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# Combined effects of best management practices on water quality in oxbow lakes from agricultural watersheds☆

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**Abstract**

Water quality conditions in three oxbow lakes were examined before and after best management practices (BMPs) implementation within the Mississippi Delta. Experimental design called for the development of structural and cultural treatments to reduce sediment and associated pollutants entering watershed oxbow lakes. Three watersheds were selected and developed with different levels of BMPs. Changes in lake water quality were used as measures of management success. Analyses of water quality data prior to the implementation of BMPs suggested the lakes were stressed and ecologically damaged due to excessive sediment inflow. Significant improvements in water quality were observed with the use of cultural and structural BMPs. Sediments decreased 34–59%, while Secchi visibility and chlorophyll generally increased. The most dramatic improvements in water quality occurred in the two watersheds that featured cultural practices and combinations of cultural and structural practices. Reducing suspended sediment concentrations in these oxbow lakes favored phytoplankton production resulting in increased chlorophyll concentrations and higher concentrations of dissolved oxygen. Cultural BMPs, more so than structural BMPs, play a vital role in improving lake water quality, and are needed in addition to structural measures to ensure improved water quality in oxbow lakes receiving agricultural runoff.

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*Keywords:* Best management practices; Suspended sediments; Chlorophyll; Water quality; TMDL; Oxbow lakes

## 1. Introduction

Soil erosion is a significant national problem, with 1.36–1.82 billion metric tonnes of topsoil eroded annually (Brown, 1984). The Mississippi River transports 300 million metric tonnes of soil to the Gulf of Mexico annually (Brown, 1984). Fowler and Heady (1981) reported that stream suspended sediments are, by volume, the most significant pollutants in the United States. Much of the decline in aquatic habitats over the past century can be attributed to draining and clearing land for agriculture. An estimated 60% of the approximate 2.72 billion tonnes of sediment per year deposited in the United States' waterways originated from agricultural lands (Knight and Welch, 2004). In addition, these sediments often are accompanied by other contaminants such as pesticides and nutrients. The natural 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

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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 (Fig. 1) 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, isolated oxbow lakes in agricultural regions tend to become less heterotrophic and more autotrophic. As a result, they become closed entities functioning like farm ponds and other small impoundments.

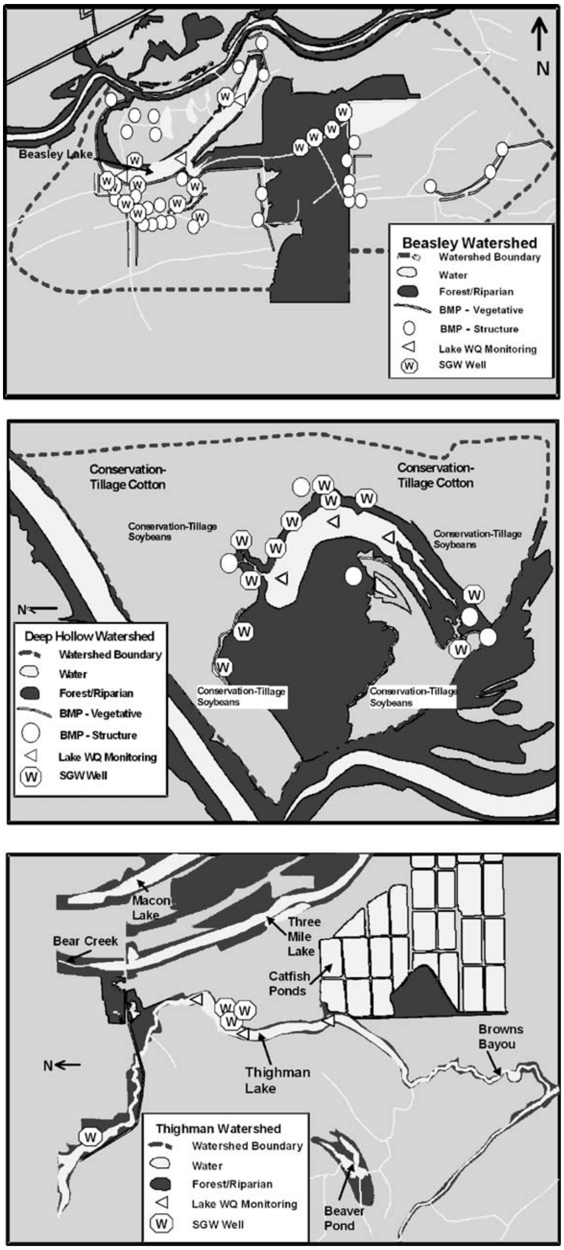


Fig. 1. Maps of the three watersheds denoting placement of structural or cultural BMPs.

If suspended sediment concentrations are low enough to allow suitable light penetration, oxbow lakes provide conditions conducive to photosynthesis, primarily via phytoplankton, and may support a sustainable sport fishery. However, conventional tillage practices in the Mississippi Delta region often result in excessive soil erosion leading to increased turbidity in the oxbow lakes and subsequent inhibition of photosynthesis (Knight et al., 2002). Turbidity in oxbow lakes can be persistent in areas having soils with high clay content such as the Mississippi Delta. Nutrients such as phosphorus are commonly associated with Delta soils. Although isolated oxbow lakes tend to concentrate 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 load may also occur, most oxbow lakes are eutrophic enough to boost primary productivity under improved light penetration to support a sustainable fishery. Research is needed to examine the impact of management practices placed on the watershed on the water quality and productivity of oxbow lakes that receive runoff from these watersheds.

The National Management Systems Evaluation Areas (MSEA) program was chosen as a suitable framework to evaluate agricultural non-point pollution in the Mississippi Delta, one of the most intensively farmed agricultural areas of the United States in the southern part of the Mississippi Alluvial Plain in Mississippi (Rebich and Knight, 2001). The National MSEA program, involving five Midwestern states, began in the early 1990s as part of USDA Water Quality Program to research the economic viability of alternative farming methods to reduce over dependency on agricultural chemicals and to accelerate the transfer and adoption of such methods (Council for Agricultural Science and Technology, 1992). Scientists assessed landscapes for their vulnerability to water contamination from farm operations, provided information about the behavior and effects of agrichemicals on watershed ecology, and identified economically/environmentally sound BMPs as components of farming systems to reduce possible farm-generated contamination of soil, water, air, and biological resources.

A consortium of federal, state, local, and university personnel was formed in 1994 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.

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, increase the chances for soil erosion and chemical movement within Delta watersheds (McGregor et al., 1995).

This study examines, documents, and compares pre-BMP water quality and ecological conditions on three oxbow lakes to water quality and ecological conditions following implementation of BMPs designed to control erosion and non-point source pollution within MDMSEA.

## 2. Materials and methods

### 2.1. Project overview and study site description

Three oxbow lake watersheds were selected to receive management practices based on BMPs that fell into one of two categories, structural and cultural (Fig. 1). Generally, structural categories include physical barriers such as surface drain pipes or grass hedges while cultural practices include conservation tillage and cover crops. An attempt was made to apply BMPs to affect surface runoff from as much as 95% of the watersheds' area. The dash line around the Beasley and Deep Hollow watershed (Fig. 1) denotes the boundary or highest elevation contributing surface runoff into the lakes.

The MDMSEA study sites included the three oxbow lakes of Thighman and Beasley Lakes near Indianola, Mississippi in Sunflower County and Deep Hollow Lake near Greenwood, Mississippi in Leflore County. Each oxbow lake was approximately 2 m in depth. One of the three watersheds was originally planned to be a "control" watershed that would demonstrate the water quality effects of conventional tillage and typical farming practices of the region. While no structural or cultural practices were recommended or encouraged, the farmers within the 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 with one watershed with cultural practices, a second watershed with structural practices, and the third watershed with a combination of both structural and cultural practices.

Thighman Lake has a surface area of 10 ha and drains a 1500 ha catchment. Soils in the watershed vary from loam to very heavy clay. The primary row crop grown from 1995 to 1996 was cotton (*Gossypium hirsutum* L.). Beginning in 1996, much of the land originally farmed in conventional-tilled cotton was converted to conservation-tilled cotton and corn (*Zea mays*). In 1997, growers began to diversify from cotton to rice (*Oryza sativa*), corn, and soybeans because of changing prices in markets. By 1999, very little cotton was grown in the Thighman watershed. In addition to runoff from these cropland areas, Thighman Lake receives water discharged from at least four channel catfish (*Ictalurus punctatus*) ponds.

Beasley Lake is a 25 ha oxbow with a large wooded riparian zone located on the lake's eastern side. The total drainage area of this watershed is approximately 850 ha. The Sunflower River levee defines the northern part of the watershed boundary. Soils are generally loam to heavy clay. The Beasley watershed differs from the other two watersheds in that the difference in elevation from the top of the watershed boundary to the lake is about 5.5 m as compared to 1.5 m. As was the case in Thighman, cotton and soybeans (*Glycine max*) dominated the Beasley watershed at the beginning of the project, with some shift to corn in 1998 as a result of changes in market and price. Conventionally-tilled cotton was the principal crop in the watershed. Beasley Lake watershed was protected solely with structural practices such as slotted pipes and slotted board inlets (Fig. 2). These physical pipes were located in ditches or edge-of-field outlets throughout the watershed as shown in Fig. 1 of the Beasley Lake watershed. A few of these structural practices had grassed buffers and stiff grass hedges planted in front of the pipes in concentrated flow pathway to trap sediments.

Deep Hollow Lake has a surface area of 8 ha and a drainage area of 202 ha. Much of the watershed has 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,


Fig. 2. Pictures of typical slotted inlet pipes (A and B) and slotted board risers (C, D, and E) located at outlets of agricultural fields.

and a large riparian area lies between this levee and the lake. Deep Hollow Lake was protected with a combination of the aforementioned structural practices as well as cultural methods including conservation tillage and winter cover crops to reduce sediments and other nonpoint source pollutants (Fig. 1).

### 2.2. BMP selection and installation

Two options existed to study the effects of BMP implementation 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 selected 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 implementation of specific BMPs.

A BMP committee composed of growers and USDA agency representatives was formed in November 1994 to select the BMPs. One watershed was identified to serve as a control. Best management practices 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 structural edge-of-field BMPs. The third watershed would contain structural edge-of-field BMPs and cultural or agronomic BMPs. Best management practices 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.

The BMP committee recommended the Thighman Lake watershed as the watershed where no Mississippi Delta MSEA-sponsored BMPs would be installed; however, the growers in the upper Thighman drainage began to use cultural practices of reduced tillage and no-tillage for soybeans, cotton, and rice starting in 1997. All changes in Thighman Lake were attributed to shift in cropping practices because only cultural practices were applied to this watershed. Best management practices implemented in the Beasley watershed located at edge-of-field were structural practices only based on USDA-NRCS recommendations (National Handbook of Conservation Practices, 1996) that included maintaining riparian zones around the oxbow lake, grass filter strips, turn rows, and impoundments created by slotted-board risers and slotted pipes. An impoundment can be classified as a detention pool or sediment basin that is designed to pond water in critical flow areas so as to allow the heavier sediments transported in runoff an opportunity to deposit in the detention pool before reaching the lake. The sediment basin also facilitates pesticide biodegradation and denitrification. 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 water quality.

Best management practices implemented in the Deep Hollow watershed were the same edge-of-field BMPs used in the Beasley Lake watershed with addition of cultural or agronomic BMPs. These BMPs based on USDA-NRCS practice standards included: reduced-tillage (NRCS Code 329B) cotton which included fall subsoiling, roll hipping, and planting in winter cover crop residues, no-tillage (NRCS Code 329A) soybean which included planting in the stubble or residue from the previous year, application of a fall winter wheat (*Triticum aestivum* L.) cover crops (NRCS Code 340) for both cotton and soybean with chemical burndown in early spring, and precision-application technology which included reduced herbicide application using weed sensor technology. These cultural BMPs were expected to produce the highest level of lake water quality improvement, but they were also considered to be the least economical to area growers.

The installation of these BMPs was placed under the direction of the USDA-NRCS through farm plans and was applied to the entire watersheds. This approach was used because farm plans are part of the conservation programs that growers normally use and are required for most cost-sharing programs. Maps of these BMPs are found in Rebich et al. (1996) and under the watershed sites section of the internet web site http://msa.ars.usda.gov/ms/oxford/nsl/msea/index.html. Several agencies worked together to fund and maintain BMPs at minimal or no cost to the participating growers (Rebich et al., 1996).

### 2.3. Data collection

Three sampling sites on each of the three lakes were installed starting in October 1995 for water quality monitoring. Locations for these floating platforms with automated sampling devices were at one-third distance from inlet, mid-point of lake, and one-third distance from outlet. Yellow Springs Instruments Model 6000 (YSI Environmental, www.ysi.com) automated water quality monitoring equipment was used to obtain hourly measurements of water temperature, pH, dissolved oxygen, and conductivity. At these same locations on each of the three lakes, water was collected in sample bottles within 5 cm of the lake's surface on a biweekly basis from May 1995 through December 1999 and analyzed for total, suspended, and dissolved solids, total phosphorus, filterable ortho-phosphate, ammonium nitrogen, nitrate nitrogen, chlorophyll, coliform and enterococci bacterial counts, and Secchi visibility. Rainfall was monitored at one central location for all the three oxbow lakes using a tipping-bucket rain gauge.

The data was organized into two time periods based on BMPs establishment. The pre-BMP was before September 1996 and the post-BMP was after September 1996. Analytical and chemical methods were based on procedures from APHA (1992). Calculation of means and statistical analysis were completed using SAS STAT software (SAS Institute, Inc., 1996). All parameters were tested for differences at the 5% level of significance. Data were subjected to Kolmogov–Smirnov test for normality (Steel and Torrie, 1980) and two-way analyses of variance to test difference among lakes and pre-post means. When transforming data did not correct for normality or other basic assumptions, Mann–Whitney rank sum test was applied for paired comparisons (Conover, 1971).

## 3. Results and discussion

### 3.1. General water quality

Annual rainfalls of the four water years (October 1995 through September 1999) were 1157, 1321, 1122, and 1029 mm, respectively. These annual rainfalls were lower than the 30-year average annual rainfall for this area of 1387 mm. No abnormal rainfall patterns or amounts occurred during this time period so differences in lake water quality were not likely a result of these parameters.

Mean physical and chemical water quality data for the three MDMSEA lakes prior to establishment of erosion and pollution control structures and management practices are shown in Tables 1 and 2. Thighman Lake had significantly higher conductivity, and concentrations of dissolved solids and nitrate than either Deep Hollow or Beasley Lakes. Beasley Lake had higher concentrations of ortho-phosphate as compared to either Deep Hollow or Thighman lakes.

Water quality prior to the implementation of management practices indicated that lakes were stressed and ecologically damaged due to excessive inflowing sediments. Mean annual total water column sediment concentrations ranged from 351 to 505 mg/L

Table 1
Physical and bacteriological data (first row—averages; second row—standard deviations) from MDMSEA lakes before implementation of best management practices in September 1996

| Lake | BMP | Area ratio | Crop | Temperature (°C) | Conductivity (mS/cm) | Dissolved oxygen (mg/L) | pH |
|---|---|---|---|---|---|---|---|
| Beasley | s | 34 | Cotton, corn soybean | 25.61 (12.98) | 74.96 (20.14) | 6.38 (3.74) | 7.00 (0.37) |
| Deep Hollow | c, s | 25 | Cotton soybean | 24.42 (6.52) | 67.89 (46.21) | 4.04 (1.59) | 6.68 (0.75) |
| Thighman | c | 150 | Cotton, corn soybean, rice | 29.80 (2.44) | 174.7 (91.80) | 5.06 (2.17) | 7.21 (0.39) |

| Lake | Secchi (cm) | Coliform count (colonies/100 mL) | Enterococci count (colonies/100 mL) |
|---|---|---|---|
| Beasley | 16.6 (16.87) | 86 (86) | 7 (16) |
| Deep Hollow | 12.2 (9.37) | 863 (958) | 0 (0) |
| Thighman | 11.5 (8.52) | 4593 (5416) | 27 (43) |

c = cultural, s = structural, number of samples analyzed = 234 (3 lakes by 3 sites on each lake by 26 dates). Area ratio is the ratio of drainage area to lake surface area.

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 (24.4 μg/L) as well as the lowest mean concentration of suspended sediment (289 mg/L). Temperature, conductivity, and pH values fell within ranges expected for the oxbow lakes in the Mississippi Delta. The standard deviation of temperature in Beasley Lake is greater than the other two lakes due to its more exposed surface to wind activity and its narrow and long shape making this lake more acceptable to fetch. While all three lakes experienced occasional periods of low dissolved oxygen concentrations, average annual dissolved oxygen concentrations were adequate to maintain warm water fisheries.

Water quality differences between MDMSEA lakes before and after implementation of BMPs are found in Table 2. Water quality of all MDMSEA lakes was statistically similar to one another prior to implementation of BMPs.

### 3.2. Solids

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 80–100 mg/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 in gill structure (Herbert and Merkins, 1961). While high

Table 2
Pre- and post-BMPs comparisons of water quality for MDMSEA lakes from 1996 to 1999

| Parameter | Beasley structural | | | Deep Hollow cultural and structural | | | Thighman cultural | | |
|---|---|---|---|---|---|---|---|---|---|
| | Pre | Post | Percent change | Pre | Post | Percent change | Pre | Post | Percent change |
| Secchi (cm) | 17 | 21 | 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 | 616* | 24.4 | 61 | 150 | 9.9 | 72.2 | 629* |

Number of water samples before BMPs = 234. Number of water samples after BMPs = 468.
* Indicates a significant difference ($P < 0.05$).

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 best management practices were sufficiently high to consider the MDMSEA lakes sediment stressed systems (Table 2). The MDMSEA lakes had suspended solids concentrations 84% 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 429, 289, and 405 mg/L for Beasley, Deep Hollow, and Thighman, respectively. Compared to historical turbidity data collected from Yazoo Basin lakes from 1969, the three MDMSEA lakes (part of the Yazoo Basin lakes) exceeded estimated suspended solids concentrations of all lakes with the single exception of Arkabutla Reservoir (Knight et al., 1998; USCOE, 1975). However, the 1969 data were collected prior to the increase of intensive cultivation of soybeans in the Mississippi Delta that occurred in the 1970s and were based on sediment-turbidity models developed by Sigler et al. (1984).

A reduction in suspended solids also was found when plotting the temporal data of before and after BMPs installation for each of the three lakes (Fig. 3). The trend lines for each lake are decreasing with time and are significantly different from the 0-slope line. Since annual rainfall amount and distribution were similar over this study, the reduction of suspended solids in the lakes was attributed to the change in management factors in the watersheds.

Cultural and structural management practices, as well as combinations of the two, reduced total and suspended sediments on all three MDMSEA lakes (Table 2). The greatest percent reduction occurred in Deep Hollow Lake (76%), which featured a combination approach to erosion control. This reduction in suspended sediment significantly improved Secchi visibility in the MDMSEA lakes. Prior to BMP establishment, Secchi visibility was exceptionally low averaging less than 17 cm and further supporting the contention that the MDMSEA lakes were sediment stressed. As a result of sediment reductions due to management practices, Secchi visibility increased from 12 to 25 cm on Deep Hollow Lake, from 14 to 17 cm on Beasley Lake, and from 11 to 15 on Thighman Lake. This represents a 108, 36, and 21% increase in water visibility from combination of cultural and structural practices, cultural practices, and structural practices, respectively.

### 3.3. 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 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 MDMSEA lakes exceeded these values, they never exceeded the 1 mg/L at pH 7 and 30 °C standard for ammonium nitrogen nor the 0.02 mg/L standard for the highly toxic un-ionized form ($NH_3$). MDMSEA lakes were also well below the

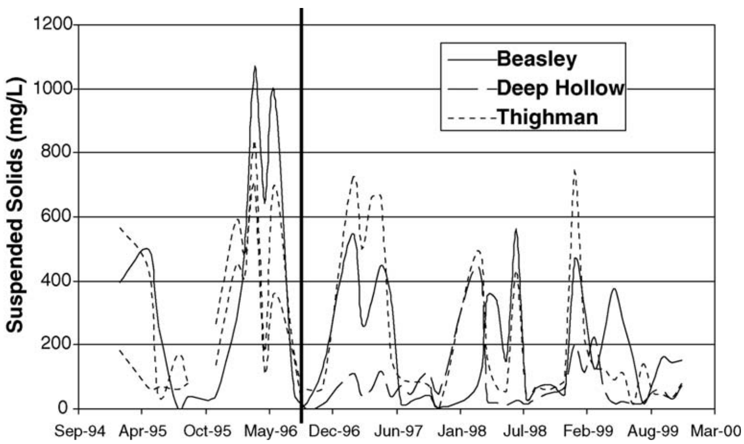


Fig. 3. Suspended solids in MSEA lakes from 1995 to 1999. The vertical lines indicate implementation of BMPs.

10 mg/L nitrate USEPA (1987) standard for water and fish ingestion. MDMSEA lakes had nitrate nitrogen concentrations that compared similarly to those values reported for other Yazoo Basin lakes in 1969 (Knight et al., 1998). Best management practices had little discernable effect on the concentration of nitrogen compounds in the MDMSEA lakes. Deep Hollow was the only lake to show a significant decrease in ammonium nitrogen (Table 2).

### 3.4. Phosphorus

Phosphorus plays a major role in biological metabolism and is typically the limiting factor in lake productivity and eutrophication (Hutchinson, 1957; 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 0.17 mg/L total phosphorus and 0.02 mg/L orthophosphate. USEPA (1987) stated that lake or reservoir waters should not exceed 0.025 mg/L total phosphorus in order to prevent nuisance growth of plants and eutrophication. Total phosphorus in the three MDMSEA lakes prior to BMPs ranged from an average of 0.437 to 0.522 mg/L (Table 2). Although these values are high, they are not unexpected given the relatively high phosphorus content of Mississippi Delta soils. Decreases in total phosphorus occurred in all MDMSEA lakes following implementation of BMPs. These decreases ranged from 31 to 55% (Table 2). While total phosphorus decreased, filterable orthophosphate significantly increased in all lakes from 53 to 144%.

A reduction in total phosphorus also was found when plotting the temporal data of before and after BMPs installation for each of the three lakes (Fig. 4). The trend lines for each lake are decreasing with time. Since phosphorus normally attaches to sediments that are entering the lakes through runoff and the sediments are being reduced by the management system, the reduction of total phosphorus in the lakes was attributed to the change in management factors in the watersheds.

### 3.5. Chlorophyll

Cooper and Bacon (1980) reported that primary productivity 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. Cooper et al. (1995) demonstrated that when suspended sediments were reduced through diversion of sediment-laden runoff, chlorophyll concentration doubled. While chlorophyll concentrations also were impacted by high suspended sediments in the MDMSEA lakes, reductions in sediments due to management practices contributed to corresponding increases in chlorophyll on all MDMSEA oxbows, ranging from 150 to 629% (Table 2). Relationships between sediments and chlorophyll for these oxbow lakes were further developed by Knight et al. (2002).

An increase in chlorophyll production was found when plotting the temporal data of before and after BMPs installation for each of the three lakes (Fig. 5). The trend lines for each lake are increasing with time. Since management factors resulted in decreasing suspended solids in the lakes, more light was transmitted into the lakes thereby resulting in increased chlorophyll production.

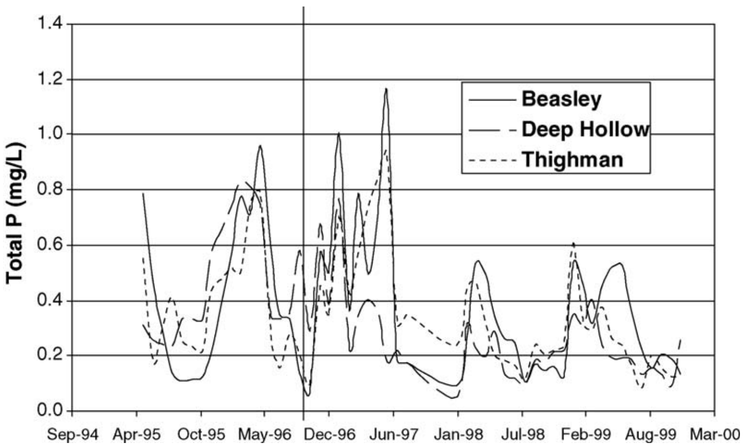


Fig. 4. Total phosphorus in MSEA Lakes from 1995 to 1999. The vertical lines indicate implementation of BMPs.

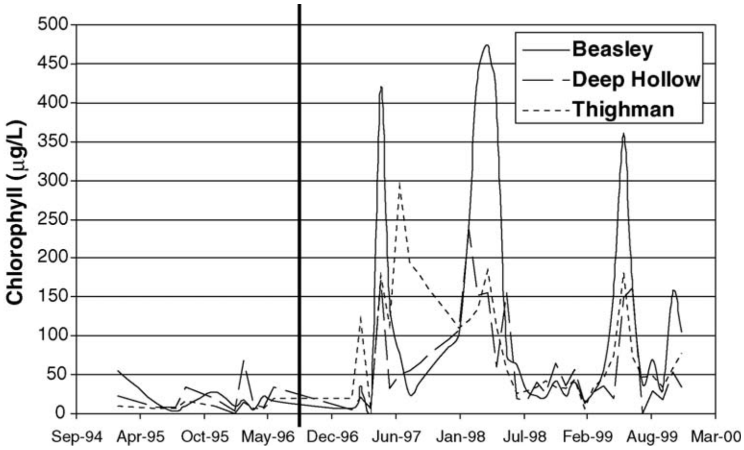


Fig. 5. Chlorophyll in MSEA Lakes from 1995 to 1999. The vertical lines indicate implementation of BMPs.

## 4. Conclusions

This study examined and documented pre-management water quality conditions on three oxbow lakes and resulting changes following the implementation of best management practices. Analyses of water quality prior to the implementation of management practices indicated lakes that were stressed and ecologically damaged due to excessive in-flowing sediments. Mean total suspended sediment concentrations for the three MDMSEA lakes exceeded concentrations estimated for regional lakes in 1969. Because all MDMSEA lakes had low concentrations of chlorophyll despite relatively high concentrations of phosphorus, it was assumed that high suspended solid concentrations likely suppressed phytoplankton production. This conclusion was further supported by Deep Hollow Lake having 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 produced 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 (Thighman) or combinations of cultural and structural practices (Deep Hollow) 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. Results indicate that cultural BMPS may play the more vital role in improving lake water quality and are needed in addition to structural measures to ensure sufficient water parameters to promote fisheries in oxbow lakes receiving agricultural runoff.


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