

Effects of Suspended Sediments on the Chlorophyll-Phosphorus Relationship in Oxbow Lakes

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ABSTRACT

Agricultural activities are considered, by some, to be a major source of nonpoint source pollution in the United States. The Clean Water Act requires states to improve impaired waters by establishing Total Maximum Daily Loads (TMDLs) of such pollutants as sediment, nutrients and pesticides. Most states attempt to establish TMDLs for nutrient levels in such a way that a balance is achieved between nutrient and chlorophyll *a* concentrations so that a sustainable fishery is maintained. Several authors have published chlorophyll-phosphorus relationships for southeastern lakes and impoundments based on annual means. Unfortunately, these relationships will not necessarily be valid in light-limited lakes damaged by sediment. Regression analysis of total phosphorus, total sediment and chlorophyll *a* concentrations indicate significant relationships between all three water quality parameters in three Mississippi Delta oxbow lakes. Total phosphorus and total sediment concentrations were positively correlated, while total phosphorus and chlorophyll *a* were negatively correlated. While this relationship seems counterintuitive, further analysis indicates that when suspended solids are less than 150 mg L⁻¹ there is a positive significant relationship between chlorophyll *a* and total phosphorus. When suspended solids exceed 150 mg L⁻¹ there is a negative significant relationship between chlorophyll *a* and total phosphorus. This information should prove useful to water resource managers responsible for establishing TMDLs and water quality criteria where both sediments and nutrients cause impairment.

Key Words : Agriculture, Water Quality, Nutrients, Impairment, Turbidity, Secchi Depth, Primary Productivity.

INTRODUCTION

Agricultural activities are considered, by some, to be 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. Furthermore the Clean Water Act calls for the establishment of a list of impaired waters for each state, the setting of Total Maximum Daily Loads (TMDL) of contaminants necessary to meet water quality goals, and an action plan that relies primarily on BMPs to meet these TMDL targets.

The southern part of the Mississippi River alluvial plain provides an excellent venue for testing and evaluating BMPs. This 11,263 km² area locally referred to as the Mississippi Delta is one of the most intensively farmed agricultural areas of the United States. The humid sub-tropical 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, can increase the chances for soil erosion and chemical movement within Delta watersheds. Cooper and Bacon (1980) demonstrated that this sediment laden runoff can lead to increased turbidity in 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.

Effective solutions to controlling nonpoint source contaminants such as sediment, nutrients and pesticides were developed, tested and evaluated in the Mississippi Delta Management Systems Evaluation Project (MDMSEA) project. The MDMSEA 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 and ground water. Knight et al. (2002) and Rebich and Knight (2001) demonstrated that the use of BMPs such as grass filter strips, reduced tillage, winter cover crops, and field level grade control structures reduced suspended sediment concentrations to the point of providing suitable light penetration necessary to support photosynthesis, improved primary productivity and a sustainable sport fishery.

There are several issues that must be considered in order to establish scientifically sound TMDLs. Foremost is a clear understanding of how the pollutant impairs the water body. In the case of excessive nutrients damage occurs as a result of oxygen depletion following over production of phytoplankton and subsequent population crash, not to some toxic effect of the nutrient itself. A second important consideration is establishing the level of reduction necessary to achieve the goal. In the case of nutrients, the question becomes what concentration of nutrients is necessary to meet TMDL goals thus allowing the water body to meet its designated use. This must be weighed with possible side-effects of reducing the contaminant. For example, if phosphorus is reduced too much, the primary productivity may not be at levels necessary to sustain a sports fishery.

Most states attempt to establish TMDLs for nutrient levels in such a way that a balance is achieved between nutrient and chlorophyll a concentrations so that secondary productivity (sustainable fishery) is

maintained. Several authors have published chlorophyll phosphorus relationships for southeastern lakes and impoundments based on annual means (Brown et al., 2000, Canfield 1983, Dillon and Rigler 1974, Baker et al. 1981, Ground and Groeger 1994, Huber et al. 1982, Jones and Bachmann 1976, Jones and Knowlton 1993, Maceina et al. 1996). Unfortunately these relationships will not necessarily be valid in light limited lakes damaged by sediment. The purpose of this research is to document effects of high sediment concentrations on the phosphorus chlorophyll relationship in oxbow lakes of the Mississippi Delta.

MATERIALS AND METHODS

The National Management Systems Evaluation Project (MSEA) program was a federal and state funded program designed to test and evaluate farm management practices for the control of non-point source pollution of water. The MSEA framework or farming systems approach to controlling contaminated agricultural runoff 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 agricultural related pollutants in the Delta and to identify BMPs that were most effective in reducing transport of those pollutants to surface and ground water.

The MDMSEA project was designed around three Mississippi Delta oxbow lake watersheds. Thighman and Beasley Lakes near Indianola, MS, in Sunflower County and Deep Hollow Lake near Greenwood, MS, in Leflore County were chosen as the three oxbow lake study sites. Thighman Lake has a watershed of approximately 769 ha and a surface area of 10 ha. Beasley Lake is a 16 ha oxbow located in a 405 ha watershed. The watershed also contained a large wooded riparian zone. Deep Hollow Lake has a surface area of 8 ha and a watershed size of 16 ha. All watersheds were farmed in conventional tillage cotton and soybeans and each received farm management practices designed to reduce water velocity, erosion and discharge of sediment laden water. Treatments included reduced tillage, winter cover crops, field level grade control structures, grassed buffer strips, stiff grass hedges, and grassed waterways.

Water quality was measured on three oxbow lakes from February 1995, through December 2002. Water sampling sites were located at three locations on each lake; one in the middle of the lake and one at each distal end. Surface water was collected at each site at the depth approximately 0.25 m. 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 bi-weekly 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. Additional and more specific details of sampling regimes, physical and chemical parameters measured, and analysis procedures for the project varied with the different aspects of the project and are provided in Rebich and Knight (2001).

Analytical and chemical methods were based on procedures from APHA (1992). Calculation of means and statistical analysis was completed using SigmaStat for Windows version 2.03 statistical software (SPSS, Inc. 1997). All parameters were tested for differences at the 5% level of significance. Log transformed data were subjected to simple linear regression to determine relationships between total phosphorus, total sediment and chlorophyll a concentrations (Steel and Torrie 1980).

RESULTS AND DISCUSSION

Because phosphorus is an essential element in biological metabolism and is typically the limiting factor in lake productivity and eutrophication (Hutchinson 1957, Lee 1970), it is routinely added to ponds in the form of inorganic fertilizer to increase primary productivity and fish growth (Mortimer 1954, Hickling 1962). Boyd (1976) reported that farm ponds in Alabama treated with phosphorus fertilizer averaged 0.17 mg L^{-1} total phosphorus and 0.02 mg L^{-1} ortho-phosphate. Excessive amounts of phosphorus, however, have been implicated as the cause of massive phytoplankton blooms and corresponding oxygen depletion. USEPA (1987) stated that lake or reservoir waters should not exceed 0.25 mg L^{-1} total phosphorus in order to prevent nuisance growth of plants and eutrophication. Currently state agencies responsible for

setting water quality standards and TMDLs are attempting to balance the role of phosphorus in both promoting primary and secondary productivity against the risk of eutrophication. Alabama and Mississippi are exploring the possibility of setting phosphorus standards, first by examining the level of chlorophyll a necessary to sustain a viable sports fishery, then using the relationship between annual means of total phosphorus and annual means of chlorophyll a to set the desired phosphorus level.

Mean annual concentration of total phosphorus for all three MDMSEA lakes was 0.32 mg L^{-1} . While this concentration exceeds EPA recommendations, it is not unexpected given the relatively high phosphorus content of Mississippi Delta soils (McDowell et al. 1988). Additionally management practices did decrease total phosphorus in all MDMSEA lakes ranging from 31 to 55 %.

Suspended and total solids concentrations prior to implementation of management practices were sufficiently high to consider the MDMSEA lakes sediment stressed systems (Grissom 1957). When compared to historical turbidity data collected from Yazoo Basin lakes from 1969, the three MDMSEA lakes exceeded estimated suspended solids concentrations of all lakes with the single exception of Arkabutla Reservoir (USCOE 1975). The MDMSEA lakes had suspended solids concentrations that were also 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^{-1} for Morris Pond compared to 405 mg L^{-1} , 429 mg L^{-1} , and 289 mg L^{-1} respectively for Thighman, Beasley and Deep Hollow. While high concentrations of suspended solids rarely cause direct fish mortality, relatively low concentrations can affect lake productivity (Murphy 1962).

Within field and edge of field management practices specifically designed to reduce water velocity and trap sediments reduced total and suspended sediments on all three MDMSEA lakes. This reduction in suspended sediment significantly improved Secchi visibility in two of the MDMSEA lakes. Prior to BMP establishment, Secchi visibility was exceptionally low averaging less than 12.5 cm for all three lakes. As a result of sediment reductions due to management practices, mean Secchi visibility increased to 19 cm (a 34% increase in water visibility). Cooper and Bacon (1980) reported that 100 mg L^{-1} of suspended sediments, chlorophyll concentration was reduced to less than 20 mg L^{-1} . Cooper et al. (1995) demonstrated

that when suspended sediments were reduced through diversion of sediment laden runoff chlorophyll concentration doubled. Reductions in sediments due to management practices contributed to corresponding increases in chlorophyll on all MDMSEA oxbows, ranging from 61 to 629%.

Regression analysis of total phosphorus, total sediment and chlorophyll *a* concentrations indicated significant relationships between all three water quality parameters. Total phosphorus and total sediment concentrations were positively correlated, while total phosphorus and chlorophyll *a* were negatively correlated (Table 1). While this relationship seems counter-intuitive, further analysis indicates that when suspended solids are less than 150 mg L^{-1} there is a positive significant relationship between chlorophyll *a* and total phosphorus. When suspended solids exceed 150 mg L^{-1} there is a negative significant relationship between chlorophyll *a* and total phosphorus. It is likely that this negative correlation between phosphorus and chlorophyll *a* is due to both light limitation by sediment and the phosphorus adsorbed to clay particles comprising the suspended sediments. While suspended sediments suppress light and thus phytoplankton production, they are also high in phosphorus (McDowell et al. 1988). When sediment is reduced and light is no longer limited the relationship between phosphorus and chlorophyll becomes positive.

Table 1. Slope, intercept and R squares for the relationships between mean annual total phosphorus and chlorophyll *a* for the MDMSEA oxbow lakes.

| | Y intercept | Slope | R ² |
|--|-------------|-------|----------------|
| All MDMSEA data | 0.48 | -1.48 | 0.479 |
| >150 mg L ⁻¹ total sediment | 0.40 | -1.66 | 0.487 |
| <150 mg L ⁻¹ total sediment | 1.64 | 0.29 | 0.410 |

Many factors likely affect concentration of chlorophyll *a* in oxbow lakes. Physical characteristics such as temperature, pH, alkalinity, conductivity as well as nutrients such as nitrate and ammonium nitrogen play a role in phytoplankton production (Boyd 1979, 1990). This concept of multiple factors affecting chlorophyll *a* is certainly supported by our data as indicated by relatively low r^2 values for our chlorophyll-phosphorus

relationships. A comparison of total phosphorus versus chlorophyll *a* relationships for several lakes in the southeastern United States is found in Figure 1. The figure shows that the MDMSEA lake phosphorus-chlorophyll *a* relationships are unique in that the slopes are negative for the total data set and when sediment concentration exceeds 150 mg L^{-1} and have a much higher y-intercept for all three curves.

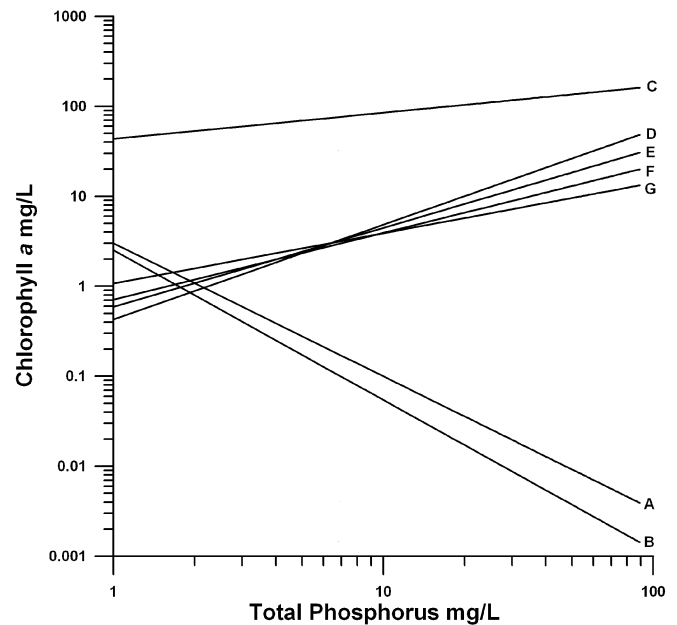


Figure 1. Plots of annual mean total phosphorus versus annual mean chlorophyll *a* for several lakes in the southeastern United States as well as MDMSEA lakes. A- MSEA data regardless of suspended sediment concentration; B - MSEA data where suspended sediment is $>150 \text{ mg L}^{-1}$; C - MSEA data where suspended sediment is $<150 \text{ mg L}^{-1}$; D - Brown et al. 2001, E - Canfield 1983, F - Ground and Groeger 1994, G - Jones and Knowlton 1993.

Based on this research, the relationships between sediment, nutrients and chlorophyll *a* must be considered before effective TMDLs can be established. Mitigation strategies that simply remove sediment may in turn trigger oxygen depletion due to excessive eutrophication in fertile oxbow lakes. Multifaceted management practices that remove sediment and nutrients may be necessary to meet water quality goals. Additionally future research that more accurately defines the point at which turbidity no longer limits productivity will be necessary before effective nutrient standards can be established.

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