples. A PE Nelson 2700 chromatography data system, consisting of three model 970 interfaces, Turbochrom 4.11™ software, and a Gateway 2000 P5-66 microcomputer with Hewlett Packard 5L LaserJet printer, was used for automated quantification and reporting of pesticide peak data. A multi-level calibration procedure was used with standards and samples injected in triplicate. Calibration curves were updated every tenth sample. The main analytical column for all pesticides except the pyrethroids (cyfluthrin, λ-cyhalothrin, and tralomethrin) was a 15m x 0.53mm i.d. J & W Scientific DB 1 (1.5µm film thickness) Megabore™ column. The carrier gas was ultra-high purity (UHP) helium at 5.5 cc/min and the column makeup and electron capture detector (ECD) purge gas was UHP nitrogen at 60 and 10 cc/min, respectively. Column oven, inlet, and ECD temperatures were 185, 240, and 350°C, respectively. The main analytical column for the three pyrethroids was a J & W Scientific DB 210 Megabore column (15m 0.53mm i.d. x 1.0µm film thickness). The carrier gas was (UHP) helium at 12 cc/min and the column oven temperature was 215°C. The other GC conditions were as before. Pesticide residues were confirmed with a second Megabore column (DB 17). Fluometuron analysis was performed with a DB 1 column and a nitrogen phosphorus detector (NPD).

The older Tracor gas chromatographs were recently replaced with two Hewlett Packard model 6890s each equipped with dual HP 7683 ALS auto-injectors, dual split-splitless inlets, dual capillary columns, a HP Kayak XA chemstation, and a HP laserjet 4000 printer. 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). All pesticide analyses of samples (surface and ground water, sediment, soil, and plant material) collected in the MDMSEA and other projects (e.g. DEC) are currently being conducted with this state-of-the-science technology, including MDMSEA shallow ground water samples collected and processed (extracted, cleaned-up, stabilized) since late 1998. Because of changes in scientific interest and changes in pesticide usage in the MDMSEA watersheds, a new list of pesticides has been targeted for analysis (Table 2). The main analytical column is a HP 5MS capillary column (30m x 0.25mm i. d. x 0.25µm film thickness). Column oven temperatures are as follows: initial at 75°C for 1min, ramp at 25°C/min to 185°C, hold at 185°C for 25min, ramp at 25°C to 235°C, and hold for 15min. The carrier gas is UHP helium at 27cm/sec flow velocity with the inlet pressure at 13.24psi and inlet temperature at 250°C. The ECD temperature is 325°C with a constant make up gas flow of 65cc/min UHP nitrogen. The auto-injector is set at 1.0µL injection volume in the fast mode. Under these GC conditions the first 15 pesticides on the list in Table 2 (including the first two pyrethroids bifenthrin and λ-cyhalothrin) can be analyzed in a single run of 47.40min (*Figure 1*). Pesticide residues are confirmed with a HP 1MS capillary column (30m x .25mm i. d. x 0.25µm film thickness) under the same GC conditions and/or with the MSD. Online Pesticide and NIST search libraries are used when needed. GC methodology for analyzing the 6 pyrethroids in Table 2 (last 6 compounds) as a group in a single run has been reported elsewhere (Smith et al., 2000).

RESULTS AND DISCUSSION

As indicated earlier in this paper, the locations of the shallow ground water well sites (total of 26) can be found on the three watershed maps (Deep Hollow Lake, Thighman Lake, and Beasley Lake) on the MDMSEA web site (*www.sedlab.olemiss.edu/msea.html*). There are 12 well sites in the Deep Hollow Lake watershed designated DH_1 through DH_{12}. This watershed has the most MDMSEA project-implemented BMPs, which are both cultural (conservation tillage, winter wheat cover, weed sensor weed control) and structural (slotted-board risers, slotted-inlet pipes, grass filter strips, riparian areas). The 12 well sites are at these structural BMPs, as they are designed to slow surface flow with resulting increased infiltration. The other well sites in this watershed (designated Hg) are deeper wells related to a hydrogeology research effort and are discussed in another paper in this publication (Adams and Davidson, 2000). The Thighman Lake watershed was originally intended to serve as the 'control' watershed with no project-imposed BMPs. Thus, there are only 4 well sites (two in a riparian area, one on a main field drainage to Thighman Lake, and one along the inlet to Thighman Lake). The Beasley Lake watershed has only structural BMPs imposed by the project. The 10 well sites (outside and west of the large forested wetland/riparian area) are primarily located at structural BMPs and along field drainage ditches.

Over the three water years (1996-1998), a total of 622 well samples were collected. A water year is from October of the previous year through September of the so-called water year. Thus, water year 1996 (WY96) is from October 1995 through September 1996, and so forth. There were 103 well samples collected in WY96, 160 in WY97, and 359 in WY98. Of the 622 well samples collected, there were only 5 detections and all were in WY96 (Table 3). All 5 detections were in the Beasley Lake watershed. Norflurazon was detected once at 0.4ppb and metolachlor was detected 4 times at levels ranging from 3-8ppb. All detections were at extremely low levels and present no water quality problems, as they were transient in nature. There were no detections in WY97 or in WY98. It appears then that the project-imposed BMPs caused no shallow ground water quality problems in any of the three MDMSEA watersheds. Pesticides leached into the soil profile were likely degraded/processed in the biologically-active upper soil horizons. Evaluation of shallow ground water quality in the MDMSEA watersheds continues, but at a greatly reduced level.

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Mention of a pesticide in this paper does not constitute a recommendation for use by the U. S. Department of Agriculture nor does it imply registration under FIFRA as amended. Names of commercial products are included for the benefit of the reader and do not imply endorsement or preferential treatment by the U. S. Department of Agriculture. All programs and services of the U. S. Department of Agriculture are offered on a nondiscriminatory basis without regard to race, color, national origin, religion, sex, marital status, or handicap

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Table 1. Initially targeted pesticides.

Pesticide	GC Retention time (min)
Atrazine	2.74
Methyl Parathion	3.99
Heptachlor	4.69
Metolachlor	5.14
Aldrin	5.65
Endosulfan	8.29
p, p'-DDE	8.80
Dieldrin	9.22
Endrin	10.22
p, p'-DDD	10.81
Norflurazon	12.22
p, p'-DDT	13.70
Methoxychlor	18.76
Cyfluthrin	4.78, 5.37, 5.91
λ-Cyhalothrin	3.18
Tralomethrin	7.53
Fluometuron	1.92

Table 2. Presently targeted pesticides.

Trifluralin	Chlorfenapyr
Atrazine	p,p'-DDD
Methyl parathion	p,p'-DDT
Alachlor	Bifenthrin
Metolachlor	λ-Cyhalothrin
Chlorpyrifos	Cyfluthrin
Cyanazine	Zeta-cypermethrin
Pendimethalin	Esfenvalerate
Dieldrin	Deltamethrin
p,p'-DDE	

Table 3. Pesticides in shallow ground water in WY96.

				PESTICIDE CONCENTRATION --- ppb																
Sample #	Date	Site	Depth (ft)	Atrazine	Methyl parathion	Metolachlor	Norflurazon	Heptachlor	Aldrin	Endosulfan	pp' DDE	Dieldrin	Endrin	pp' DDD	pp' DDT	Methoxychlor	λ-Cyhalothrin	Cyfluthrin	Tralomethrin	Fluometuron
1	12/14/1995	B1	15	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
2	"	B2	5	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
3	"	B2	10	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
4	"	B7	10	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
5	"	B8	10	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
6	"	B10	5	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
7	"	B10	10	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
8	"	B10	15	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
9	"	DH1	15	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
10	"	DH9	15	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
11	12/26/1995	DH9	5	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
12	"	DH9	10	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
13	"	DH9	15	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
14	1/5/1996	B1	15	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
15	"	B2	5	ND	ND	ND	0.4	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
16	"	B2	10	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
17	"	B6	5	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
18	"	B7	10	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
19	"	B8	10	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
20	"	B10	5	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
21	"	B10	10	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
22	"	B10	15	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
23	"	DH9	5	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
24	"	DH9	10	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
25	"	DH9	15	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
26	2/12/1996	B10	5	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
27	"	B1	15	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
28	"	B2	5	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
29	"	B2	10	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
30	"	B6	5	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
31	"	B7	5	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
32	"	B7	10	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
33	"	B8	10	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
34	"	B10	10	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
35	"	B10	15	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
36	"	DH9	5	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
37	"	DH9	10	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
38	3/21/1996	B1	15	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
39	"	B2	5	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
40	"	B2	10	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
41	"	B6	5	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
42	"	B7	10	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
43	"	B8	5	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
44	"	B8	10	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
45	"	B10	5	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
46	"	B10	10	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
47	"	B10	15	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
48	"	DH9	5	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
49	"	DH9	10	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
50	5/8/1996	B1	15	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
51	"	B2	5	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND

				PESTICIDE CONCENTRATION --- ppb																
Sample #	Date	Site	Depth (ft)	Atrazine	Methyl parathion	Metolachlor	Norflurazon	Heptachlor	Aldrin	Endosulfan	pp' DDE	Dieldrin	Endrin	pp' DDD	pp' DDT	Methoxychlor	λ-Cyhalothrin	Cyfluthrin	Tralomethrin	Fluometuron
52	"	B2	10	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
53	"	B6	5	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
54	"	B7	5	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
55	"	B7	10	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
56	"	B8	5	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
57	"	B8	10	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
58	"	B9	10	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
59	"	B10	5	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
60	"	B10	10	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
61	"	B10	15	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
62	"	DH8	5	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
63	"	DH9	5	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
64	"	DH9	15	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
65	"	DH9	10	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
66	6/4/1996	B1	15	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
67	"	B2	5	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
68	"	B2	10	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
69	"	B6	5	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
70	"	B7	10	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
71	"	B8	10	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
72	"	B9	10	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
73	"	B10	5	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
74	"	B10	10	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
75	"	B10	15	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
76	"	DH9	5	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
77	"	DH9	10	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
78		B10	15	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
79		B1	15	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
80		B2	10	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
81		B6	5	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
82		B7	10	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
83		B8	10	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
84		B10	5	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
85		B10	10	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
86	8/12/1996	B2	10	ND	ND	3	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
87	"	B1	15	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
88	9/19/1996	B7	10	ND	ND	5	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
89	"	B10	15	ND	ND	8	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
90	"	B2	10	ND	ND	6	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
91	"	DH2	5	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
92	"	DH1	10	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
93	"	B1	15	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
94	"	B6	5	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
95	"	B10	5	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
96	"	B2	5	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
97	9/30/1996	B7	5	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
98	"	B10	15	ND	ND	5	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
99	"	B2	10	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
101	"	B10	5	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
102	"	B7	10	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
103	"	B2	5	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND

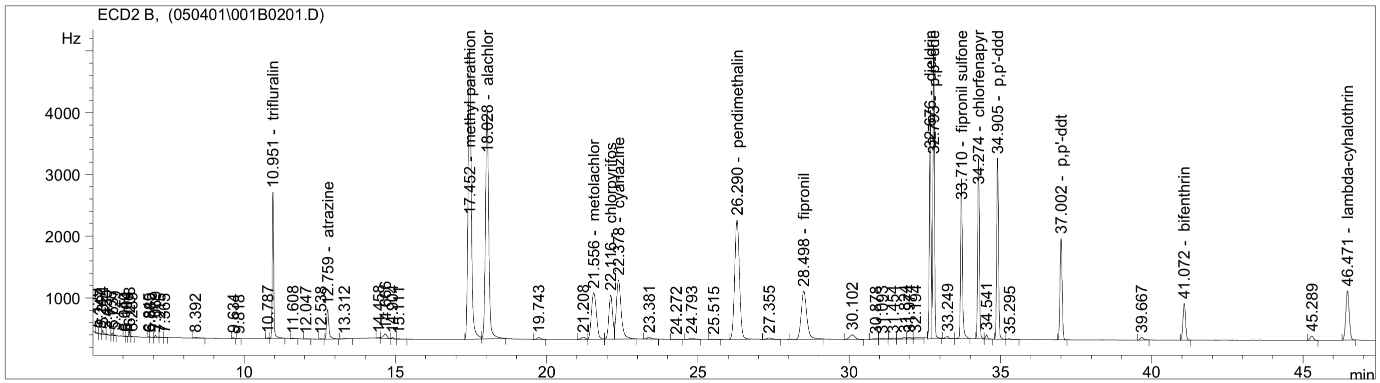

Figure 1. Typical gas chromatogram of 15 pesticides on HP 5MS column

APPENDIX

Chemical names of pesticides mentioned in this paper

alachlor (2-chloro-2′,6′-diethyl-*N*-methoxymethylacetanilide)
aldrin [(1*R*,4*S*,4a*S*,5*S*,8*R*,8a*R*)-1,2,3,4,10,10-hexachloro-1,4,4a,5,8,8a-hexahydro-1,4:5,8-dimethanonaphthalene]
atrazine (2-chloro-4-ethylamino-6-isopropylamino-1,3,5-triazine)
bifenthrin [2-methylbiphenyl-3-ylmethyl (*Z*)-(1*RS,*3*RS*)-3-(2-chloro-3,3,3-trifluoroprop-1-enyl)-2,2-dimethylcyclopropanecarboxylate] **Capture**
chlorfenapyr [4-bromo-2-(4-chlorophenyl)-1-(ethoxymethyl)-5-(trifluoromethyl)-1H-pyrrole-3-carbonitrile]
chlorpyrifos (*O*,*O*-diethyl *O*-3,5,6-trichloro-2-pyridyl phosphorothioate)
cyanazine [2-(4-chloro-6-ethylamino-1,3,5-triazin-2-ylamino)-2-methylpropionitrile]
cyfluthrin [*RS*-*α*-cyano-4-fluoro-3-phenoxybenzyl(1*RS*,3*RS*)-*cis,trans*-3-(2,2-dichlorovinyl)-2,2-dimethylcyclopropanecarboxylate] **Baythroid**
DDD [1,1-dichloro-2,2-bis (*p*-chlorophenyl) ethane]
DDE [1,1-dichloro-2,2-bis(*p*-chlorophenyl)ethylene]
DDT [1,1,1-trichloro-2,2-bis(*p*-chlorophenyl)ethane]
deltamethrin [(*S*)-*α*-cyano-3-phenoxybenzyl (1*R*,3*R*)-3-(2,2-dibromovinyl)-2,2-dimethylcyclopropanecarboxylate]
dieldrin (1,2,3,4,10,10-hexachloro-6,7-epoxy-1,4,4a,5,6,7,8,8a,octahydro-1,4,5,8-dimethanonaphthalene)
endosulfan (6,7,8,9,10,10-hexachloro-1,5,5a,6,9,9a-hexahydro-6,9-methano-2,4,3-benzodioxathiopin-3-oxide)
endrin (1,2,3,4,10,10-hexachloro-1*R*,4*S*,4a*S*,5*S*,6,7*R*,8*R*,8a*R*-octahydro-6,7-epoxy-1,4:5,8-dimethanonaphthalene)
esfenvalerate {[*S*-(*R*,R**)]-cyano(3-phenoxyphenyl)methyl 4-chloro-α-(1-methylethyl)benzeneacetate} **Asana XL**
fluometuron [*N,N*-dimethyl-*N′*-(3-(trifluoromethyl)phenyl)-urea]
heptachlor (1,4,5,6,7,8,8-heptachloro-3a,4,7,7a-tetrahydro-4,7-methanoindene)
methoxychlor (2,2-bis(p-methoxyphenyl)-1,1,1-trichloroethane)
methyl parathion (*O,O*-dimethyl-*O*-*p*-nitrophenyl phosphorothioate)
metolachlor [2-chloro-6'-ethyl-*N*-(2-methoxy-1-methylethyl)acet-*o*-toluidide]
norflurazon [4-chloro-5-(methylamino)-2-(*α,α,α* -trifluoro-*m*-tolyl)-3(2*H*)-pyridazinone]
pendimethalin [N-(1-ethylpropyl)-3,4-dimethyl-2,6-dinitrobenzenamine]
trifluralin (*α,α,α*-trifluro-2,6-dinitro-*N,N*-dipropyl-*p*-toluidine)
zeta-cypermethrin [(*S*)-*α*-cyano-3-phenoxybenzyl (1*RS*,3*RS*;1*RS*,3*SR*)-3-(2,2-dichlorovinyl)-2,2-dimethylcyclopropanecarboxylate] **Fury**
λ-cyhalothrin {[1α(*S**),3α(*Z*)]-cyano(3-phenoxyphenyl)methyl 3-(2-chloro-3,3,3-trifluoro-1-propenyl)-2,2-dimethylcyclopropanecarboxylate]} **Karate**

WATER QUALITY RESEARCH IN THE BEASLEY LAKE FORESTED WETLAND/RIPARIAN AREA OF THE MISSISSIPPI DELTA MSEA

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BACKGROUND

Surface and ground water contamination by agrichemicals (pesticides and nutrients) is determined by a complex combination of chemical, soil, management, and climatic factors (Rao and Jessup, 1983; Helling and Gish, 1986; Cheng and Koskinen, 1986; Jury et al., 1987; Seiber, 1987; Leonard and Knisel, 1988; Mc Bride et al., 1988). Specific factors include: flow path length from source to receiving water and the residence time and decomposition rate of the agrichemical (Moody, 1990). High levels of agrichemical use, intensive and continuous cropping, poor water management, permeable soils and subsoils, and shallow water tables increase this potential dramatically (U.S. Department of Agriculture, 1989). Practices and features designed to slow runoff and enhance agrichemical processing/retention include conservation tillage (no-till, reduced-till, etc.) grass filter strips/stiff grass hedges, grassed waterways (e.g. vegetated drainage ditches), and wetlands. Natural wetland riparian areas (often forested) situated between agricultural lands and receiving water bodies possess this ability as do constructed wetlands (Hammer and Bastian, 1989; Cooper et al., 1993). However, the most important but least understood function of wetlands is water quality improvement, at least in terms of the complex processes involved. In several recent studies, evidence strongly indicated that a substantial part of the nitrate in agricultural drainage water was denitrified in forested buffer strips (Weil et al., 1990; Lowrance, 1992; Jordan et al., 1993). While riparian zones have the ability to remove nitrate-N from receiving waters, there is considerable uncertainty as to the mechanism. Both denitrification and vegetative uptake may be important processes (Ambus and Lowrance, 1991; Groffman et al., 1992). The ability of these wetland riparian areas to trap and process pesticides is not well characterized or documented. The purpose of this research is to provide additional insight into the ability of Mississippi Delta wetland riparian areas to mitigate the effects of offsite movement of agrichemicals.

MATERIALS AND METHODS

In July and August of 1997, three shallow ground water well sites (three wells per site at depths of 5', 10' 15') were established in the forested wetland riparian area of the Beasley Lake watershed in the MDMSEA project as described by Smith (1999). These sites are designated B_{11}, B_{12}, and B_{13} on the site map (*Figure 1*) and are adjacent to surface water sampling sites R_1, R_2, and R_3. In February of 1998, additional shallow ground water wells (2'-depth) were established at B_{11}, B_{12}, B_{13}, and B_{14} using a hand auger. The sampling of shallow ground water was similar to that previously reported (Smith et al., 1991). Usually within 24h of a rainfall event, a 500-mL sample was collected from each well (using a battery-operated ISCO AccuWell model 150 portable pump fitted with a teflon-lined intake line) in a 0.5-L amber bottle with teflon-lined screw cap. Each well was pumped dry and the excess well water was discarded. Shallow ground water samples were placed on ice, immediately transported to the National Sedimentation Laboratory, stored at 4°C (<48 h), and prepared for pesticide analyses via gas chromatography. Suspended sediment traps were also established at sites R_{1-4} and were sampled on the same schedule as shallow ground water.

Analysis of ground water and suspended samples for the pyrethroid insecticides {8-cyhalothrin, **Karate™** [*RS*-α-cyano-3-phenoxybenzyl 3-(2-chloro-3,3,3-trifluoropropenyl)-2,2,-dimethylcyclopropanecarboxylate]; cyfluthrin, **Baythroid™** [*RS*-α-cyano-4-fluoro-3-phenoxybenzyl(1*RS*,3*RS*)-cis,trans-3-(2,2-dichlorovinyl)-2,2-dimethylcyclo-propanecarboxylate]; and deltamethrin, **Decis™** [(*S*)-α-cyano-3-phenoxybenzyl (1*R*,3*R*)-3-(2,2-dibromovinyl)-2,2-dimethylcyclopropanecarboxylate]} was similar to the method of Smith et al. (1995), with modifications. Ground 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) with 1g reagent-grade KCl and 100 mL pesticide-grade EtOAc, partitioning in a separatory funnel, and discarding the water phase. 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 gas chromatographic (GC) analysis. Suspended sediments were air-dried and ground to pass a 2mm sieve. A 10.00 sub-sample was extracted and cleaned up in a manner similar to that used for the shallow ground water samples. Mean extraction efficiencies, based on fortified samples, were >90% for all pesticides from shallow ground water and in suspended sediment.

Initially, the gas chromatographs were Tracor model 540s equipped with Dynatech Precision GC-411V autosamplers to facilitate unattended injection of samples. A PE Nelson 2700 chromatography data system, consisting of three model 970 interfaces, Turbochrom 4.11™ software, and a Gateway 2000 P5-66 microcomputer with Hewlett Packard 5L LaserJet printer, was used for automated quantification and reporting of pesticide peak data including gas chromatograms. A multi-level calibration procedure was used with standards and samples injected in triplicate. Calibration curves were updated every tenth sample. The main analytical column for the three pyrethroids was a 15m x 0.53mm i. d. J & W Scientific DB 210 Megabore column (15m 0.53mm i. d. x 1.0µm film thickness). The carrier gas was ultra-high purity (UHP) helium at 12 cc/min and the column makeup and detector purge gas was UHP nitrogen at 60 and 10 cc/min, respectively. Column oven, inlet, and electron-capture detector (ECD) temperatures were 215, 240, and 350°C, respectively. Pesticide residues were confirmed with a second Megabore column (DB 17).

The older Tracor gas chromatographs were recently replaced with two Hewlett Packard model 6890s each 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. 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). The main analytical column was a HP 1MS capillary column (30m x .25mm i. d. x 0.25µm film thickness). Column oven temperatures were as follows: initial at 75°C for 1min, ramp at 40°C/min to 225°C, and hold at 225°C for 35min. The carrier gas was UHP helium at 27cm/sec with the inlet pressure at 13.24psi and inlet temperature at 250°C. The ECD temperature was 325°C with a constant make up gas flow of 60cc/min UHP nitrogen. The autoinjector was set at 1.0µL injection volume in the fast mode. Pesticide residues were confirmed with a HP 5MS capillary column (30m x .25mm i. d. x 0.25µm film thickness) and/or with the MSD.

Nutrient sample preparation and analyses for PO_4-P, NH_4-N, and NO_3-N was as previously reported by Schreiber (1992) using Dionex anion chromatography and Bran-Lubbe (Technicon) automated flow-through colorimetry. Total organic carbon (TOC) analyses were performed with a Rosemount Analytical Dohrmann DC-190 carbon analyzer with automatic liquid sampler.

RESULTS AND DISCUSSION

Nutrients

For the entire 1300 acre Beasley Watershed, the mean 1998 concentrations (all depths and sites) of PO4-P, NH4-N, NO3-N, and TOC (total dissolved organic carbon) were 0.16, 1.82, 0.72, and 61 ppm, respectively (Table 1). The relatively high PO4-P concentration reflects the naturally high phosphorus fertility status of Delta soils. The relatively low NO3-N concentrations are more than likely the result of high rates of denitrification during the winter months when the soil profile is saturated (low oxygen levels). Further evidence for this scenario is offered by the high concentrations of TOC, a necessary requirement for denitrification. Examination of nutrient concentrations in shallow ground water within the natural wetland/riparian zone provides dramatic evidence for the ability of these landscape areas to process nutrients. The mean concentration (all depths and all sites - riparian zone only) of PO4-P, NH4-N, NO3-N, and TOC were 0.02, 0.27, 0.20, and 145 ppm. With the exception of TOC, these concentrations were considerably lower than those observed within other landscape areas of the Beasley Watershed. As mentioned previously, the much higher concentration of dissolved organic carbon in ground water within the riparian zone would tend to promote denitrification. Additional evidence can be found by a closer analysis of nutrient data by depth within the soil profile. For example, at the B11 site, the mean NO3-N and TOC concentrations at the two-foot depth were 0.49 and 58 ppm, respectively, compared with 0.01 and 374 ppm, at the five-foot depth. A thorough study of denitrification within this riparian zone is required to determine with certainty the disappearance pathway for NO3-N. The processing of NO3-N could prove to be one of the strongest arguments for the maintenance of wetlands/riparian zones in the Mississippi Delta.

Pesticides

A controlled-release runoff event was simulated in September of 1997 as part of a riparian area surface water quality study being conducted in conjunction with the current riparian area shallow ground water study. The simulation was based on a 0.25" runoff event from a 22-acre cotton field in the vicinity of the riparian area, occurring within 12 h of applying 8-cyhalothrin and cyfluthrin (each at a rate of 0.03 lbs/acre), 10% of each pyrethroid leaving the field in runoff, and a sediment concentration in runoff typical of the area. Results indicated that the applied pyrethroid insecticides, 8-cyhalothrin and cyfluthrin, were transported almost exclusively in the sediment phase of the runoff. Data from sediment traps generally showed decreasing insecticide concentration gradients both spatially (east to west) and temporally (0-4mo). The 4-mo samples from the sediment traps at R_4 contained very low levels [<10 µg/kg (ppb)] of the two insecticides, whereas, the 1h samples from R_1 contained concentrations of each insecticide at about 3 µg/g (ppm). Additional information on the surface water study was reported elsewhere (Harrington, 1998). Since the beginning of 1998 through the present time (October 1999), suspended sediment samples from sites R_{1-4} and shallow ground water samples have been collected from sites B_{11-14}. Results for pyrethroid insecticides (of great interest because of their very high toxicity to many fish and aquatic invertebrate species) found in the sediment are shown in Table 2. Values at each site and date represent the means of two sediment traps. These samples represent sediment that has been transported through the riparian area and trapped in special collectors. By March of 1998, mean concentrations of 8-cyhalothrin and cyfluthrin in sediment were 5 and 1 µg/kg (ppb), respectively. By October, 8-cyhalothrin concentrations had decreased to about 2 ppb and cyfluthrin was not detectable (N.D.). Neither pyrethroid was detected in samples collected in March and October of 1999. Although never detected, deltamethrin was included in the analytical scheme because it had been used in fields that drain into the riparian area.

Transported sediments are likely the source of pyrethroids in shallow ground water (Table 3). The values for each well site for each sampling date represent the means for all depths. This was done to keep the table to a manageable size as nearly 300 well samples were collected in 1998-1999. Although the riparian well sites were established prior to the controlled-release runoff event and checked weekly, no shallow ground water was present in the wells until January of 1998. The initial concentrations of 8-cyhalothrin and cyfluthrin were about 0.02 µg/L each, well below the reported LC_{50}s of 0.2 and 1.5 µg/L, respectively, for bluegill sunfish (EXTOXNET, 1999). Concentrations of both compounds in shallow ground water fluctuated at very low levels over the next several months (0.001 to 0.0019 µg/L). By August of 1998, cyfluthrin could no longer be detected and 8-cyhalothrin was very infrequently detected (<0.005 µg/L). As with the suspended sediment, cyfluthrin dissipated more quickly than 8-cyhalothrin.

Sampling the suspended sediment and shallow ground water in the Beasley Lake riparian area will continue for about one more year. Currently, the newer pesticide analytical instrumentation is facilitating lower detection limits and additional pyrethroid insecticides to be determined in a single GC run (*Figure 2*). These additional pyrethroids include: bifenthrin **Capture™** [2-methylbiphenyl-3-ylmethyl (*Z*)-(1*RS*,3*RS*)-3-(2-chloro-3,3,3-trifluoroprop-1-enyl)-2,2-dimethylcyclopropanecarboxylate], zeta-cypermethrin **Fury™** [(*S*)-α-cyano-3-phenoxybenzyl (1*RS*,3*RS*;1*RS*,3*SR*)-3-(2,2-dichlorovinyl)-2,2-dimethylcyclopropanecarboxylate], and esfenvalerate **Asana XL™** {[*S*-(*R**,*R**)]-cyano(3-phenoxyphenyl)methyl 4-chloro-α-(1-methylethyl)benzeneacetate}.

ENDING NOTE

As mentioned earlier in this report, a controlled-release runoff event with applied pyrethroids was simulated to evaluate the pesticide mitigation ability of the Beasley Watershed riparian area. The reason for the simulation was that for about a year prior to this event, surface water and suspended sediment samples were collected on a regular basis from sites R_{1-4}. However, no pyrethroids were detected even though they had been applied to fields draining into the riparian area via a network of ditches. The drainage ditches themselves (generally heavily populated with aquatic plants during the months of the year when pyrethroids are applied) were hypothesized to have mitigated the movement of applied pyrethroids in runoff. As a result of this hypothesis, several comprehensive studies with vegetated drainage ditches in both Beasley Lake and Thighman Lake watersheds have been conducted or are ongoing. These results will be the subject of future reports. Preliminary results have or are being present elsewhere (Moore et al., 2000; Bennett et al., 1999; Farris et al., 1999).

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Mention of a pesticide in this paper does not constitute a recommendation for use by the U. S. Department of Agriculture nor does it imply registration under FIFRA as amended. Names of commercial products are included for the benefit of the reader and do not imply endorsement or preferential treatment by the U. S. Department of Agriculture. All programs and services of the U. S. Department of Agriculture are offered on a nondiscriminatory basis without regard to race, color, national origin, religion, sex, marital status, or handicap

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Table 1. Nutrients in shallow ground water in the MDMSEA watersheds---preliminary results

Waterhsed	PO4-P Conc. In water *ppm*	NH4-N Conc. In water *ppm*	NO3-N Conc. In water *ppm*	TOC Conc. In water *ppm*
Beasley (entire watershed)	0.16	1.82	0.72	61
Deep Hollow (entire watershed)	0.25	0.11	0.36	52
Thighman (entire watershed)	0.07	0.18	0.62	29

Table 2. Pyrethroids in Sediment Traps from Beasley Riparian Area

Date	Site*	Cyhalothrin Conc. In sed. ug/kg	Cyfluthrin Conc. In sed. ug/kg	Deltamethrin Conc. In sed. ug/kg	Date	Site*	Cyhalothrin Conc. In sed. ug/kg	Cyfluthrin Conc. In sed. ug/kg	Deltamethrin Conc. In sed. ug/kg
3/6/98	B11	6.76	2.16	N. D.	9/17/98	B11	2.21	N. D.	N. D.
	B12	4.15	0.67	N. D.		B12	2.24	N. D.	N. D.
	B13	6.36	0.91	N. D.		B13	2.26	N. D.	N. D.
	B14	3.46	N. D.	N. D.		B14	2.33	N. D.	N. D.
4/10/98	B11	2.82	1.26	N. D.	10/16/98	B11	1.82	N. D.	N. D.
	B12	2.79	N. D.	N. D.		B12	2.32	N. D.	N. D.
	B13	6.57	0.36	N. D.		B13	1.99	N. D.	N. D.
	B14	3.18	N. D.	N. D.		B14	1.72	N. D.	N. D.
5/26/98	B11	3.54	0.72	N. D.	3/25/99	B11	N. D.	N. D.	N. D.
	B12	3.54	N. D.	N. D.		B12	N. D.	N. D.	N. D.
	B13	3.16	0.30	N. D.		B13	N. D.	N. D.	N. D.
	B14	3.22	0.36	N. D.		B14	N. D.	N. D.	N. D.
6/23/98	B11	1.74	0.84	N. D.	10/5/99	B11	N. D.	N. D.	N. D.
	B12	3.78	0.84	N. D.		B12	N. D.	N. D.	N. D.
	B13	5.66	N. D.	N. D.		B13	N. D.	N. D.	N. D.
	B14	4.74	N. D.	N. D.		B14	N. D.	N. D.	N. D.
7/23/98	B11	3.96	0.72	N. D.					
	B12	3.54	N. D.	N. D.					
	B13	3.24	N. D.	N. D.					
	B14	3.10	N. D.	N. D.					

*B11-14 well sites equivalent to R1-4 surface sites.

Table 3. Pyrethroids in Beasley Riparian shallow ground water.

Date	Site	Cyhalothrin Conc. in water ug/L	Cyflythrin Conc. in water ug/L	Deltamethrin Conc. in water ug/L	Date	Site	Cyhalothrin Conc. in water ug/L	Cyflythrin Conc. in water ug/L	Deltamethrin Conc. in water ug/L	Date	Site	Cyhalothrin Conc. in water ug/L	Cyflythrin Conc. in water ug/L	Deltamethrin Conc. in water ug/L
01/23/98	B11	0.016	0.016	N. D.	02/02/99	B11	N. D.	N. D.	N. D.	04/20/99	B11	N. D.	N. D.	N. D.
02/27/98	B11	0.004	0.009	N. D.		B12	N. D.	N. D.	N. D.		B12	N. D.	N. D.	N. D.
	B12	0.004	0.009	N. D.		B13	N. D.	N. D.	N. D.		B13	N. D.	N. D.	N. D.
	B13	0.003	0.014	N. D.	02/09/99	B11	N. D.	N. D.	N. D.		B14	N. D.	N. D.	N. D.
	B14	0.005	0.007	N. D.		B12	N. D.	N. D.	N. D.	04/28/99	B11	N. D.	N. D.	N. D.
06/23/98	B11	0.006	0.008	N. D.		B13	N. D.	N. D.	N. D.		B13	N. D.	N. D.	N. D.
	B12	0.008	0.004	N. D.		B14	N. D.	N. D.	N. D.		B14	N. D.	N. D.	N. D.
	B14	0.014	N. D.	N. D.	02/23/99	B11	N. D.	N. D.	N. D.	05/01/99	B13	0.003	N. D.	N. D.
07/07/98	B14	0.017	N. D.	N. D.		B12	N. D.	N. D.	N. D.	05/21/99	B11	N. D.	N. D.	N. D.
07/23/98	B14	0.002	0.002	N. D.		B13	N. D.	N. D.	N. D.		B12	N. D.	N. D.	N. D.
08/05/98	B11	0.002	N. D.	N. D.		B14	N. D.	N. D.	N. D.		B13	N. D.	N. D.	N. D.
	B12	0.011	N. D.	N. D.	03/03/99	B11	N. D.	N. D.	N. D.		B14	N. D.	N. D.	N. D.
	B14	0.018	N. D.	N. D.		B12	N. D.	N. D.	N. D.	06/01/99	B11	N. D.	N. D.	N. D.
08/21/98	B12	0.012	N. D.	N. D.		B13	N. D.	N. D.	N. D.		B12	N. D.	N. D.	N. D.
09/11/98	B14	0.019	N. D.	N. D.		B14	N. D.	N. D.	N. D.		B13	N. D.	N. D.	N. D.
09/17/98	B12	N. D.	N. D.	N. D.	03/10/99	B11	N. D.	N. D.	N. D.		B14	N. D.	N. D.	N. D.
11/12/98	B11	0.001	N. D.	N. D.		B12	N. D.	N. D.	N. D.	06/08/00	B11	N. D.	N. D.	N. D.
	B14	0.005	N. D.	N. D.		B13	N. D.	N. D.	N. D.		B12	N. D.	N. D.	N. D.
11/23/98	B11	N. D.	N. D.	N. D.		B14	N. D.	N. D.	N. D.		B13	N. D.	N. D.	N. D.
	B12	N. D.	N. D.	N. D.	03/16/99	B11	N. D.	N. D.	N. D.		B14	N. D.	N. D.	N. D.
	B13	N. D.	N. D.	N. D.		B12	N. D.	N. D.	N. D.	06/16/99	B11	N. D.	N. D.	N. D.
	B14	0.003	N. D.	N. D.		B13	0.004	N. D.	N. D.		B12	N. D.	N. D.	N. D.
12/18/98	B11	N. D.	N. D.	N. D.		B14	N. D.	N. D.	N. D.		B13	N. D.	N. D.	N. D.
	B12	N. D.	N. D.	N. D.	03/23/99	B11	N. D.	N. D.	N. D.		B14	N. D.	N. D.	N. D.
	B14	0.001	N. D.	N. D.		B12	N. D.	N. D.	N. D.	06/22/99	B11	N. D.	N. D.	N. D.
12/30/98	B11	N. D.	N. D.	N. D.		B13	N. D.	N. D.	N. D.		B12	N. D.	N. D.	N. D.
	B12	N. D.	N. D.	N. D.		B14	N. D.	N. D.	N. D.		B13	N. D.	N. D.	N. D.
01/15/99	B11	N. D.	N. D.	N. D.	03/30/99	B11	N. D.	N. D.	N. D.		B14	N. D.	N. D.	N. D.
	B12	N. D.	N. D.	N. D.		B12	N. D.	N. D.	N. D.	06/30/99	B11	N. D.	N. D.	N. D.
	B13	N. D.	N. D.	N. D.		B13	N. D.	N. D.	N. D.		B13	N. D.	N. D.	N. D.
	B14	N. D.	N. D.	N. D.		B14	N. D.	N. D.	N. D.		B14	N. D.	N. D.	N. D.
01/20/99	B11	N. D.	N. D.	N. D.	04/06/99	B11	N. D.	N. D.	N. D.	07/12/99	B11	N. D.	N. D.	N. D.
	B12	N. D.	N. D.	N. D.		B12	N. D.	N. D.	N. D.		B12	N. D.	N. D.	N. D.
	B13	N. D.	N. D.	N. D.		B13	N. D.	N. D.	N. D.		B13	N. D.	N. D.	N. D.
	B14	N. D.	N. D.	N. D.		B14	N. D.	N. D.	N. D.		B14	N. D.	N. D.	N. D.
01/26/98	B11	N. D.	N. D.	N. D.	04/13/99	B11	N. D.	N. D.	N. D.	07/29/99	B11	N. D.	N. D.	N. D.
	B12	N. D.	N. D.	N. D.		B12	N. D.	N. D.	N. D.		B12	N. D.	N. D.	N. D.
	B13	N. D.	N. D.	N. D.		B13	N. D.	N. D.	N. D.		B13	N. D.	N. D.	N. D.
	B14	N. D.	N. D.	N. D.		B14	N. D.	N. D.	N. D.	08/10/99	B11	N. D.	N. D.	N. D.

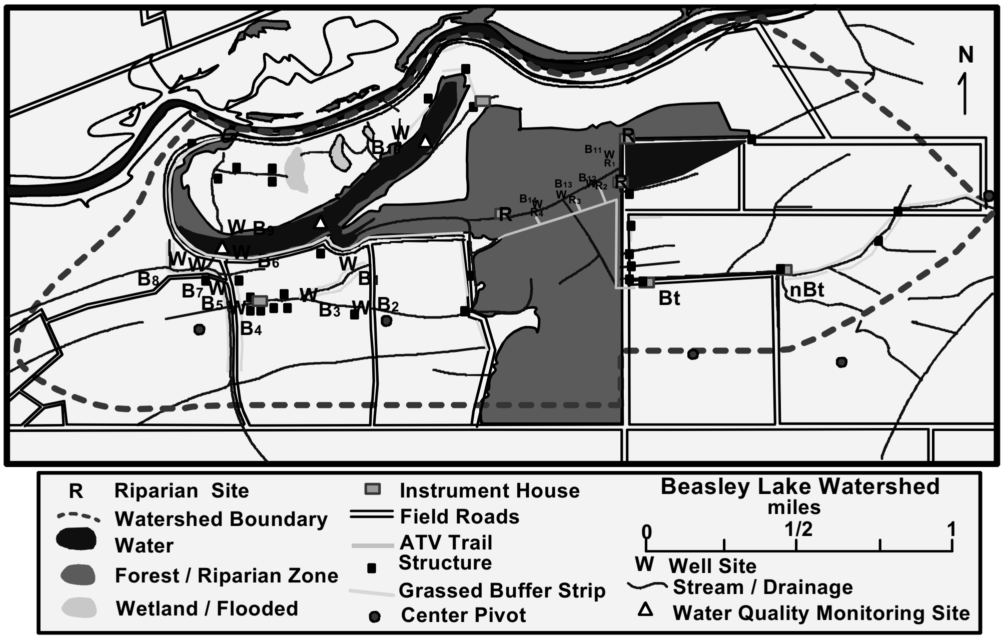

Figure 1a. Beasley Lake Watershed.

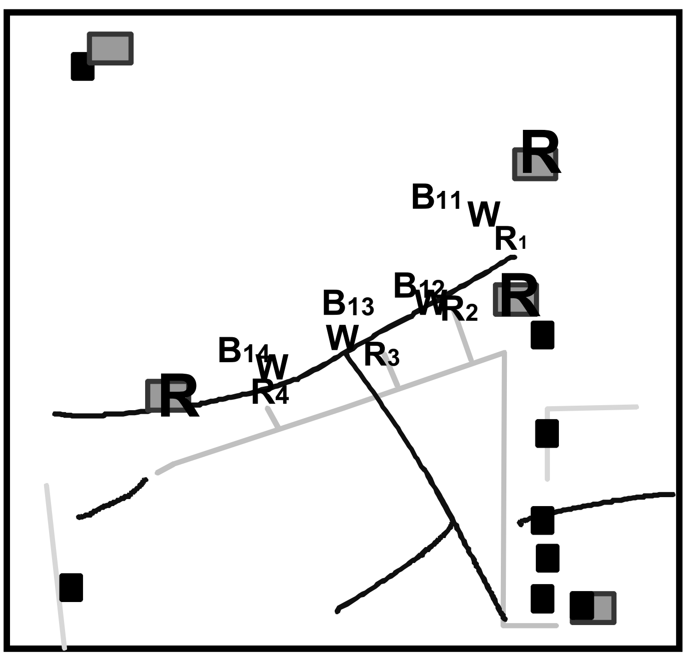

Figure 1b. Close-up of riparian sampling sites.

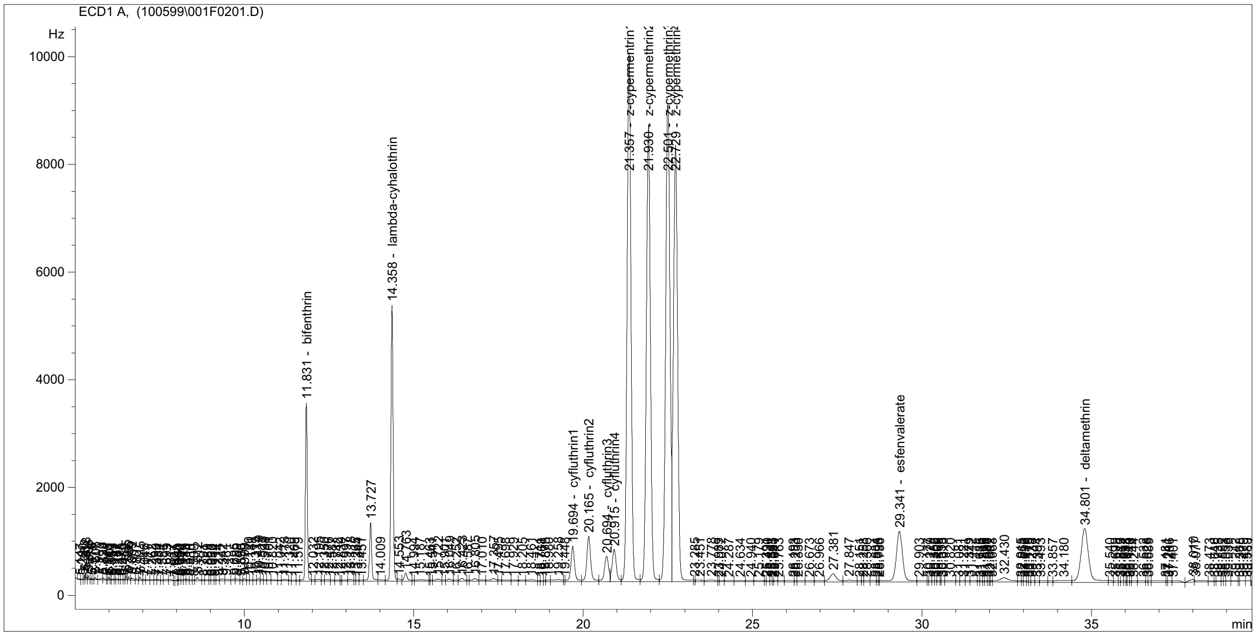

Figure 2. Typical gas chromatogram for 6 pyrethroid insecticides.

THE MSEA AND STRIDE EDUCATIONAL COLLABORATION

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ABSTRACT

The Student and Teacher Research Institute – the Delta Experience (STRIDE): Targeting Mississippi Schools and the Environment is a collaborative effort between Mississippi State University and the Mississippi Delta Management Systems Evaluation Area (MSEA). Funded in part by the National Science Foundation in 1998 for three years, the project involves more than 80 Delta middle school students and teachers in environmental research in the Mississippi Delta. The primary objective of this project is to train teachers and students from middle schools in the Mississippi Delta in research data collection and analysis techniques through real scientific research through meaningful interdisciplinary research experiences. Participants learn how to design and evaluate best management practices in farming procedures for improving water quality and ecology. The student and teacher teams work side-by-side with MSEA scientists on existing research projects and assist with all aspects of the projects from collecting and recording data to analysis. Participants received an introduction to research methodology and an awareness of careers in science and engineering through participation in one of the three four-week summer institutes and in annual academic follow-up. Funding from the NSF ends in March 2001.

INTRODUCTION

With her rich soil, the Mississippi Delta is home to some of the most productive farmland in the world. Student and Teacher Research Institute – the Delta Experience (STRIDE) is a project that works in cooperation with the Mississippi Delta Management Systems Evaluation Area Project (MSEA) to involve for the past three summers more than 80 Delta middle school students in environmental research in the Mississippi Delta. The project described herein offered on a yearly basis an opportunity for ten groups of students, partnered with middle school science teachers, to connect science, engineering, technology, and agriculture while developing skills needed to prepare for future educational experiences. These research experiences enhance the teacher/student teams' knowledge in scientific methodology through participation in current MSEA projects. Such projects have been designed to study the agricultural effects on water resources and ecological processes at three Mississippi Delta oxbow lake sites.

Research experiences provide students with skills they need to compete in today's world. Today's job market requires employees to acquire a range of skills that may not be attainable in the typical classroom. Industry leaders consistently state that skills needed by their workforce include communication, creative problem solving, working in collaboration, decision-making, mathematical skills and computer skills. Involving students in conducting on-going research enhances their opportunity to develop these skills while providing teachers with experiences that they subsequently transfer to the classroom.

The primary objective of this project is to train teachers and students in research data collection and analysis techniques through real scientific research experiences. Through their experiences, teachers understand the role of research in the classroom and enhance their scientific content knowledge. Students in upper middle schools in the Mississippi Delta receive meaningful interdisciplinary research experience and learn how to design and evaluate best management practices for improving water quality and ecology in the Mississippi Delta. Participants increase awareness of environmental and management issues relating to the Mississippi Delta rivers and lakes. STRIDE participants also increase their awareness of careers in science and engineering.

MSEA is part of a consortium of Federal, State, and local agencies that provide a unique opportunity for research experiences for students and teachers in the Delta region. Co-principal investigator Jonathan Pote commented that the MSEA project wants to encourage adoption of good water practices. In particular, MSEA wants to involve young people in working on issues of importance to our state and nation. The MSEA/STRIDE collaboration provides an excellent opportunity to allow students to experience research that is important to the environment and economy of the Mississippi Delta. The collaboration also meets a primary goal of MSEA, providing education, research, and community service in issues of water and associated land-use problems, assuring that a valuable resource will be available to future generations.

The project focuses on three watersheds located in west central Mississippi in the Delta counties of Sunflower and Leflore, each utilizing a different farming management practice. The three practices are structural and cultural best management practices (BMPs), only structural practices, and no BMPs initially. The four major objectives of MSEA are: (1) to develop alternative farming systems for improved water quality and ecology in the Mississippi Delta rivers and lakes; (2) to increase knowledge of the design and evaluation of economical environmentally-sound BMPs as components of farming systems; (3) to assess the effects of agricultural activities on surface and shallow ground-water quality; and, (4) to increase awareness by farmers and landowners of alternative farming systems to reduce adverse agricultural effects on water resources and ecological processes. On-going research projects, in which teachers and students participate, are being conducted by scientists who are employed by the various agencies and institutions associated with the MSEA project.

This paper describes STRIDE as a cooperative effort between the Mississippi Delta Management Systems Evaluation Area project and Mississippi State University, funded in part by the National Science Foundation. Designed to introduce research methodology to middle school teachers and students by working side-by-side with MSEA scientists on existing projects, the student and teacher teams assist with different aspects of research from collecting and recording data to analysis. This paper also describes one of the ongoing collaborations between one of the STRIDE teacher/student teams and MSEA investigators.

MATERIALS AND METHODS

Teacher/Student Participant Recruitment and Selection

Teams of one teacher and two high-potential/highly-motivated students from schools in the Mississippi Delta were selected to participate in a research experience with scientists from the MSEA project. To date, three summer workshops have been held. During the summer of 1998, ten teachers from Sunflower, Leflore and Washington counties, and twenty-two of their academically talented/motivated students, participated in the first of three summer institutes funded by the National Science Foundation. During the 1999 summer, eight teachers from Sunflower, Leflore and Bolivar counties and twenty-two students participated. STRIDE 2000 had ten teachers and twenty students from Bolivar, Holmes, Humphreys, Leflore and Washington counties. The superintendents of the identified school districts and school principals were asked to nominate from each school a middle school science teacher and two high-potential/high-ability students. Teacher nominees were to demonstrate ability in science teaching, commitment to hands-on experiences for students, and leadership qualities. Evidence of students' ability and potential included grades in science, science fair participation, aptitude/achievement tests, and/or essays on their interest in science and reasons for wanting to participate in this program. The project staff, with significant input and guidance from the school systems, selected the teacher and student participants. The schools' input was important in the selection process as they could best assess the potential for maximum benefit to the school system and the local area. School leaders committed to allowing research experiences to be implemented into the local curriculum and to allow teachers to present in-service training to their faculty on research collection and analysis and subsequent connection to the classroom.

Participating Agencies and Other Partners

More than 16 agencies and 50 researchers contribute to make STRIDE a success. Primary research participating agencies on the MSEA project are the USDA Agricultural Research Service, the U.S. Geological Survey, and the Mississippi Water Resources Institute. Cooperating agencies/partners/supporters include USDA-ARS National Sedimentation Laboratory, Mississippi Department of Environmental Quality Control, USDA-Natural Resources Conservation Service, Mississippi Soil and Water Commission, Delta Council, Mississippi Farm Bureau Federation, U.S. Fish and Wildlife Service, Delta Wildlife Foundation, USDA-Wildlife Services, Mississippi Department of Wildlife, Fisheries and Parks, USDA-Farm Service Agency, Yazoo Mississippi Delta Joint Water Management District, the University of Mississippi, Mississippi Agricultural and Forestry Experiment Station, and Mississippi State University.

Several faculty and staff from Mississippi State University played a large role in STRIDE 1998 and 1999. Sandra H. Harpole, Ed.D., Professor of Physics and Director of the Center for Science, Mathematics and Technology, was the Principal Investigator and served as Project Director. She was responsible for the overall management of the project and the coordination of Mississippi State University activities. Jonathan Pote, Ph.D., Professor of Agricultural and Biological Engineering, and Associate Vice President for Research, coordinated the interaction between Mississippi State University and MSEA. Giselle Thibaudeau, Ph.D., Associate Professor, Department of Biological Sciences, assisted with on-site management of the project in the Delta and participated in academic year follow-up workshops. Taha Mzoughi, Ph.D., Assistant Professor, Department of Physics and Astronomy, assisted with on-site management of the project, academic year follow-up, and was responsible for the technology training and Web information dissemination. M. Lynn Prewitt, Ph.D., Senior Research Assistant, Forest Products Laboratory, provided valuable laboratory experiences at Mississippi State University and assisted with follow-up activities. Jean Bailey, Project Coordinator for the Center for Science, Mathematics and Technology, was responsible for the administrative coordination of STRIDE and served as liaison with the research scientists, school district personnel, and university personnel. Frank Gwin, Jr., Project Coordinator for the Mississippi Delta MSEA Project, was responsible for the tremendous task of establishing coordination and collaborations between farmers, research scientists, school district personnel and STRIDE personnel.

RESULTS

Four-Week Institutes:

During the four-week, summer institutes, participants conducted research at three Mississippi Delta oxbow lakes, Deep Hollow Lake, Beasley Lake, and Thighman Lake. In addition to working at these watersheds, they also worked with scientists in the various MSEA labs associated with the three watersheds. Workshops were conducted similarly implementing suggestions from the preceding years. In brief, activities of the first week of the summer programs took place in the Mississippi Delta at research sites associated with the MSEA project. During orientation sessions, all participating scientists were introduced to teacher/student teams. A discussion of the overall project and the contributions of various research components were provided. The entire group was then divided into two groups of five teams that visited laboratory and field sites of each of the scientists to learn different collection and analysis techniques. Teacher/student teams were exposed to each area of research in order for them to experience different data collection techniques and to understand the experimental design of the project and how each component fits into the overall experimental design of the MSEA project. They also gained an overall picture of the impact of the MSEA project on the local area and its economy. By the end of the first week, each team was assigned to a scientist, and in collaboration with them, they were given a basic research problem associated with the researcher's project. Teams worked with these different scientists during the last two weeks of STRIDE.

Week two of STRIDE was spent at Mississippi State University interfacing with scientists and engineers to increase awareness of careers in science and engineering, to learn to use technology as a tool of research, and to learn laboratory analysis techniques associated with state and university laboratories. The research focus of several on-campus laboratories deals with environmental issues. Participants were divided into four groups who rotated through labs in order to learn different research methods. Teacher/student teams worked with scientists from the Forest Products Laboratory, the Department of Agricultural and Biological Engineering, the Department of Industrial Engineering, the Diagnostic Instrumentation and Analysis Laboratory, the College of Veterinary Medicine, and the Engineering Research Center. Presentations on conducting ethical research were made to groups by the Human Subject Regulatory Officer, Radiological Safety Officer and the Laboratory Animal Regulatory Officer. In addition, participants attended sessions designed to teach them how to use the Web and to conduct library background research, to use scientific graphing packages for data analysis, and to use e-mail and mailing lists.

For weeks 3 and 4, teacher/student teams returned to the Delta in order to work with MSEA scientists on location. The schedules differed for each group but a subset of places visited and activities performed during these two weeks are presented here. Groups went to the USDA-ARS National Sedimentation Lab or met the scientists in the field to participate in studies designed to determine shallow ground water quality in edge-of-field and within-field filter/procession systems (e.g. buffer strips, grass hedges, grassed waterways, and slotted board riser impoundments). They also learned to evaluate the ability of such systems to trap sediment and process pesticides. Teams also examined and evaluated watershed ecology and lake-water quality. They learned to evaluate the effects of riparian zones, forested wetlands and best management practices on physical/chemical stresses imposed on agricultural pollution. In addition, they investigated the impact of MSEA on fisheries characteristics and ecology on the Mississippi Delta oxbow lakes. Fisheries data collected to assess the ecological health of the lakes included growth rates, condition factors, length-frequency distributions and other stock-assessment measures. Studies in the field also included the evaluation of interacting effects of fall deep tillage, gypsum application, cover crop burn down date, and soil type on the growth and yield of cotton planted into a desiccated winter wheat cover crop without spring tillage. Students took sediment core samples and penetrometer resistance samples to test water infiltration (Fig. 1). Teams traveled to the U.S. Geological Survey in order to process data collected in the field. Storm runoff samples were used to assess how agricultural activities affect surface-water quality and evaluate management practices that may reduce non-point source pollution. Researchers from the Yazoo Mississippi Delta Joint Water Management District (YMD) taught teachers and students the uses of GPS/GIS mapping equipment. Teams used GPS units to map fields and surrounding areas within the different watersheds being investigated. Teams later imported this information into the GIS software and learned to manipulate map information while at the YMD. While at the Southern Weed Science Lab, teams participated in data collection and analysis involved in the determination of weed infestation levels, weed species identification, shifts in population levels over intervals and general plant communities in different cotton and soybean production systems. They were also exposed to new application technologies for more efficient methods of applying herbicides in crop production areas.

Figure 1. Photo of STRIDE participants and MDMSEA researchers collecting field data.

Saturday workshops were held quarterly throughout the academic year, as well as classroom visits, to assist the teacher and student teams with independent research projects. Teams met, and will meet, with project leaders and research scientists to update their particular project, learn of new research data, design new potential experiments, and be exposed to various forms of scientific presentation. Teachers and students discuss implementation of the research experiences in their local curriculum. Project leaders selected one project from each institute to be presented at the Mississippi Water Resources Conference held in Raymond, Mississippi each spring.

Individual Projects:

Each student/teacher team identified a lead scientist and a research problem associated with the scientist's research to work on during the year. Teams selected the following projects, scientists, and agencies with whom to work:

In 1998

- *Amount of O_2 used by plants and animals*, Teachers Angie Abernathy and Donna Graham, Scientist Jonathan Pote, Mississippi State University;
- *Comparison of basic water quality in an oxbow lake versus a commercial catfish pond*, Teacher Helen Beamon, Scientist Sammie Smith, USDA-Agricultural Research Service-National Sedimentation Laboratory;
- *Safe drinking water*, Teachers Teresatta Hodges and Carolyn Hood, Scientist Dean Pennington, Yazoo Mississippi Delta Joint Water Management District;
- *Water quality of Indian Bayou*, Teacher Hope Lang, Scientist Robert Zablotowicz, USDA-Agricultural Research Service-Mid South Area-Southern Weed Science Laboratory;
- *Which depth of sandy soil produces the most weeds*, Teacher Dorothy Lay, Scientist Charles Bryson, USDA-Agricultural Research Service-Mid South Area-Southern Weed Science Laboratory;
- *Inverness Bayou water quality testing*, Teacher Mary Brown McGee, Scientist Robert Zablotowicz, USDA-Agricultural Research Service-Mid South Area-Southern Weed Science Laboratory;
- *Best management practices on MSEA area lakes*, Teacher Betty Wagner, Scientist Scott Knight, USDA-Agricultural Research Service-National Sedimentation Laboratory.

In 1999

- *Comparing water quality between Moon Lake and Deep Hollow Lake,* Teachers Sheri Bell, Catherine Climons, Myra Coleman and Ida

Robinson, Scientists Dean Pennington, Yazoo Mississippi Delta Joint Water Management District and Richard Rebich, USGS-Water Resources Division;

- *Comparing water quality between Thighman Lake and Beasley Lake,* Teacher Helen Beamon, Scientist Sammie Smith, USDA-Agricultural Research Service-National Sedimentation Laboratory;
- *Comparing abiotic factors in water in different sections of Indian Bayou,* Teacher Draughon McPherson, Scientist Jonathan Pote, Mississippi State University.

In 2000

- *Comparison of water quality of samples from different sources in Carroll County*, Teacher Charlotte Gilmer, Scientist Sammie Smith, USDA-Agricultural Research Service-National Sedimentation Laboratory;
- *Invertebrate diversity as related to water quality at Blue Lake*, Teacher Shantell Larry, Scientist Scott Knight, USDA-Agricultural Research Service-National Sedimentation Laboratory;
- *How blue is Blue Lake,* Teacher Rylander Lee, Scientist Karrie Pennington, USDA-Natural Resources Conservation Service;
- *Causes of water quality changes*, Teacher Glenda Washington, Scientist Karrie Pennington, USDA-Natural Resources Conservation Service;
- *The effect of seasons on water quality of pond water*, Teacher Vivian Taylor, Scientist Karrie Pennington, USDA-Natural Resources Conservation Service.

Scientists assisted with project plans, project design and data collection. Agency facilities were used for data analysis. Many of the students used their research projects as the basis for their science fair projects. Students were given the opportunity to present their projects at annual spring STRIDE banquets and poster sessions.

Details of An Individual Project:

One example of the collaboration between teacher/student teams and MSEA scientists resulting from the 1998 workshop through the individualized research projects was research done by Helen Beamon, science teacher at Moorhead Middle School in Moorhead, Mississippi, and her two students, Monique Cocroft and Reginald Williams. As mentioned above, Beamon, Cocroft and Williams worked with Sammie Smith, Jr., Research Chemist and MSEA Project Leader at USDA-ARS-National Sedimentation Laboratory. Their study investigated the comparison of basic water quality in a Mississippi Delta oxbow lake versus an adjacent commercial catfish pond. The objective of the project was threefold: to measure and evaluate basic water quality parameters in Thighman Lake and in the commercial catfish pond; to compare measurements and reach conclusions about overall water quality of each water body; and to compare measurement results taken with a commercial surface water quality test kit versus those taken with high-tech instrumentation at the USDA-ARS-National Sedimentation Laboratory.

Beamon and her students collected water samples and recorded data once a month from November 1998 through April 1999. Using a commercial surface water quality testing kit, Thighman Lake and adjacent catfish pond water samples were taken. Measurements were recorded for turbidity, dissolved oxygen, pH, and temperature in the oxbow lake and nearby pond. Measurements were made in triplicate to ensure quality control.

Data is still being collected and is currently being analyzed and compared with data collected by scientists at the National Sedimentation Laboratory. Because of her leadership abilities, Beamon participated in the 1999 workshop as a consultant and selected additional two students from Moorhead Middle School to work with her. Beamon's team will use the same 1998 research plan to meet the project objectives. Data from 1999 was analyzed as for 1998 and was compared to the 1998 data.

Beamon, as well as other STRIDE teachers, has transferred her STRIDE experiences into the classroom. She has taught units on research methodology and has used the data collected to teach graphing skills to her students. Her students have also conducted literature reviews in water quality and the measurements collected on the water samples. Her continued association with the scientists at the National Sedimentation Laboratory has been a valuable resource for development in curriculum and hands-on activities. She reports that her students have strengthened their skills in critical thinking (making generalizations, evaluating information, problem solving and decision-making inquiry) and have enriched their entire thinking process (observation, organizing information, communicating, and inferring relationships).

DISCUSSION

Evaluation of the project is an ongoing process. Focusing on the assessment of implementation and outcome objectives, the evaluation of the project is being handled by The Southeastern Regional Vision for Education, SERVE, Inc., Greensboro, North Carolina. Specifically, SERVE is assessing the project for implementation of workshops and academic follow-up through the administration of interviews and survey instruments. Project staff and participating students and teachers have input into the evaluation process. Outcome objectives are being assessed on two levels: changes to students, from an increase awareness of science to attitudinal change to knowledge acquisition, and to teachers, from an increased awareness of environmental issues to acquisition of research and analytical skills. In addition to interviews and surveys, SERVE will also evaluate teacher notebooks of classroom lesson plans and activities impacted by their STRIDE experiences.

Feedback and preliminary data obtained from participants has indicated the project is achieving stated objectives. A majority of the teachers interviewed stated that their students were given a solid foundation in science to build on throughout high school, college, and career. Teachers identified improvements in skills such as critical thinking, cooperative learning, communication, and research. Teachers were impacted in terms of having research scientists who are a resource in the sharing of knowledge, technology and equipment, and in gaining content knowledge in data collection and scientific methodology. Teaching has been impacted through an increase in use of cooperative work groups in the learning process, an increase in focus on research, an inclusion of field trips to provide opportunity for observation and hands-on activities, and science fair participation. Students indicate that they have an increase awareness of career opportunities available though the study of science and have a better understanding of the processes involved in conducting research. Students have also improved their communication skills through poster presentations at the spring STRIDE banquets. Students and teachers also have indicated an increase in the appreciation and knowledge of their local area and the agricultural practices that are environmentally friendly. They have information to build on and ultimately make better-informed decisions about agricultural and environmental activities in the Delta.

Beamon and her students presented an overview of the STRIDE project and their individual project concerning water quality comparison of a Mississippi Delta oxbow lake and a commercial catfish pond at the Mississippi Water Resources Conferences in Jackson in 1999 and 2000. Assisted by principal investigator Sandra Harpole, Beamon presented in 1999 *MSEA and STRIDE: A Cooperative Experience in Science Education* and a poster session on the same topic in 2000. Beamon and students presented the same paper at the spring STRIDE banquet and to the Sunflower County District School Board. The Board recognized the team's accomplishments by presenting them a certificate of achievement for their work with STRIDE.

STRIDE is providing the model for the Environmental Education Program at Noxubee/Starkville Conservation Education Center, developed at the Noxubee National Wildlife Refuge through a cooperative effort of Starkville Public Schools, the U.S. Fish and Wildlife Service, the Noxubee Refuge and Mississippi State University. Project staff will be working with Noxubee staff to incorporate research experiences for teachers and students in Starkville and Oktibbeha County schools.

CRACKING MODES OF AN EXPANSIVE MISSISSIPPI DELTA SOIL

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ABSTRACT

Modes of cracking in expansive soils of the Mississippi delta and their impact on infiltration were examined. Preliminary laboratory infiltration studies suggested an evolutionary pattern of the crack network. Subsequent studies were conducted to investigate the primary modes of crack formation and their impact on infiltration. Of particular importance in the evolution of the crack morphology, the role of the seal and development of stress within the substrate is discussed. Understanding the developmental aspects of cracked soils permits further development of infiltration relationships that are used to determine the transport capabilities of cracked soils.

INTRODUCTION

Many soils in the Mississippi delta have swelling characteristics due to a high content of expansive clay minerals. The resulting cracks, typical during extended dry periods, appreciably affect infiltration and the movement of agricultural chemicals in watersheds; therefore, information about the crack development is imperative to the understanding and quantification of the hydrologic and chemical mobility status of watersheds with expansive soils.

Several authors (Ritchie et al., 1972; Bouma and Wosten, 1979; Beven and German, 1982) have discussed the impact of crack networks on infiltration. Cracks are a unique feature in soils with high shrink-swell potential. Various chemical, mineralogical, and physical properties such as initial soil water content, soil fabric, type and amount of exchange cations, and desiccation/rewetting cycles influence shrink-swell behavior.

Infiltration in dry clay soils is a function of the size and patterns of the cracks (Bouma and Dekker, 1978). Wilding and Tessier (1988) also noted that the water behavior and shrink/swell potential were related to the change in particle size and arrangement of particles. In shrink-swell soils, infiltration is controlled mainly by the cracks because the water is not influenced by the conductivity of the matrix. The cracks lead to enhanced infiltration and delayed runoff (Prasad et al., 1999). Free water moves to greater depths in relatively short periods of time (Quisenberry and Phillips, 1976). Figure 1 is a graph of the cumulative infiltration at various stages of crack development. A model of cumulative infiltration into cracking soils was discussed by Prasad et al. (1999) and employs the morphological characteristics of width, length, and depth of the existing soil structure.

The importance of the seal, as a primary contributor in the evolution of the overall structure, warrants considerable review. In preliminary infiltration experiments, carried out in a large box (65cm x 85cm x 15cm), a pronounced surface deformation of uniform structure was observed. During the early stages of the rainstorm, a longitudinal waveform appeared to develop, followed shortly thereafter by a lateral waveform. In short, the surface deformation resembled a checkerboard.

During the post rainfall period, when drying occurred and the cracks had fully developed, we recognized structural similarities between the surface deformation pattern, witnessed early in the rainstorm, and the crack pattern. As the work progressed, we continued to witness this phenomenon and hypothesized how best to interpret this process. The role of the seal in the evolution of the crack structure appeared to be the focal point in understanding the mechanics of the process.

Seal development is a complex process of detachment, migration, and compaction of the soil surface. Exposed to the energy of the rainstorm, surface aggregates are vulnerable to collapse and slaking. A portion of the detached material is reconstituted into the pores of the larger aggregates or voids between aggregates forming a layer, which clogs surface macropores. The continual process of detachment and migration of pore-blocking material, coupled with the inevitable compaction of the layer, creates a thin, semi-flexible surface seal, effectively reducing infiltration. Water movement below the developing seal, hydrates the clay and causes expansion of the soil substrate. The expanding material exerts a compressive stress on the seal, which eventually leads to a deformation as the force exceeds the mechanical strength of the seal.

In the field, dry periods promote vertical crack network development, similar to Figure 2. The cracked clay soils form a polygonal structure of individual soil islands (peds). The cumulative infiltration curves presented in Figure 1 are related to the changing features presented in Figure 2. As the crack network develops and the cracks increase in size, the preliminary capacity of the sample is increased.

The developmental picture for the formation of this structure is composed of two prominent features: seal formation and swelling stress. In as much as the entire matrix is composed of highly expansive materials, each rainstorm provides the energy required for the material to rebound, pass through equilibrium into stress, and then evolve into a reduced state. The modes of cracking evolve as the seal matures and the stress history increases. This is not to say that the matrix reformulates itself after each rainstorm. The initial stress regime continually manifests itself in the structure as the dominant feature of the network (Wells, 1995; White, 1972). Individual peds develop similar structural features through stress induced cracking. The process is a continual struggle of stress balance through fracture relief.

A series of experiments were conducted to investigate the evolution of the crack network. Based on the patterns observed in our preliminary infiltration experiments on the large sample with many cracks, we decided to reduce the sample width and focus on one longitudinal deformation/crack. Our objective was to investigate the role of the seal in the evolution of the crack network. If the seal is the determining factor in the crack pattern, then we needed to determine the cracking pattern that would develop in the absence of a seal, which can be done by protecting the surface from the impact energy of the rainstorm. This was accomplished by placing a rainfall energy-absorbing filter just above the surface.

MATERIALS AND METHODS

A sample from 0-30cm depth of a Sharkey silty clay (Vertic Haplaquepts) from the Hester farm in Bolivar County, MS (Grid 87, 1958 USDA Soil Survey, MSEA site), was brought to the laboratory, air-dried, and crushed to pass through a 2-mm sieve. Soil texture was 65% clay, 32% silt, and 3% sand. An X-ray analysis of the soil revealed smectite as the dominant clay mineral.

Soil samples were packed in a rectangular box (20cm x 94.3cm x 20cm), fitted with a subsurface drainage system. The soil was packed to a depth of 16cm, over a 4cm layer of fine sand. The packing density varied from 1.4g/cm^3 to 1.5g/cm^3. The box was fitted with a center divider, parallel to the sidewalls, providing two identical test surfaces during each rainstorm. Three experiments were conducted to observe crack development. During the experiments, one side of the test sample was protected from raindrop impact by an energy-absorbing filter, minimizing seal development. The other side was left unprotected to allow seal development. All samples were subjected to 15mm/hr simulated rainstorms for a duration of 6 hours, allowing 9cm of water to be applied to each sample.

Experiment I

A sample was prepared with an initially flat surface. The surface was lightly brushed to provide an initial surface roughness. The surface of the sample was profiled using an infrared laser on a 0.5mm by 0.5mm grid. During the rainstorm, point gauge measurements, cumulative infiltration measurements, and surface runoff measurements were taken. At the cessation of the rainstorm, point gauge measurements were taken and the surface profile was mapped with the laser. Laser profile measurements were taken every 12 hours for two days following the rainstorm. Figure 3 is a plot of the surface profile of the unprotected surface prior to the rainstorm, immediately after the rainstorm, and after crack development following drying.

Experiment II

The entire experiment was similar to Experiment I, except that grease was used on the sidewalls, front, and rear of the sample. The measurement scheme was identical to Experiment I. Figure 4 is a plot of the surface profile prior to the rainstorm, immediately after the rainstorm, and after crack development. The grease film was thought to reduce soil adhesion to the wall during expansion and shrinkage.

Experiment III

The entire experiment was similar to Experiment I, except that the surface was prepared with a concave profile with a radius of 6cm. The measurement scheme was identical to Experiment I. Figure 5 is a plot of the surface profile prior to the rainstorm, after the rainstorm, and after crack development. Figure 6 is a picture of the experimental setup.

RESULTS AND DISCUSSION

Unprotected Surface Experiments

We begin our discussion of the unprotected experimental samples by focusing on the soil water regime. During the rainstorm, the wet front penetrated to a depth of 3.5cm. In the preliminary experiment, the wetted portion of the sample was dug up to determine the wetting front profile. The shape of the wetted profile was convex, with the center approximately 0.5cm higher than that at the edges. In the experiments that followed, the wetted portion was dug up after crack formation. This revealed a linear wet front profile, suggesting that the primary mode of redistribution was horizontal.

The surface profiles presented in Figures 2, 3, and 4 contain several features worthy of discussion. First, we point to the role of the seal. Point gauge measurements, taken during the rainstorm, show an increasing trend leading to a pronounced surface deformation 0.8cm in height in the center and 0.6cm in height near the sidewalls. The seal develops in the first 15 to 30 minutes of the rainstorm as particles are redistributed and compacted by raindrop impact. As the seal matures, the clay in the substrate begins to expand from the infiltrating water and a compressive stress develops beneath the seal. As more water infiltrates, the seal deforms to accommodate the increasing volume/pressure of the substrate. The grease experiments were implemented to allow the material on the sidewalls to move with the central material, but point gauge measurements revealed that the seal continued to deform in the same fashion. The difference in results between the two experiments was an overall height increase of the deflected shape in the samples with grease. At this point, one might suggest that the sides of the sample were zones of continuous deposition of material from runoff. The concave experiments were implemented to address this issue. Point gauge measurements, taken after cessation of the rainstorm, revealed that the center was continuing to move vertically more than the sidewalls.

Experiments I-III point to the compressive stress, stored within the material, as a major factor contributing to the deformation of the seal. Micro-cracking occurs as the compressive stress builds and the material comprising the seal is no longer able to maintain integrity. After the rainstorm has ceased, a longitudinal crack appears, followed by lateral cracks. The width of the longitudinal and lateral cracks was 1cm and the depth was a function of the wet front depth, typically 3cm to 3.5cm. The spacing of the lateral cracks was approximately 10cm.

Protected Surface Experiments

The primary goal of the protective filter was to dissipate the energy of the raindrop, prevent seal formation, and thus allow maximum infiltration. During the rainstorm, the wet front penetrated to a depth of 6.5cm, almost twice the depth recorded from the unprotected samples. Similar to the unprotected samples, protected samples were dug up at the cessation of rainfall and after crack formation. A linear wetted profile was observed in each case.

The filter was not always effective in disrupting seal formation and localized seals did form. However, point gauge measurements of the surface, taken after the rainstorm, showed a similar deformation profile, with the center at 1.4cm and 1.2cm near the sidewalls. Without the seal to retard the movement of water into the sample, the material expanded an additional 0.6cm. After the rainstorm had ceased, lateral cracks appeared at regularly spaced intervals, followed by longitudinal cracks, if localized seals were formed.

Modal Process

The unprotected experiments and the protected experiments exhibited two modes of cracking. Figure 7 is a picture of a sample where the RHS was unprotected and the LHS was protected. The first mode is most pronounced in the unprotected samples where the seal is allowed to develop. The seal develops as a function of the rainstorm and continues to evolve throughout the rainstorm. Internal stress develops as the expanding clay beneath the seal causes a deformation/bending of the structure. The energy is released with a fracture of the seal, creating a longitudinal fracture plane in the center of the sample. This mode is a structural failure of the seal.

The secondary features of the unprotected samples, appearing as primary features in the protected samples, comprise the second mode of the system. Lateral cracks are the primary energy release mode for the expanding substrate. This pattern can also be seen in samples where the wet material is removed and the remaining portion allowed to stand for a few weeks. Lateral cracks appear in the matrix of a material that at most has been subjected to vapor transport. The increasing compressive stress creates an energy release mode for the material. Both the structural failure mode and the energy release mode give rise to ped formation we observe in the field.

CONCLUSIONS

The observations presented herein are intended to expand upon the mechanical aspects of crack network formation and its fundamental modes. A modal system was presented as a simplistic view of the structure formation we find in the field. Experiments on large samples provided key information in the development of a composite system of mechanical behavior. A model is currently being developed which simulates the unprotected system as a composite beam subjected to axial loading conditions. The model accounts for the deformation of the seal and predicts the zone of rupture. Predicting structural deformations related to cracking networks may prove to be a valuable tool for infiltration and solute transport problems.

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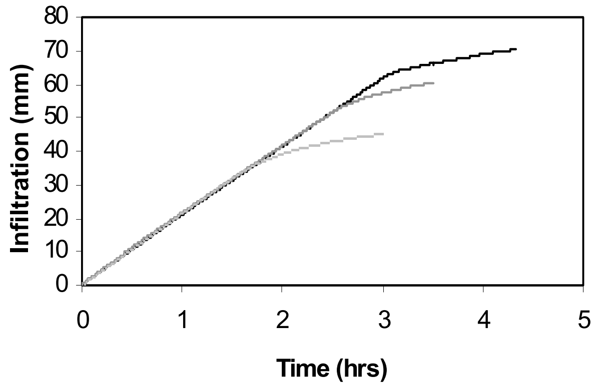

Figure 1. Cumulative infiltration curves.

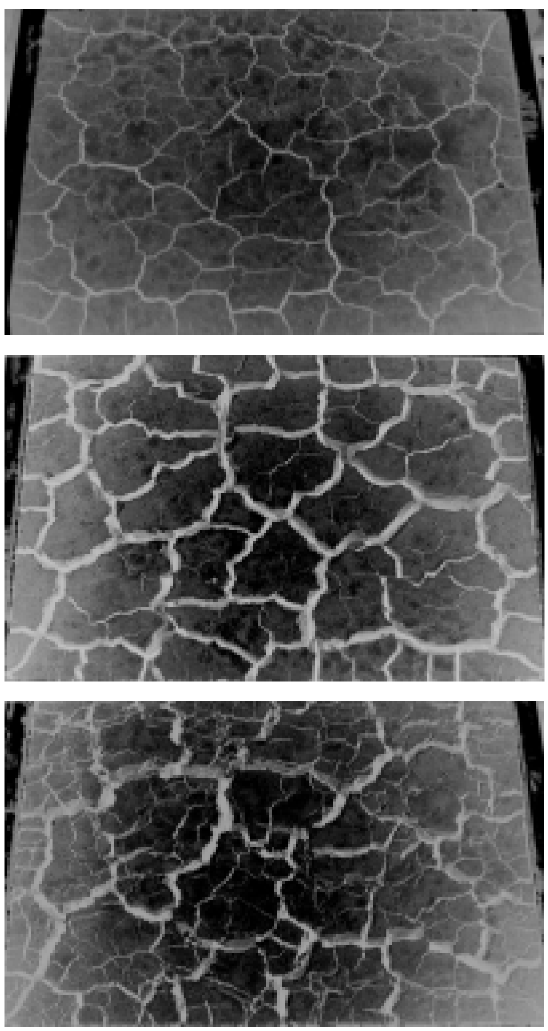

Figure 2. Evolution of crack network.

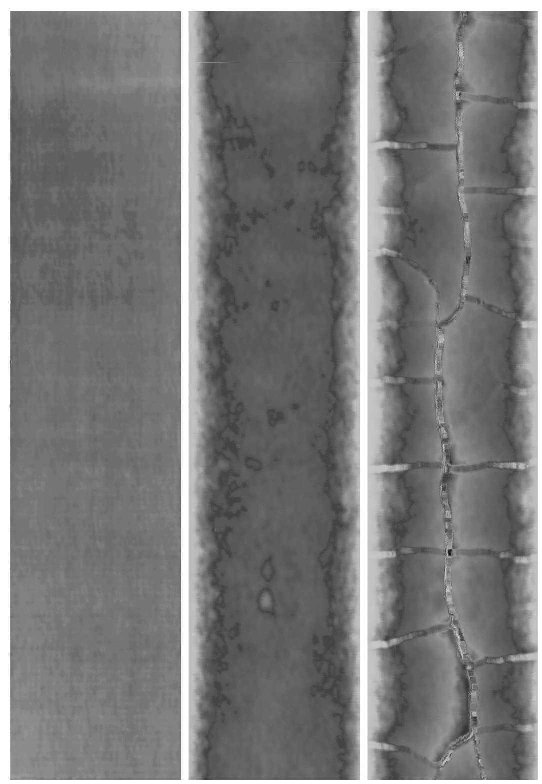

Figure 3. Laser profile of the soil surface before, immediately after, and following

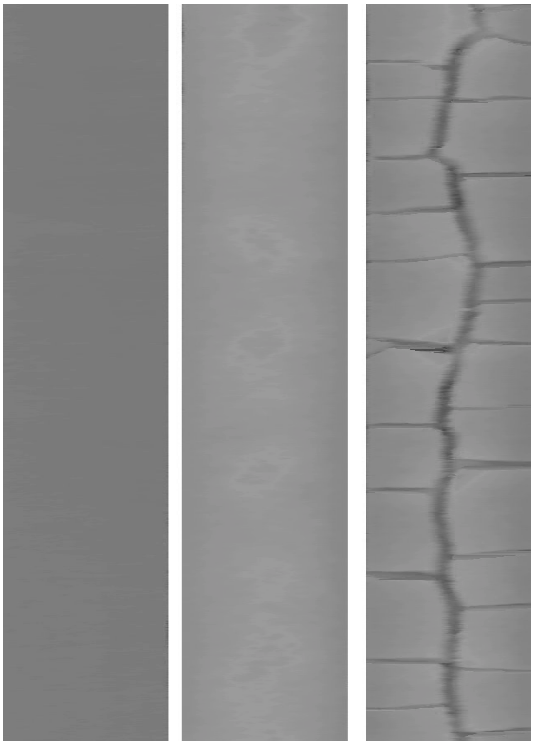

Figure 4. Laser profile of the soil surface before, immediately after, and following drying.

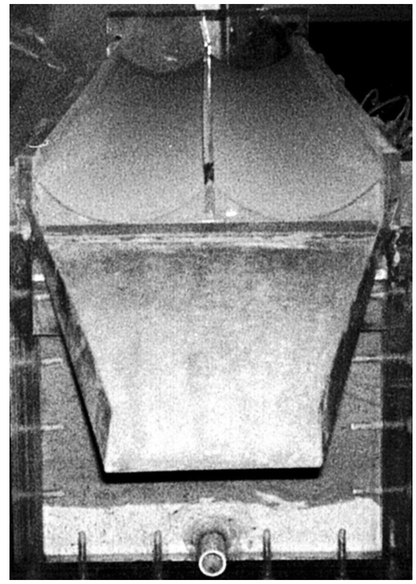

Figure 6. Picture of curvature setup.

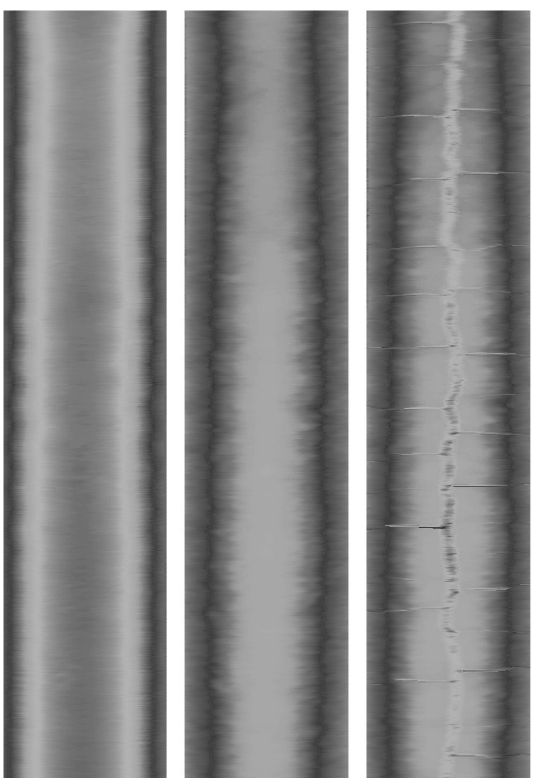

Figure 5. Laser profile of the soil surface before, immediately after, and following drying.

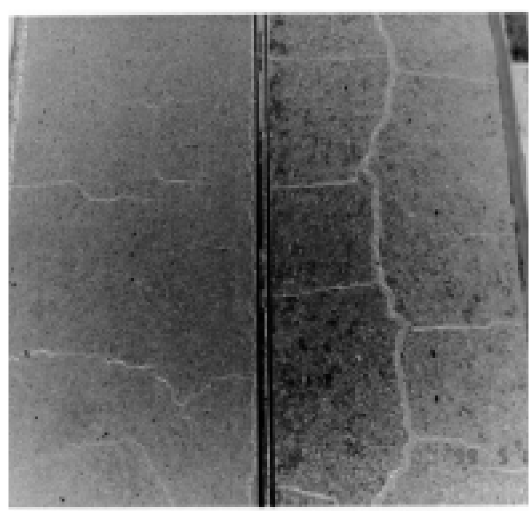

Figure 7. Picture of sample. RHS is unprotected and LHS is protected.

MICROBIOLOGICAL CHARACTERISTICS AND FLUOMETURON CONCENTRATIONS IN MISSISSIPPI DELTA OXBOW LAKES

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ABSTRACT

Populations of bacteria and algae, suspended solids, hydrolytic enzymatic activity, and fluometuron concentrations were studied in the three oxbow lakes of the Mississippi Delta MSEA project from May 1996 through July 1999. Decreased levels of suspended solids were observed in Deep Hollow lake and has contributed to increased algal populations during the winter and spring. Thighman lake maintained the highest bacterial populations and also had the greatest level of fluorescein diacetate hydrolytic activity. Fluometuron and its metabolite desmethyl fluometuron were observed in all three lakes in 1996 and 1997. However, concentrations decreased in 1998 and 1999, likely due to decreased cotton acreage and subsequent fluometuron use. These results suggest that conservation management practices imposed in the Deep Hollow watershed reduced the movement of sediments into the lake and subsequently influenced the population dynamics of bacterioplankton and phytoplankton.

INTRODUCTION

The biological, chemical and physical quality of surface water (lakes, rivers, and streams) is a concern from a standpoint of health of humans, wildlife and overall productivity and sustainability of the environment (U.S.E.P.A., 1992). Agricultural practices (tillage, fertilization, and pesticides) have been considered a major factor affecting water quality. The Mississippi Delta MSEA project has been established to ascertain the effects of agricultural management practices on water quality and define appropriate management practices that enhance soil and water quality (Schreiber et al., 1996). In this project, three small watersheds were chosen as study sites. Each of these watersheds drain into oxbow lakes, thus facilitating direct assessment of agricultural management practices on lake water.

Although oxbow lakes are common in the Mississippi Delta landscape, there is limited knowledge on microbial population dynamics of these aquatic systems. Microorganisms associated with aquatic systems can be subdivided into two basic populations: those that form biofilms on surfaces and planktonic organisms that are suspended in the water column (Lewis and Gattie, 1998). Phytoplankton (algal) populations represent the primary productivity of the lakes. However, recent studies (Zablotowicz et al., 1998) indicate their potential to also contribute to pesticide detoxification in aquatic systems. Bacterial populations are responsible for many of the biogeochemical processes governing nutrient availability and the decomposition of natural materials and xenobiotics such as pesticides. For our contribution to the MD-MSEA project, we evaluated algal and bacterial populations in three oxbow lakes as influenced by management practices imposed on these watersheds. In addition enzyme activity, suspended solids and concentrations of the herbicide fluometuron (FLM) and its metabolite desmethyl fluometuron (DMF) were determined as well as other characteristics of water quality.

MATERIALS AND METHODS

Surface water samples were collected from three small oxbow lakes (8 to 25 ha) in the Mississippi Delta: Beasley and Thighman lakes are located in Sunflower County, MS, near Indianola and Moorhead respectively, while. Deep Hollow lake is located in Leflore County, MS, near Sidon. Thighman is the largest of the lakes, with most of the watershed was planted to cotton and soybeans, although corn, rice and catfish production are also components of this watershed. Beasley lake is intermediate in size and the watershed was cropped predominantly in cotton and soybeans and contains a large forested riparian zone. Structural best management practices (BMP's) such as slotted board risers and vegetative filter strips have been implemented to minimize sediment movement into Beasley lake. Deep Hollow is the smallest lake whose watershed was cropped mostly in cotton and soybeans. The most extensive levels of BMP's: winter wheat cover crop, no-tillage farming practices, grass filter strips and slotted board risers, have been adopted at the Deep Hollow watershed.

Surface water samples (0 to 20 cm depth) were collected monthly from stationary sampling rafts (three per lake) from May 1996 through July 1999. Samples were refrigerated upon collection and processed for microbial enumeration within 24 h of collection. Suspended solids were determined by centrifugation of well-agitated water samples in tared 250 mL polypropylene centrifuge bottles at 10,400 x g for 10 min. Following each centrifugation, supernatants were carefully removed and saved for pesticide analysis with a total 500 mL sample centrifuged in the same bottle. Dry weight of solids was determined following drying at 60^{o}C for 24 h. Fluorescein diacetate (FDA) hydrolysis was used as an indicator of metabolic activity (Schnürer and Rosswall, 1982). Briefly, triplicate 10 mL water samples were treated with 100 µL of an acetone solution of FDA (2 mg mL^{-1}) in sterile 25 mL Corex centrifuge tubes. Samples were incubated at 24^{o}C for 24 h with reciprocal shaking. Assays were terminated by extraction with 10 mL of acetone, vortexed, centrifuged at 12,000 x g for 10 min, and measurement of absorbance at 490 nm.

Bacterioplankton populations were determined by serial dilution and spiral plating using similar methodology as previously described for soil bacteria (Gould et al., 1985). Total aerobic heterotrophic bacteria, gram-negative and fluorescent pseudomonads were enumerated by plating on dilute (1/10 strength) tryptic soy agar (TSA), dilute TSA with crystal violet (5 mg ml^{-1}), and S-1 selective media (Gould et al., 1985), respectively. Algal populations were estimated by serial dilution and most-probable-number (MPN) technique using 5 replicate tubes per dilution and Bristol's mineral salts broth as media (Starr, 1964).

FLM concentrations in water samples were determined following concentration. Briefly 250 ml of clarified water (supernatant) was acidified to pH 3.0 with hydrochloric acid, and passed through an C-18 Empore disc (3M). FLM and metabolites were eluted from the C-18 disc 30 mL of ethyl acetate. Water was removed with anhydrous sodium sulfate, and the ethyl acetate volume reduced to 2 mL under N_2 gas. FLM and DMF were determined using HPLC methods described elsewhere (Zablotowicz et al., 1998).

RESULTS AND DISCUSSION

A summary of suspended solids, FDA-hydrolytic activity and estimates of total culturable bacteria and algae for 1998 are presented in Fig. 1A-D. During the experimental period, differences in microbial populations and activities could be attributable to seasonal variation, effects of BMP practices and interactions between these two factors. In the first year of our assessment (1996), only minor differences in suspended solids were observed among lakes (data not shown). However, during 1997 differences in concentrations of suspended solids among the lakes were evident in winter and spring. Levels of suspended solids observed in water from Deep Hollow lake were 80 % lower than that found in either Beasley or Thighman lake, and this pattern continued during both 1998 and 1999 (Fig 1A). Throughout December to June levels of suspended solids in Beasley and Thighman remained over 100 mg L^{-1} and these lakes could be considered as sediment stressed (Cooper and Bacon, 1998). High levels of suspended solids can reduce light penetration and may consequently affect primary productivity. Lower levels of suspended solids during the later part of the year reflect lower rainfall

Throughout the study, Thighman lake had the highest FDA-hydrolytic activity, Deep Hollow intermediate and Beasley the lowest as presented in the 1998 data (Fig 1B). FDA-hydrolysis represents a wide variety of enzymatic transformations: esterase, lipase and certain proteases and has been correlated with microbial respiratory activity (Schnürer and Rosswall, 1982). All lakes had a similar pH, which is one factor affecting esterase activity. However, differences in activity could be attributed to microbial populations (higher bacterial populations at Thighman), or perhaps availability of substrates or nutrients.

When this study was initiated only minor differences in bacterial or algal populations were observed among lakes (Zablotowicz et al., 2000). However, As the study progressed differences in algal and bacterial populations among lakes were evident. Bacterial populations in Thighman lake were generally greater than either Deep Hollow or Beasley lake, although there were occasional population bursts where similar high bacterial populations were observed for all three lakes (Fig 1c). Populations of bacterioplankton observed in Mississippi oxbow lakes are similar to those observed in other fresh water lakes (Jeppesen et al., 1997). Gram-negative bacteria, such as fluorescent pseudomonads, were initially a dominant component of the bacterial population representing up to 44 % of the total culturable heterotrophic bacteria (Zablotowicz et al., 2000). However during subsequent years, their relative numbers declined and were typically less than 10% of the total culturable heterotrophic bacterial population during 1997 to 1999 (data not shown). This change in bacterioplankton population composition may have been due to either an overall reduction of sedimentation in all three lakes or perhaps to the effects of rotenone (used to kill fish prior to restocking) in the fall of 1996.

During certain months, significant differences in algal populations were observed in the three lakes as presented for 1998 (Fig 1D). These differences were most evident in the winter and spring months with Deep Hollow maintaining higher algal populations than Thighman with intermediate levels in Beasley lake. As discussed earlier, suspended solids affect light penetration and may have been the major factor responsible for differences in algal population among these lakes. Greater primary productivity potential in Deep Hollow lake may be one reason for superior game fish production (Knight et al.,2000).

FLM concentrations observed in these lakes were greatest in 1996 and 1997 reflecting the higher acreage in cotton production in these watersheds and FLM usage, subsequently only data for 1997 is presented (Table 1). Using HPLC methodology, FLM and its major metabolite DMF were only detected between May or June (depending upon year) and September. The highest concentrations were observed shortly after planting and declined to below detection limits after 3 to 4 months. Concentration of DMF represented about 20% that of the concentration of the parent herbicide. No FLM or DMF was detected via HPLC analysis in water samples from either Deep Hollow or Thighman lakes in 1998 and 1999. Less than 1.0 $\mu g\ L^{-1}$ FLM was detected, in water samples from Beasley lake with detections only in June of 1998 and June and July of 1999. Appearance and dissipation of both fluometuron and DMF indicate biodegradation via *N*-dealkylation occurred in these lakes. Certain algae, e.g. *Ankistrodesmus* and *Selenastrum* species have been shown to participate in the degradation of fluometuron and atrazine via *N*-dealkylation (Zablotowicz et al., 1998), while common bacteria such as *Pseudomonas fluorescens* were unable to degrade FLM (Zablotowicz et al., 2000). Concentrations of fluometuron and DMF observed in these studies are similar to those reported in surface water for other herbicides (Thurman et al., 1991).

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Table 1. Fluometuron and desmethyl fluometuron concentrations in MSEA oxbow lakes, 1997.

Sample	Concentration ($\mu g\ L^{-1}$)	
Lake / month	Fluometuron	Desmethyl fluometuron
Beasley		
May	< 0.1	< 0.1
June	3.2 ± 1.9	0.8 ± 0.6
July	5.7 ± 3.4	2.0 ± 0.5
Aug	4.8 ± 2.2	1.8 ± 0.6
Sept.	0.7 ± 0.6	0.7 ± 0.6
Oct.	< 0.1	< 0.1
Deep Hollow		
May	< 0.1	< 0.1
June	5.0 ± 0.6	1.1 ± 0.3
July	3.3 ± 1.5	0.4 ± 0.2
Aug.	3.8 ± 0.6	0.7 ± 0.4
Sept.	< 0.1	< 0.1
Oct.	< 0.1	< 0.1
Thighman		
May	< 0.1	< 0.1
June	11.2 ± 8.9	2.9 ± 4.8
July	2.1 ± 1.0	0.3 ± 0.2
Aug	0.9 ± 1.3	0.3 ± 0.2
Sept.	< 0.1	< 0.1
Oct.	< 0.1	< 0.1

Mean and standard deviation of three replicate samples

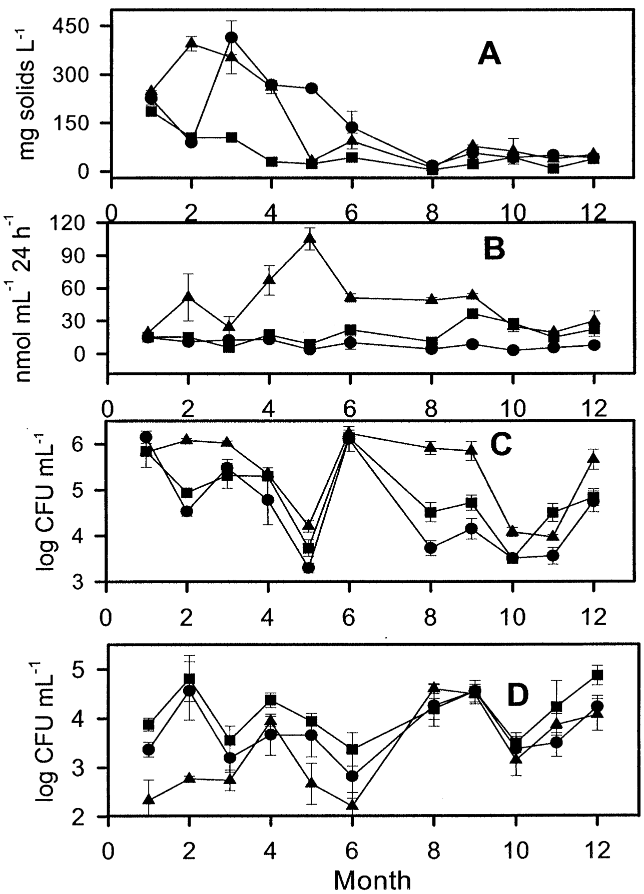

Figure 1. Levels of suspended solids (A), FDA-hydrolytic activity (B), Total bacterial populations (C) and total algal populations (D) observed in Beasley (•), Deep Hollow (■), and Thighman (▲) lakes during 1998.

MICROBIOLOGICAL CHARACTERISTICS OF A MISSISSIPPI DELTA FORESTED RIPARIAN ZONE

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ABSTRACT

Soil microbiological characteristics along a channel transect of a forested riparian zone in the Beasley watershed were studied. Aerobic and anaerobic bacteria, fluorescent pseudomonads, and algae were 10- to 100-fold greater along the riparian zone compared to cultivated soil from an adjacent field. Fungi were greater in the initial 25 m of the riparian channel compared to either adjacent field soil or other distal sampling points along the riparian channel. Three enzymatic activities, esterase, dehydrogenase, and aryl acylamidase, were about 8 to 18, 3 to 12, and 1.5 to 3 fold-greater in riparian soil compared to the cultivated soil, respectively. Assessment of microbial communities, based on substrate utilization, indicate that microflora associated with riparian zones soils were distinct compared to cultivated field soil. The potential for fluometuron degradation in riparian zone soils was determined in aerobically incubated soil suspensions. Fluometuron *N*-demethylation was about 2- to 4-fold greater in riparian zone soils compared to field soil. Increased microbial populations/activities in riparian soils are due to patterns of organic matter accumulation, and sedimentation should provide a zone for enhanced pesticide degradation.

INTRODUCTION

Riparian zones, wetlands adjacent to streams, are an important component of the Mississippi Delta landscape. They are key in preventing the movement of agrochemicals and fertilizers into surface waters in these zones, and have an intrinsic capability to capture and retain these potential pollutants (Lowrance et al., 1985). Riparian zones generally have higher clay, organic matter and water holding capacity compared to adjacent land (Patrick, 1981). These edaphic conditions, typically high fertility, and seasonal flooding provide a unique ecosystem for vegetation and associated microflora. These studies were designed to characterize the microflora and microbial activities associated with the Beasley Lake forested riparian zone, to understand how these microbial populations may contribute to removal of pesticides and thus minimize movement into the lake. These studies complement studies by Shaw et al. (2000) in understanding the fate of herbicides in forested Mississippi Delta riparian zones.

MATERIALS AND METHODS

Soil Samples

Nine composite soil samples were collected along a transect of the Beasley riparian drainage channel, in October 1997 using a sampling as described elsewhere (Shaw et al., 2000). These nine samples represent three zones: zone 1 (dam, 10 and 25m), zone 2 (50, 100, 200m), and zone 3 (400, 600, and 800m) and were compared to three samples collected in an adjacent field. These sampling zones represent distinct changes due to sedimentation and organic matter accumulation. Soils were maintained in original moisture content and stored at 5^{o}C until processed for microbial and enzymatic activity. Similar texture, pH and organic matter content were observed in these samples as reported by Shaw et al. (2000, data not shown). Although soils were collected in the dry season, moisture contents were relatively high (moisture zone 1 and 2 = 69 %, and zone 3 = 139% compared to 7% in the adjacent field).

Microbiological Characteristics

Soil bacterial and fungal populations were assessed using serial dilution and spiral plating. Total and anaerobic bacteria were estimated on dilute tryptic soy agar (1/10th strength with cycloheximide 100 mg L^{-1}), and fluorescent pseudomonads were estimated on S-1 media (Gould et al., 1985). Anaerobic bacteria were counted after incubation (4 day) in a N_2, H_2 and CO_2 environment (BBL Gas Pak system, Powers and McQuen, 1988). Total fungi were plated on rose bengal potato dextrose agar with streptomycin (300 mg L^{-1}) (Martin, 1950). Green algae populations were estimated using a five tube MPN technique with Bristol's media (Starr, 1964).

Heterotrophic bacterial community diversity was assessed on a basis of sole-carbon-source utilization (Garland and Mills, 1991). Microflora were separated from soil by diluting in phosphate buffer and differential centrifugation (Staddon et al., 1997), Microbial suspensions were diluted to an optical density of 0.10 (660 nm). Gram-negative biolog microplates (Biolog Inc., Hayward, CA) were inoculated with 100 µL of washed organisms per well and were incubated at 28°C in the dark. Color development was monitored using a Biotek 311a plate reader at 585 nm with readings taken every 12 h between 24 and 72 h. Average well color development was calculated and principal component analysis was determined according to Garland and Mills, 1991.

Three spectrophotometric enzyme assays were conducted to estimate heterotrophic microbial activity and the potential for pesticide degradation. Hydrolytic enzyme activity (esterase, lipase and protease) assays were conducted using fluorescein diacetate (FDA) as substrate (Schnürer and Rosswall, 1982) after 1 hour shaking incubation at 30°C and 125 rpm. Dehydrogenase activity was assessed using triphenyl tetrazolium chloride (TTC) as substrate (3.0% aqueous with 0.1% yeast extract as an exogenous carbon source (Casida, 1977), incubated statically at 37°C for 24 h. Aryl acylamidase was assessed using 2-nitroacetanilide (2-NAA) as substrate incubating for 20 h at 30°C (Zablotowicz et al., 1998). All assays were conducted with three substrate replicates and one no-substrate control for each sample. Activities per hour were calculated based upon previously reported extinction coefficients and are reported as nmole of product formed (fluorescein for FDA, triphenyl formazan for TTC, and 2-nitroaniline for 2-NAA) g^{-1} soil (oven dry weight) h^{-1}.

The potential for aerobic fluometuron (FLM) degradation was determined in a soil slurry assay. A 1:10 dilution of soil (fresh soil weight) prepared in Novacks media. One mL of the soil dilution was transferred to sterile screw cap tubes, and 1.0 mL of filter sterilized Novacks solution containing FLM 20 µg mL^{-1} was added to five replicate tubes per sample. Tubes were incubated on a shaking incubator (25°C, 75 rpm) for 28 days. The study was terminated by adding 2 mL of methanol, shaking at 75 rpm for an additional 24 h and filtration through a 0.2 µm filter. Concentrations of fluometuron and the metabolite desmethyl fluometuron (DMF) were determined via HPLC using a fluorescence detector as described elsewhere (Zablotowicz et al., 2000). Fluormeturon-demethylating activity is reported as nmole DMF formed g^{-1} soil (oven dry weight) 28 $days^{-1}$.

RESULTS AND DISCUSSION

Microbial Populations

A significant enrichment of bacterial and algal populations was observed in soils from the riparian zone compared to adjacent cropland soil (Table 1). Aerobic heterotrophic bacterial populations are 10-fold higher in the riparian soil. Fluorescent pseudomonads, a group of aerobic microorganisms capable of nitrate respiration and/or denitrification, are 100-fold greater in riparian soil compared to cropland soil. The enrichment of pseudomonads is likely associated with the higher organic matter and water content and the rhizosphere effect due to abundant wetland vegetation. The high moisture condition promotes an environment conducive to anaerobic bacteria, and populations of anaerobic bacteria increase along the riparian channel (Table 1). Enrichment of anaerobic bacteria and fluorescent pseudomonads indicate the potential for enhanced removal of nitrate by the riparian zone (Lowrance et al., 1985). Most fluorescent *Pseudomonas* isolates characterized from the MSEA lakes are capable of either denitrification or nitrate reduction (Zablotowicz et al., 2001).

Fungal populations were greatest in the riparian zone entrance, and populations were reduced further along the riparian channel, while algal populations were modulated by water content and increased towards the lake. Algal populations associated with zone 3 of the riparian zone were 10- to 100-fold greater than that observed in Beasley lake water (Zablotowicz, et al., 2000).

Microbial community analysis based upon substrate utilization (Biolog) confirms that microbial populations in the riparian zone are unique from that observed in cropped soil (Fig. 1). Principal component analysis (PCA) was used to compare differences in substrate utilization among riparian and cropped samples. This analysis compared the major sources of variance among microbial communities. Microbial populations in soils from the riparian zone (except one replicate from zone 2) are distinctly clustered compared to field soil (Fig. 1).

Enzymatic activity and fluometuron degradation

Three enzyme activities, esterase, dehydrogenase and aryl acylamidase, were significantly greater in riparian zone soil compared to cropland soil (Table

2). Esterase, dehydrogenase, and aryl acylamidase activities were about 8 to 18, 3 to 12, and 1.5 to 3 fold-greater in riparian soil compared to the cultivated soil, respectively. The highest levels of all three enzymes were observed in zone 3 that had the highest organic matter content, moisture content and algal populations. Soil enzymatic activity can be used either in a low resolution application, used as an index of general soil microbial activity, or may be used for higher resolution application for understanding a specific process (Sinsabaugh, 1994). FDA hydrolytic activity represents a wide range of hydrolytic activity (esterase, lipase and protease) activity and correlates with soil respiratory activity. Dehydrogenase activity actually measures electron transport system activity in that the substrate TTC is used as an alternative electron acceptor (Trevors, 1983), under both aerobic and anaerobic conditions. Both FDA-hydrolysis and TTC-dehydrogenase thus described the generic spatial variation in microbial activity due to position along the riparian zone. Aryl acylamidase activity is an assay designed to assess hydrolytic cleavage of the amide bond of propanil and other herbicides containing an amide bond such as the phenylureas, and thus can be used to describe a process such as herbicide degradation.

Fluometuron Degradation

The potential for soils to degrade fluometuron in a soil slurry system was studied by monitoring both dissipation of the parent compound and accumulation of metabolites. The demethylated metabolite of fluometuron DMF accumulated in all soils with the greatest accumulation occurring in soil suspensions from the riparian zones (Table 2). Patterns of FLM dissipation exhibited a similar trend as DMF accumulation (data not shown). The metabolite, trifluoromethyl-phenylurea, was observed only in samples from Zone 3 (less than 3% of initial FLM). This assay confirms the potential for enhanced fluometuron in the Beasley riparian soil as described by Shaw et al. (2000). Studies by Entry and Emminham, 1996, indicate that atrazine and 2,4-D are more rapidly degraded in riparian zones under coniferous forests compared to grasslands. Higher microbial activity and populations observed in Mississippi Delta riparian zones should facilitate rapid degradation of pesticides. Preservation and maintenance of forested riparian zones should be an important management practice to reduce non-point pollution of surface waters by agrochemicals.

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The technical assistance of Ben Cash, Earl Gordon and Jennifer Tonos are greatly appreciated.

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Table 1. Microbial populations associated with soils collected along a transect of the Beasley riparian zone.

Sample	Total Bacteria	Anaerobic Bacteria	Fluorescent pseudomonads	Fungi	Algae
	log (10) colony forming units / g soil				
Cultivated Field	6.4 ± 0.4	5.4 ± 0.2	3.9 ± 0.1	4.0 ± 0.2	3.9 ± 0.6
Zone 1 Dam to 25 m	7.5 ± 0.2	6.5 ± 0.3	6.1 ± 0.1	5.1 ± 0.1	5.3 ± 0.2
Zone 2 50 to 200 m	7.3 ± 0.2	7.0 ± 0.3	6.2 ± 0.1	4.2 ± 0.1	5.2 ± 0.3
Zone 3 400 to 800 m	7.5 ± 0.2	7.2 ± 0.2	6.2 ± 0.1	4.4 ± 02	6.2 ± 0.1

Mean (±) standard deviation of three replicates

Table 2. Soil enzyme activity and in vitro fluometuron degradation in soils collected along a transect of the Beasley riparian zone.

Sample	FDA-esterase	TTC-dehydrogenase	2-NAA aryl acylamidase	Fluometuron *N*-demethylation
	nmole g^{-1} soil h^{-1}			nmole g^{-1} soil 28 d^{-1}
Cultivated Field	133 ± 44	1.8 ± 0.8	28 ± 4	28 ± 15
Zone 1 Dam to 25 m	1507 ± 566	6.1 ± 0.8	42 ± 6	57 ± 17
Zone 2 50 to 200 m	1106 ± 93	6.4 ± 3.3	67 ± 22	62 ± 13
Zone 3 400 to 800 m	2361 ± 494	22.7 ± 14.7	88 ± 33	111 ± 27

Mean (±) standard deviation of three replicates

Figure 1. Principal component analysis of substrate utilization (Biolog analysis) by microbial populations isolated from riparian zone and cultivated soils.