NUTRIENT ASSESSMENTS SUPPORTING DEVELOPMENT OF NUTRIENT CRITERIA FOR MISSISSIPPI LAKES AND RESERVOIRS

Final Project Report: Grant Number X974454-06

Submitted

To

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Prepared for:

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EXECUTIVE SUMMARY

This report presents the results from nutrient criteria development studies funded by Environmental Protection Agency Grant Number X796445406. It presents the results of detailed analyses performed by FTN Associates, Ltd. on lakes and reservoir water quality data provided by Mississippi Department of Environmental Quality (MDEQ). The overall objective of the project was to perform extensive analysis of the data, primarily in water bodies > 100 acres, to support recommendations for nutrient criteria Mississippi's Lakes and Reservoirs.

Three years of data collected in 40 lentic systems specifically for developing nutrient criteria was supplemented with historical monitoring data for the past 10 years and analyzed to support development of nutrient criteria recommendations. Products from this study include suggested nutrient categories for Mississippi reservoirs and oxbows; reference sites and conditions for these water bodies; and quantitative relationships linking designated uses, assessment/management endpoints, stressors, and hydrogeomorphic modifiers for Mississippi reservoirs and oxbows, by strata, and 2-tier indicator thresholds. The transferability of these relationships to smaller water bodies was considered.

MDEQ considers this work to be significant toward the development of nutrient criteria for the state's lakes and reservoirs. FTN Associates, Ltd. (FTN) did excellent work in analyzing the data and provided a scientifically defensible approach for MDEQ to consider in moving forward with nutrient criteria recommendations. These recommendations will be use by MDEQ in developing nutrient criteria for Mississippi's lakes and reservoirs. MDEQ will use the results of this study along with other data and resources to continue working toward developing nutrient criteria for Mississippi's lakes and reservoirs. However, MDEQ is not ready at this point to adopt the lakes and reservoir nutrient criteria values recommend in this final project report.

The focus of the project was oxbow lakes and reservoirs greater than 100 acres that Mississippi Department of Environmental Quality (MDEQ) sampled from 2002 to 2004 for water quality constituents needed to establish nutrient criteria. The results from the study of lakes in size between 100 and 500 acres are included in Appendix E.

The project involved the following tasks:

Task 1. Develop and Submit Quality Assurance Project Plan (QAPP) for MDEQ and USEPA Region 4 Review And Approval

A QAPP was developed based on United States Environmental Protection Agency (USEPA) (2001), USEPA (1999), and USEPA (2002) guidance. The QAPP document was received and approved by USEPA Region 4 and is provided as Appendix A.

Task 2. Meet and Coordinate with the MDEQ Lake and Reservoir Nutrient Task Force (LRNTF) to Discuss the Scope and Approach to this Study

Meetings and discussions with the LRNTF indicated that lake and reservoir criteria should have the following features:

1. Criteria should be or be linked to numeric values of Total Phosphorous (TP) and Total Nitrogen (TN);
2. Criteria should be directly linked to fishable, swimable uses;
3. Criteria should be effects-based. That is, they should indicate nutrient conditions that are associated with adverse effects such as nuisance algae blooms, fish kills or impaired fish and/or wildlife populations; and
4. Criteria should reflect the natural productive capacity of Mississippi waters.

Task 3. Gather existing water quality data

Water quality data from oxbow lakes and reservoirs greater than 500 acres sampled from 2002 to 2004 were obtained from MDEQ and analyzed (Task 6) to provide a basis for criteria recommendations.

A search of the literature revealed 2,844 papers discussing nutrients in lakes or reservoirs. Papers were reviewed if the lakes were within the southern tier of states (AR, AL, FL, GA, KY, LA, MS, NC, OK, SC, TN, TX). The information summarized in the literature review showed:

1. A general relationship between nutrients (particularly TP) and primary productivity as indicated by chlorophyll-a (Chl-a) concentrations.
2. A large amount of uncertainty associated with nutrient-productivity relationships. In general, TP can predict Chl-a (or vise versa) within a factor of 3 to 5.
3. The literature review indicated a much weaker relationship between TN and TP or TN and Chl-a.

4. The literature clearly establishes a link between primary productivity and fish production.
5. There is considerable variability in the relationship between primary productivity and fish production due to factors such as sampling variability, habitat quality, recruitment, and harvest.
6. Fish production can be limited by primary productivity that is, in turn, limited by low nutrient concentrations.
7. A number of researchers have argued that reversal of cultural eutrophication in reservoirs can have deleterious effects on warm water sport fisheries by reducing the level of primary productivity on which productivity at higher trophic levels depends.

Task 4. Review designated uses and identity assessment/management endpoints

Designated uses and associated assessment endpoints are presented in Table ES1.

Table ES1. Assessment/management endpoints associated with designated uses.

Assessment/management Endpoint	Designated Use(s)
Biodiversity (Sustainability)	Aquatic Life
Fish Production	Aquatic Life, Fish and Wildlife
Chl-a Concentrations	Aquatic Life, Drinking Water, Fish and Wildlife
Water Clarity	Recreation, Drinking Water, Fish and Wildlife
Macrophytes	Recreation, Fish and Wildlife
Nitrate, Total organic carbon	Drinking Water
Harmful Algal Blooms	Aquatic Life, Drinking Water, Fish and Wildlife
Algal Blooms	Aquatic Life, Drinking Water, Fish and Wildlife

Task 5. Compile Information on Approaches to Nutrient Criteria Development used in other USEPA Region 4 States

A review of nutrient criteria in other states indicated:

1. Four Region 4 states have approved numeric criteria for Chl-a, three states have numeric criteria for phosphorus, and two states have numeric criteria for nitrogen (Table ES2).
2. Alabama and Georgia have developed numeric criteria for specific lakes, North Carolina for specific designated uses (trout waters and non-trout waters), South

Carolina for ecoregions within the state, and Arkansas has guidance for the entire state.

3. The Alabama Department of Environmental Management (ADEM) has compiled research on factors affecting reservoir sport fisheries to support Chl-a based nutrient criteria in that state's reservoirs:

   a. These criteria identify Chl-a levels that do not limit (in the sense of nutrient limitation) fishery production.

   b. These criteria do not identify Chl-a levels that begin to impair fishery production.

   c. Chl-a levels that begin to impair fisheries (by inducing phenomena associated with eutrophication such as dissolved oxygen depletion, toxic algae blooms, etc.) can be expected to be somewhat higher than the levels that do not limit fisheries due to nutrient limitation.

Table ES2. Numeric Standards adopted by southern states and USEPA guidance criteria for related ecoregions.

Parameter	Source	State or Ecoregion	Standard or Guidance
Chl-a (µg/L)	State Criteria	AL	5 – 27
		GA	5 – 27
		NC	15 or 40
		SC	10 or 15
	USEPA Ecoregion Guidance	IX	4.93
		X	--
		XI	2.79
		XII	2.6
TP (µg/L)	State Criteria	AR (Guidance)	50
		GA	91 – 2022
		SC	20 – 90
	USEPA Ecoregion Guidance	IX	20
		X	--
		XI	8
		XII	10
TN (µg/L)	State Criteria	GA	3 or 4
		SC	0.35 or 1.5
	USEPA Ecoregion Guidance	IX	360
		X	--
		XI	460
		XII	600

1 - USEPA criteria for Ecoregion X have not yet been developed.
2 - USEPA Ecoregion XI is not found in Mississippi (it is found in neighboring Arkansas and Alabama).

Task 6. Data Analyses

Major findings of the data analysis are as follows:

1. 70% of the variation in water quality parameters was explained by three independent factors: Water clarity/TP, ionic strength, and primary productivity/organic content;
2. A classification consisting of large reservoirs, reservoirs, and oxbows is a valid means of capturing significant variation in TP, TN, Secchi depth (SD), and Chl-a and is a valid starting point for classification of Mississippi lakes and reservoirs;
3. Sampling for nutrient-related issues should take place from June through September;
4. Causative variables (TP and TN) and response variables (SD and Chl-a) are not tightly linked as might be expected in a classical limnological setting:
    a. The likely cause of this decoupling is the presence of non-algal turbidity that characterizes many Mississippi lakes and reservoirs.
    b. The presence of relatively high levels of non-algal turbidity is a general property of Mississippi lakes and reservoirs. This property is a result of geomorphology and soil types prevalent in Mississippi.
    c. Recommendations or conclusions based on Carlson's TSI approach should be used cautiously with Mississippi lakes and reservoirs.
5. The USEPA recommendation that no TP criterion be higher than 0.1 mg/L is not, in general, valid for Mississippi lakes and reservoirs; and
6. While there is no clear alternative classification beyond "oxbows" and "reservoirs," the data could support other classifications that are based on less distinct overlapping groups such as "reservoir/large reservoir/oxbow" and "reservoir/large reservoir."

Task 7. Develop Criteria Recommendations

The preferred approach for the development of nutrient criteria was to develop effects-based criteria based primarily on the linkage between nutrient concentrations and impairment of designated uses. The preferred approach started with the designated uses, identified ecological endpoints that can be associated with these designated uses and then, using conceptual models, developed the linkage among designated uses, ecological endpoints, nutrient concentrations, and factors affecting the expression or response of the endpoint to nutrient concentrations.

Criteria Based on USEPA Guidance Criteria for Lakes and Reservoirs

USEPA has developed guidance criteria for lakes and reservoirs for USEPA Ecoregions IX (USEPA 2000b) and XII (USEPA 2000c) but not Ecoregion X. The percentile value from the MDEQ reservoirs/large reservoirs data set that corresponds to guidance criteria given by USEPA (USEPA 2000b, USEPA 2000c) is provided in Table ES3. Evaluation of this approach to nutrient criteria development indicated that:

1. USEPA guidance criteria represent the lower portions of the ranges of actual TP, TN, Chl-a, and upper range of SD values encountered in Mississippi reservoirs/large reservoirs;
2. This procedure does not consider whether or not adverse effects are associated with the concentrations at the chosen percentiles i.e., the guidance values are not effects based; and
3. ***Therefore this approach was not selected for deriving nutrient criteria for Mississippi lakes and reservoirs because the resulting guidance values are not effects based***.

Table ES3. USEPA guidance nutrient criteria for ecoregions in Mississippi.

Parameter	Ecoregion	Guidance Criterion	Percent of Values Exceeding the Guidance Criteria in the Mississippi Reservoir/Large Reservoir Data Set		
			Reservoirs	Large Reservoirs	Oxbows
TP (µg/L)	IX[1]	20	70	99	90
	X [2]	--		--	--
	XII[3]	10	93	99	90
TN (µg/L)	IX[1]	360	88	100	92
	X [2]	--	--	--	--
	XII[3]	600	55	97	70
Chl-a (µg/L)	IX[1]	4.93	91	99	93
	X [2]	--	--	--	--
	XII[3]	2.6	100	100	99
SD[4] (m)	IX[1]	1.53	92	100	93
	X [2]	--	--	--	--
	XII[3]	2.1	100	100	96

1 - USEPA (2000b), 2 - USEPA criteria for Ecoregion X have not yet been developed.
3 - USEPA (2000c), 4 - SD values are the percent of values less than the guidance criteria.

Criteria Based on USEPA Percentile Approach Using Data From Mississippi Waterbodies

As an alternative to USEPA guidance criteria the USEPA's percentile-based approach (USEPA 2000a) was used with data collected from Mississippi lakes and reservoirs. The results of this approach are provided in Table ES4. This evaluation indicated the following:

1. Selection of criteria using this approach implies than approximately 75% of lakes and reservoirs in Mississippi will be found to be impaired due to excess nutrients. The actual proportion of Mississippi lakes and reservoirs that are impaired is unknown and may be higher or lower than 75%.
2. This procedure does not consider whether or not adverse effects occur at the concentrations corresponding to the chosen percentiles (i.e., the approach is not effects-based).
3. Therefore this approach is not desirable because the resulting guidance values are not effects-based and was not selected to derive nutrient criteria for Mississippi lakes and reservoirs.

Table ES4. Potential criteria based on USEPA's percentile approach using data from Mississippi waterbodies.

Parameter	Reservoirs	Large Reservoirs	Oxbows
TP (µg/L; 25th percentile)	20	40	70
TN (mg/L; 25th percentile)	0.450	0.565	1.03
Chl-a (µg/L; 25th percentile)	7.6	9.5	25
SD (m; 75th percentile)	1.1	1.0	0.65

Criteria Based on Nutrient Conditions in Mississippi Benthic Index of Stream Quality (M-BISQ) Reference Streams

Nutrient conditions in M-BISQ reference streams represent the best theoretically attainable conditions for reservoirs. However the M-BISQ reference stream data are probably biased in favor of low values. Therefore this approach was not used to establish nutrient criteria for Mississippi lakes and reservoirs. TN and TP criteria in Yahoo Basin Reservoirs should reflect higher background TN and TP concentrations indicated by the M-BISQ reference streams.

Criteria Based on Sport Fisheries

This approach uses the MsFish index as an indicator of aquatic life use support. MsFish is an index used by the Mississippi Department of Wildlife, Fisheries, and Parks (MDWFP) to provide estimates of relative fishing quality for lakes and reservoirs and is based on the Sport Fishing Index developed by the Tennessee Valley Authority (TVA).

The approach combines the MsFish index with data describing TP,TN, SD, and Chl-a collected by MDEQ for the development of nutrient criteria in Mississippi lakes and reservoirs. For purposes of nutrient criteria development, a lake is considered to be meeting its aquatic life use if any of its three fisheries (black bass, crappie, or other sunfish) rank high according to MsFish. The distribution of TP, TN, Chl-a, and SD for lakes with high MsFish scores (i.e., meeting their aquatic life designated use) is considered to represent the range of levels of nutrients, clarity, and primary productivity that supports, and does not impair, aquatic life use.

The selection of nutrient, clarity, and Chl-a values that support aquatic life uses in reservoirs and oxbows was based on the following principles:

1. Criteria values for nutrients and Chl-a should be established such that they represent the upper range of values that support and do not impair designated uses;
2. Criteria values for nutrients, clarity, and Chl-a should be established such that the majority of nutrient, clarity, and Chl-a measurements in an attaining waterbody reflect attainment; and
3. Due to variability in the linkage among nutrients, primary production, clarity and fish production, and because the criteria are intended to represent the upper range of levels that support the aquatic life use, a precautionary approach should be applied to assure that criteria are protective of uses.

Recommended criteria values for reservoirs are provided in Table ES5.

Table ES5. Recommended criteria values for TP, TN, Chl-a, and SD in reservoirs.

Basis	TP (µg/L)	TN (µg/L)	Chl-a (µg/L)	SD (m)
Recommended Criteria	80	990	19.4	0.50

Recommended criteria values for oxbow lakes are presented in Table ES6. Recommended criteria values for TP, TN, Chl-a, and SD in lakes are based on the "Low" MsFish category.

Table ES6. Recommended criteria values for TP, TN, Chl-a, and SD in oxbow lakes.

Basis	**Recommended Criteria**			
	TP (μg/L)	**TN (μg/L)**	**Chl-a (μg/L)**	**SD (m)**
Recommended Criteria	90	1250	45.6	0.60
Demonstrated Attainment (Example: Bee Lake)	150	1620	67.8	0.42

Recommendations for Further Development of Nutrient Criteria for Mississippi Lakes and Reservoirs

Relationships between nutrient regimes and sport fishery quality provide a sound basis for evaluating the effects of nutrients on aquatic life. Responses of the sport fishery to nutrient conditions conform to expectations based on how nutrients are thought to affect productivity in aquatic ecosystems. The response of the sport fishery to nutrients in reservoirs is based on a reasonably large data set (7 to 8 waterbodies per MsFish category). However, there are only a total of eight oxbow lakes in the analysis. Because this approach appears to be promising in reservoirs, additional collection of oxbow fishery data appears warranted. It is, therefore, recommended that fishery data be collected for additional oxbow lakes to clarify the sport fishery response to nutrients in these systems.

The water quality analysis of the lakes and reservoirs between 100 and 500 acres and Lakes and reservoirs larger than 500 indicated similar structure in the data sets. Both the individual and the combined data set supported the general classification of Mississippi's lentic waterbodies into reservoirs and oxbows.

The MsFish information from the reservoirs between 100 and 500 acres supported the recommended criteria based on the MsFish index based on reservoirs larger than 500 acres presented in the draft Nutrient Criteria for Mississippi Lakes and Reservoirs submitted to MDEQ on February 8, 2007. The results of the analysis presented herein indicate that the use of the sport fishery as an indicator of aquatic life attainment provides a useful basis for nutrient criteria that are protective of designated uses and applicable to a wide variety of lentic waterbodies.

Accordingly, the values presented in Table 3.3 are presented as recommended TP, TN SD, and Chl-a criteria for reservoirs larger than 100 acres.

Based on the results of the MsFish-based approach in reservoirs, it is recommended that additional MsFish data be obtained for oxbow systems to provide a basis for TP, TN SD, and Chl-a criteria in oxbow systems.

TABLE OF CONTENTS

TABLE OF CONTENTS (CONTINUED)

LIST OF APPENDICES

LIST OF TABLES

LIST OF TABLES (CONTINUED)

LIST OF FIGURES

1.0 PROJECT OBJECTIVES AND OVERVIEW

The purpose of this project was to analyze data on nutrients and other water quality parameters to provide recommendations for nutrient criteria in Mississippi lakes and reservoirs greater than 500 acres in size. The existing data for these lakes and reservoirs and additional information were used to identify and evaluate:

1. The designated uses for these water bodies and appropriate management and assessment endpoints for these designated uses;
2. Nutrient criteria approaches and lake/reservoirs classes or categories being used by other United States Environmental Protection Agency (USEPA) Region 4 states;
3. Conditions for Mississippi lakes and reservoirs; and
4. Quantitative relationships linking designated uses, assessment/management endpoints, stressors, and hydrogeomorphic modifiers for Mississippi reservoirs and oxbows.

Mississippi Department of Environmental Quality (MDEQ) obtained the services of FTN Associates, Ltd. (FTN)(3 Innwood Circle, Suite 220 Little Rock, Arkansas, 72211) to execute the project work plan. The focus of the project was 41 oxbow lakes and reservoirs greater than 500 acres (“large lakes” data set) that MDEQ sampled during 2002 through 2004 for water quality constituents needed to establish nutrient criteria. This primary data set was supplemented with ambient monitoring data collected over the past 10 years from selected reservoirs. The data analysis included fisheries data collected from selected lakes and reservoirs by the MDWFP from 2000 through 2005. The project work plan listed seven tasks to address the overall purpose of the project.

Task 1. Prepare Project Quality Assurance Project Plan (QAPP)

The project work plan was reviewed and a QAPP for MDEQ and USEPA Region 4 review and approval was prepared.

Task 2. Meetings with Lakes and Reservoirs (L&R) Nutrient Task Force

FTN met and coordinated with the MDEQ Lake and Reservoir Nutrient Task Force (LRNTF) to discuss the scope and approach to this study. The meetings served to obtain input and recommendations from the LRNTF.

Task 3. Gather Existing Water Quality Data

MDEQ provided existing water quality databases needed to perform the work to the contractor. FTN supplemented existing data on Mississippi lakes and reservoirs with more recently available data.

Task 4. Review Designated Uses and Identity Assessment/Management Endpoints

FTN reviewed applicable designated uses and identified assessment and management endpoints for each of the designated use categories.

Task 5. Evaluate Nutrient Criteria and Water Body Classes or Strata

FTN compiled information on approaches to nutrient criteria development used in other USEPA Region 4 states as well as the neighboring USEPA Region 6 States of Louisiana and Arkansas to determine the approaches being used by these states to classify water bodies, develop lake and reservoir nutrient criteria, or develop water body specific criteria.

Data exploration procedures were used to develop a preliminary classification of reservoirs and oxbows.

Task 6. Data Analyses (Reference Sites and Condition)

The following approaches were used to analyze the data to support nutrient criteria recommendations:

1. Use nutrient conditions in “least disturbed” streams identified as part of the Mississippi Index of Stream Quality (M-BISQ) for wadeable streams to estimate best attainable nutrient conditions in reservoirs.
2. Using the 2004 303d list of impaired waters, identify lakes and reservoirs considered to be attaining designated uses that, by definition, might serve as reference sites for water bodies that are not attaining designated uses.

3. Evaluate the distribution of conditions occurring in various classes of reservoirs and oxbows using the approach found in USEPA's guidance documents for establishing nutrient criteria (USEPA 2000).
4. Evaluate the correspondence between quantitative or semi quantitative indicators of sport fish populations and nutrient conditions.

Task 7. Develop Criteria Recommendations

Based on the results of the previous tasks, nutrient criteria recommendations were developed using guidelines provided in Mississippi's Plan for Nutrient Criteria Development (MDEQ 2003) and guidance and direction received from USEPA Region 4 and MDEQ in meetings with the LRNTF. The stated goal for nutrient criteria development is to adopt scientifically defensible numeric water quality nutrient criteria (causal or response variables) to protect the designated uses of Mississippi lake and reservoir water bodies from the adverse effects of over enrichment (MDEQ 2003). The objectives within this goal are to:

- Determine the highest attainable designated use for the natural regions and subregions of Mississippi lake and reservoir water bodies,
- Develop scientifically defensible nutrient criteria[1] that will protect this designated use from adverse effects of over enrichment in each region and subregion, and
- Incorporate these nutrient criteria into nutrient Water Quality Standards (WQS) for each natural region and subregion of Mississippi lake and reservoir water bodies (MDEQ 2003).

[1] MDEQ (2003) allowed for the possibility that a combination of numeric and narrative criteria with translators will be developed for some Mississippi waterbodies.

2.0 RESOURCES OF CONCERN

2.1 Regulatory Definitions

2.1.1 Section 49 17 5 (f) of the Mississippi Air and Water Pollution Control Law:

"Waters of the state" means all waters within the jurisdiction of Mississippi, including all streams, lakes, ponds, impounding reservoirs, marshes, watercourses, waterways, wells, springs, irrigation systems, drainage systems, and all other bodies or accumulations of water, surface and underground, natural or artificial, situated wholly or partly within or bordering upon the state, and such coastal waters as are within the jurisdiction of the state, except lakes, ponds or other surface waters which are wholly landlocked and privately owned, and which are not regulated under the Federal Clean Water Act (33 USC 1251 et seq.).

2.1.2 Per 40 CFR Part 122.2: Waters of the United States or waters of the US means:

1. All waters which are currently used, were used in the past, or may be susceptible to use in interstate or foreign commerce, including all waters which are subject to the ebb and flow of the tide;
2. All interstate waters, including interstate wetlands; and
3. All other waters such as intrastate lakes, rivers, streams (including intermittent streams), mudflats, sandflats, wetlands, sloughs, prairie potholes, wet meadows, playa lakes, or natural ponds the use, degradation, or destruction of which would affect or could affect interstate or foreign commerce including any such waters:
    a. Which are or could be used by interstate or foreign travelers for recreational or other purposes,
    b. From which fish or shellfish are or could be taken and sold in interstate or foreign commerce,
    c. Which are used or could be used for industrial purposes by industries in interstate commerce,
    d. All impoundments of waters otherwise defined as waters of the United States under this definition,
    e. Tributaries of waters identified in paragraphs (a) through (d) of this definition,
    f. The territorial sea, and
    g. Wetlands adjacent to waters (other than waters that are themselves wetlands) identified in paragraphs (a) through (f) of this definition.

Waste treatment systems, including treatment ponds or lagoons designed to meet the requirements of Clean Water Act (other than cooling ponds as defined in 40 CFR 423.11(m) which also meet the criteria of this definition) are not waters of the US. This exclusion applies only to manmade bodies of water that neither were originally created in waters of the United States (such as disposal area in wetlands) nor resulted from the impoundment of waters of the US [See Note 1 of this section]. Waters of the US do not include prior converted cropland. Notwithstanding the determination of an area's status as prior converted cropland by any other federal agency, for the purposes of the Clean Water Act, the final authority regarding Clean Water Act jurisdiction remains with USEPA.

2.1.3 40 CFR Part 131.3 (i)

WQS are provisions of State or Federal law which consist of a designated use or uses for the waters of the United States and WQS for such waters based upon such uses. WQS are to protect the public health or welfare, enhance the quality of water and serve the purposes of the Act.

Therefore, WQS are applicable to all waters of the United States, which include waters of the state, which, in turn, include all waters that are not wholly landlocked and privately owned. Even if public access is provided, a lake is not state water if the lake is wholly landlocked and the land surrounding it is privately owned. This applies to many small ponds and lakes located on private property. Except for the oxbow lakes, most of the waterbodies in Mississippi are reservoirs, and are not wholly landlocked. All oxbows are state waters. However, this doesn't necessarily mean that numeric nutrient criteria must be developed for every water body in the state. For instance, numeric criteria can be developed for reservoirs greater than 100 acres with narrative criterion developed for those that are less than 100 acres. A narrative criterion might read, "Concentrations of nutrients X, Y, Z, etc., shall not cause nuisance conditions, and shall not result in adverse water quality conditions in downstream waters."

2.2 Target Population

USEPA's criteria guidance document (USEPA 2000) states that only those lakes/reservoirs greater than 10 acres are considered: "For the purposes of this document, lakes are defined as natural and artificial impoundments with a surface area greater than 10 acres and a mean water residence time of 14 or more days." However, the nutrient criteria proposed herein apply only to a target population of lakes/reservoirs consisting of lentic water bodies in the state having a surface area greater than 500 acres and a mean water residence time of 14 days or longer, except for those that are wholly landlocked and privately owned. Analyses are being conducted to determine if the conclusions based on the analysis herein can be extended to smaller lakes and reservoirs. There are two exceptions to this target population.

First, MDWFP fertilizes some of their lakes to increase fish production. Numeric criteria might not be applicable for lakes that are fertilized by various state and federal agencies for the purpose of enhancing the fisheries resources for use by the public. If a managing authority's fertilizing practices result in downstream impairment, a narrative criterion can be applied and MDEQ can coordinate with that agency to develop a solution.

Second, some lakes are tidally influenced and will be addressed by the Coastal/Estuaries Subcommittee. Lakes considered tidally influenced include: McInnis Lake, Lake Bounds, O'Leary Lake, Robertson Lake, Beardslee Lake, Bangs Lake, Marsh Lake, Big Lake, Krebs Lake, Catch em all Lake, and Cutoff Lake.

One of the first tasks completed was to develop a database of lakes in the state. Information from the United States Geological Survey's (USGS) National Hydrography Dataset (NHD) and various other sources indicated there were 938 named lakes/reservoirs/ponds in Mississippi. Seven hundred and seventy two of these lakes make up less than 10% of the total surface area of lakes in Mississippi. One hundred and sixty six lakes comprise over 90% of the total surface area of lentic water bodies in Mississippi[2]. In addition, the 40 largest lakes and reservoirs (i.e., greater than 500 acres) represented 84% of the total surface area of Mississippi lentic water bodies A total of 132 lakes and reservoirs have surface areas greater than 100 acres. Of these, nine reservoirs have a surface area greater than 4,000 acres and were classified as "large reservoirs."

The target population of 104 non-fertilized, non-tidally influenced lakes and reservoirs greater than 100 acres lakes is provided in Table 2.1.

[2] Surface acreage is the reporting unit for attainment or non-attainment of WQS in lentic water bodies.

Table 2.1. Target Population of Lakes/Reservoirs greater than 100 acres (non-fertilized and non-tidally influenced).

Name	Acres	General type	Specific type	County
Sardis Lake	30,796	Reservoir	Large reservoir	Panola
Ross Barnett Reservoir	28,917	Reservoir	Large reservoir	Madison, Rankin
Grenada Lake	19,931	Reservoir	Large reservoir	Grenada
Enid Lake	14,593	Reservoir	Large reservoir	Yalobusha
Arkabutla Lake	9,656	Reservoir	Large reservoir	Tate, Desoto
Bay Springs Lake	6,193	Reservoir	Large reservoir	Prentiss, Tishomingo
Pickwick Lake (MS Portion is 4453)	4,453	Reservoir	Large reservoir	Tishomingo
Eagle Lake	4,359	Lake	Oxbow	Warren
Okatibbee Lake	4,244	Reservoir	Large reservoir	Lauderdale
Aberdeen Lake (Tenn Tom Waterway)	4,121	Reservoir	Large reservoir	Monroe
Tunica Cutoff	3,719	Lake	Oxbow	Tunica
Lake Washington	3,069	Lake	Oxbow	Washington
Lake Mary	2,763	Lake	Oxbow	Wilkinson
Moon Lake	2,343	Lake	Oxbow	Coahoma
Hard Cash Lake	2,116	Lake	Oxbow	Humphreys
Lake Lee	1,796	Lake	Oxbow	Washington
Lake Ferguson	1,788	Lake	Oxbow	Washington
Desoto Lake	1,433	Lake	Oxbow	Coahoma
Bee Lake	1,357	Lake	Oxbow	Holmes
Pool C (Tenn Tom Waterway)	1,351	Reservoir	Reservoir	Itawamba
Horn Lake	1,263	Lake	Oxbow	Desoto
Lake Bolivar	1,086	Lake	Oxbow	Bolivar
Wolf Lake/Broad Lake	1,030	Lake	Oxbow	Yazoo Humphreys
Lake Bogue Homo	1,013	Reservoir	Reservoir	Jones
Lake Beulah	996	Lake	Oxbow	Bolivar
Dalewood Shore Lake	902	Reservoir	Reservoir	Lauderdale
Bluff Lake	785	Reservoir	Reservoir	Noxubee
Lake Whittington	761	Lake	Oxbow	Bolivar
Lake Chotard	733	Lake	Oxbow	Warren, Issaquena
Roebuck Lake	726	Lake	Oxbow	Leflore
Horseshoe Lake	713	Lake	Oxbow	Holmes
Buzzard Bayou Lake	674	Lake	Oxbow	Tallahatchie
Flint Creek Reservoir	548	Reservoir	Reservoir	Stone
Little Black Creek Reservoir	548	Reservoir	Reservoir	Lamar

Table 2.1. Continued.

Name	Acres	General type	Specific type	County
Wasp Lake	505	Lake	Oxbow	Humphreys
Archusa Creek Water Park	459	Reservoir	Reservoir	Clarke
Loakfoma Lake	458	Reservoir	Reservoir	Noxubee
Swan Lake	457	Lake	Oxbow	Coahoma
Flower Lake	441	Lake	Oxbow	Tunica
Beaverdam Lake	426	Lake	Oxbow	Tunica
Maynor Creek Water Park	419	Reservoir	Reservoir	Wayne
Dump Lake	406	Lake	Oxbow	Yazoo
Oktibbeha County Lake	393	Reservoir	Reservoir	Oktibbeha
Sky Lake	388	Lake	Oxbow	Humphreys
Horseshoe Lake (Stovall Lake)	383	Lake	Oxbow	Coahoma
Grassy Lake	373	Lake	Oxbow	Tallahatchie
Flatland Lake	359	Lake	Lake	Jefferson
Dawson, Lake	330	Lake	Oxbow	Sunflower
Halpino Lake	324	Lake	Oxbow	Warren
Lower Lake	317	Lake	Lake	Panola
Lake George	307	Lake	Oxbow	Yazoo
Anchor Lake	304	Reservoir	Reservoir	Pearl River
Town Cr. Structure #6	303	Reservoir	Reservoir	Lee
Conservation League L. (Lake Charlie Capps)	237	Lake	Reservoir	Bolivar
Long Creek Reservoir	231	Reservoir	Reservoir	Lauderdale
LT-7-1 (Chewalla Reservoir)	229	Reservoir	Reservoir	Marshall
Square Lake	219	Lake	Lake	Coahoma
Fields Lake	213	Lake	Oxbow	Adams
Hennington Lake	203	Reservoir	Reservoir	Lamar
Masonite Lake	192	Reservoir	Reservoir	Jones
Little Eagle Lake	191	Lake	Oxbow	Humphreys
Lake Hide-A-Way	188	Reservoir	Reservoir	Pearl River
Mossy Lake	188	Lake	Oxbow	Leflore
Bailey Lake	181	Reservoir	Reservoir	Lauderdale
Swan Lake	178	Oxbow	Oxbow	Tallahatchie
Cypress Lake	178	Lake	Oxbow	Issaquena
Tennessee Lake	178	Lake	Oxbow	Issaquena
Lake Cavalier	172	Reservoir	Reservoir	Madison
Lake Lorman	171	Reservoir	Reservoir	Madison
Holmes Lake	169	Lake	Oxbow	Jefferson
Pinchback Lake	169	Lake	Oxbow	Holmes

Table 2.1. Continued.

Name	Acres	General type	Specific type	County
Lake Jackson	163	Lake	Oxbow	Washington
Lake Mohawk	157	Reservoir	Reservoir	Tippah
Lake Copiah	149	Reservoir	Reservoir	Copiah
Sixmile Lake	148	Lake	Oxbow	Leflore, Sunflower
Walnut Lake	143	Lake	Oxbow	Tunica
Big Lake	140	Lake	Oxbow	Wilkinson
Henry, Lake	134	Lake	Oxbow	Leflore
Chiwapa Reservoir Structure #1	133	Reservoir	Reservoir	Pontotoc
Butler Lake	130	Lake	Reservoir	Adams
Bailey Lake	124	Reservoir	Reservoir	Carroll
Cypress Lake	121	Lake	Oxbow	Warren
Sixmile Lake	121	Lake	Oxbow	Leflore
Woodland Lake	116	Reservoir	Reservoir	DeSoto
Artonish Lake	116	Lake	Oxbow	Wilkinson
LT-7-3 (Big Snow Lake)	116	Reservoir	Reservoir	Benton
Dixie Springs Lake	113	Reservoir	Reservoir	Pike
Hurricane Lake	111	Reservoir	Reservoir	Lincoln
Lake LaRue	111	Reservoir	Reservoir	Hinds
Suffer Brake	109	Oxbow	Oxbow	Tallahatchie
Beaver Lake	109	Reservoir	Reservoir	Lamar
Long Lake	108	Lake	Oxbow	Sunflower
Hampton Lake	107	Lake	Oxbow	Tallahatchie
Gee Lake	107	Reservoir	Reservoir	Carroll
Fitler Lake	107	Lake	Oxbow	Issaquena
Long Brake	107	Lake	Oxbow	Tallahatchie
Clarks Lake	106	Reservoir	Reservoir	Lincoln
Beaver Lake	106	Reservoir	Reservoir	Smith
Deer Lake	106	Lake	Oxbow	Washington
Six mile Lake	106	Lake	Oxbow	Tunica
Five mile Lake	104	Lake	Oxbow	Issaquena
LT-7-2 (Little Snow Lake)	104	Reservoir	Reservoir	Benton
Thornburg Lake	102	Lake	Oxbow	Adams
Sanders Lake	101	Reservoir	Reservoir	Carroll

3.0 PROJECT ACTIVITIES AND ANALYSES

3.1 QAPP

A QAPP was developed according USEPA (2001), USEPA (1999) and USEPA (2002). The purpose of the QAPP was to ensure that the data analysis was scientifically sound and defensible, and that the data used for this project were of the type, quantity, and quality required for their intended purpose. The QAPP document was received and approved by USEPA Region 4 and is provided as Appendix A.

3.2 Meetings

The LRNTF was comprised of individuals from US Army Engineer Research and Development Center, MDEQ, USEPA Region 4, US Department of Agriculture (USDA) Sedimentation Laboratory (Oxford, Mississippi) and the Natural Resources Conservation Service (NRCS). Meetings and discussions with the LRNTF indicated that lake and reservoir criteria should have the following features:

1. Criteria should be or be linked to numeric values of TP and TN.
2. Criteria should be directly linked to fishable, swimable uses.
3. Criteria should be effects based. That is they should indicate nutrient conditions that are associated with adverse effects such as nuisance algae blooms, fish kills or impaired fish and/or wildlife populations.
4. Criteria should reflect the natural productive capacity of Mississippi waters.
5. Criteria should take into account lake fisheries management activities such as fertilization.

3.3 Nutrient Criteria Approaches and Lake/Reservoirs Classes or Categories Being Used by other States

State and federal nutrient criteria were compiled from state WQS documents and USEPA nutrient criteria guidance available on state and USEPA websites. This information is intended to supplement state criteria that might not be available on state websites, rather than provide an exhaustive review of state and federal development of nutrient criteria. USEPA's website (http://www.epa.gov/waterscience/standards/states/) was used to obtain nutrient and eutrophication-related criteria from WQS regulations for 13 southern states. If regulations did not discuss nutrients, TP, TN, or Chl-a, the responsible state agency was contacted to determine if a state had numeric nutrient criteria. State WQS for nutrients and related parameters are summarized for the southern tier of states in Table 3.1.

Table 3.1. Numeric Standards adopted by southern states and USEPA guidance criteria for related ecoregions.

Parameter	Source	State or Ecoregion	Standard or Guidance
Chl-a (µg/L)	State Criteria	AL	5 – 27
		GA	5 – 27
		NC	15 or 40
		SC	10 or 15
	USEPA Ecoregion Guidance	IX	4.93
		X[1]	--
		XI[2]	2.79
		XII	2.6
TP (µg/L)	State Criteria	AR	50
		GA	91 – 2022
		SC	20 – 90
	USEPA Ecoregion Guidance	IX	20
		X[1]	--
		XI[2]	8
		XII	10
TN (mg/L)	State Criteria	GA	3 or 4
		SC	0.35 or 1.5
	USEPA Ecoregion Guidance	IX	0.36
		X[1]	--
		XI[2]	0.46
		XII	0.60

1. USEPA criteria for Ecoregion X have not yet been developed.
2. USEPA Ecoregion XI is not found in Mississippi (it is found in neighboring Arkansas and Alabama).

USEPA’s guidance documents were reviewed to obtain USEPA nutrient ecoregion criteria for the three ecoregions within Mississippi (Ecoregions 9 and 12; USEPA 2000 b and 2000c) and one from neighboring Alabama and Arkansas (Ecoregion 11).

Four Region 4 states have approved numeric criteria for Chl-a, three states have numeric criteria for TP, and two states have numeric criteria for TN (Table 3.1). Alabama and Georgia have developed numeric criteria for specific lakes, North Carolina for specific designated uses (trout waters and non-trout waters), South Carolina for ecoregions within the state, and Arkansas has nutrient guidance for the entire state.

3.4 Literature Review of Relationships Between Nutrients and Biological Endpoints

A search of the literature revealed 2,844 papers discussing nutrients in lakes or reservoirs. Papers were reviewed if the lakes were within the southern tier of states (AR, AL, FL, GA, KY, LA, MS, NC, OK, SC, TN, TX). Of approximately 70 reports and journal articles reviewed, 53 sources described quantitative or qualitative relationships between nutrients and biological endpoints. A total of 149 quantitative equations or qualitative relationships linking biological endpoints to water quality parameters were identified. A summary of the information in each of these relationships was provided to MDEQ (FTN 2003) and is included herein as Appendix B.

3.4.1 Nutrients and Chl-a

Eighteen univariate quantitative equations were compiled describing relationships between phosphorus and Chl-a. Figure 3.1 shows these 18 equations plotted on one graph as well as USEPA Chl-a and TP guidance criteria for Nutrient Ecoregions in Mississippi, neighboring Arkansas and Alabama and the nutrient criteria approved by USEPA for Georgia and South Carolina (see Table 3.1). The plotted lines from the 18 equations represent the range of empirical Chl-a phosphorus relationships found in the literature review. The plotted points indicate how USEPA guidance criteria and state WQS compare to these empirical relationships. Figure 3.1 indicates that the USEPA guidance and South Carolina criteria are in general agreement with published empirical relationships while Georgia criteria show less agreement.

Of the 70 reports and journal articles reviewed, 12 sources provided quantitative or qualitative relationships among suspended sediments and nutrients or biological endpoints. These sources describe primarily the relationships between Secchi depth and parameters such as Chl-a or suspended sediments. A summary of the information in each of these relationships is provided in Appendix B (FTN 2003).

The information summarized in the literature review and in Figure 3.1 shows a general relationship between nutrients (particularly TP) and primary productivity as indicated by Chl-a concentrations. However, there is considerable uncertainty associated with these relationships. In general, TP concentrations typically predict Chl-a concentrations (or vice versa) within a factor of 3 to 5. The literature review indicated a much weaker relationship between TN and TP or TN and Chl-a.

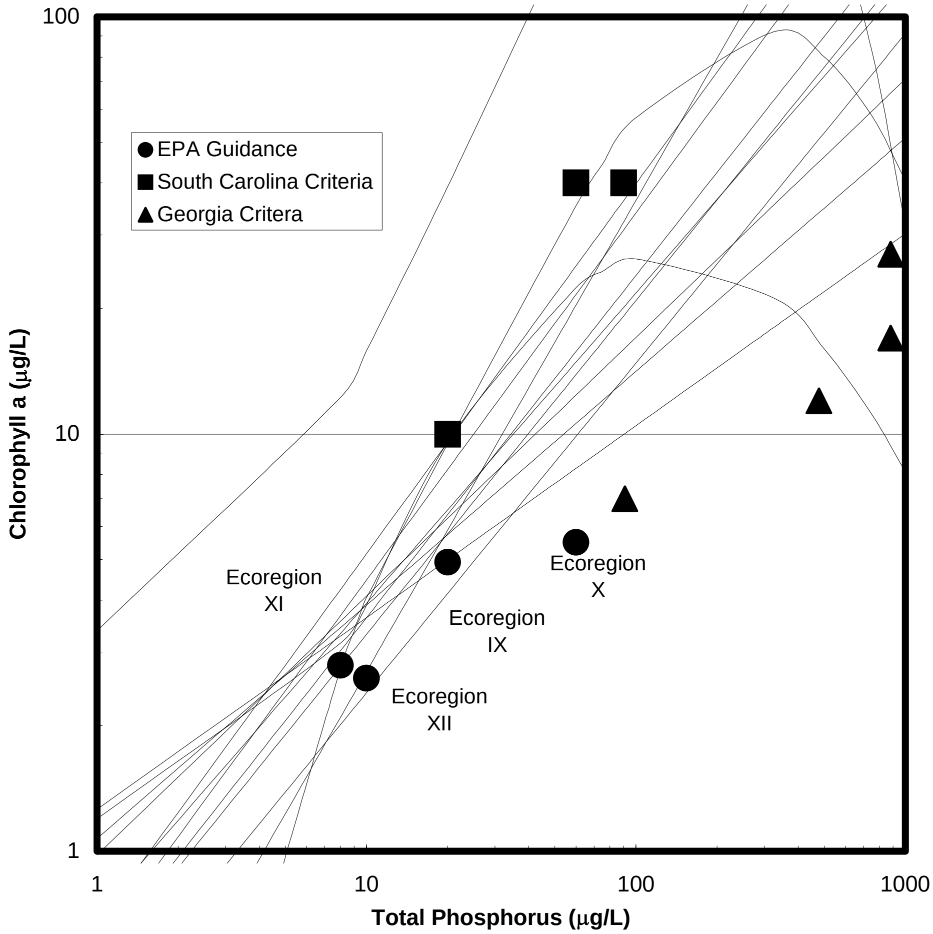


Figure 3.1. Plots of 18 quantitative Chl-a and phosphorus relationships compiled from the literature.

3.4.2 Nutrient and Fisheries

Of the literature identified, 354 papers dealt with fish production or fish communities. The literature clearly establishes a link between primary productivity and fish production (e.g., Jones and Hoyer 1982; Oglesby 1977). However, it should be noted that there is considerable variability in this relationship due to factors such as sampling variability, habitat quality, harvest, and recruitment. Fish production can be limited by primary productivity that is, in turn, limited by low nutrient concentrations. A number of researchers have argued that reversal of cultural eutrophication in reservoirs can have deleterious effects on warmwater sport fisheries by reducing the level of primary productivity on which productivity at higher trophic levels depends (Axler et al. 1988; Maceina et al. 1996; Ney et al. 1990; Ney 1996; Yurk and Ney 1989). Maceina et al. (1998) assessed the potential impacts of oligotrophication on reservoir fisheries and attempted to define target levels of primary productivity needed to support quality fisheries. They examined the relationships between primary productivity and the quality of crappie and black bass fisheries in 32 Alabama impoundments and concluded that Chl-a concentrations of 10 to 15 mg/L should not be detrimental to (i.e., should not limit) crappie and black bass fisheries in southern US reservoirs. The Alabama Department of Environmental Management (ADEM) has used these findings to support Chl-a based nutrient criteria in that state's reservoirs (ADEM 2006). While Maceina et al. (1998) identified Chl-a levels that do not limit (in the sense of nutrient limitation) fishery production, they did not identify Chl-a levels that begin to impair fishery production. Chl-a levels that begin to impair fisheries (by inducing phenomena associated with eutrophication such as dissolved oxygen depletion, toxic algae blooms, etc.) can be expected to be somewhat higher than levels that do not limit fisheries due to nutrient limitation.

4.0 NUTRIENT CONDITIONS IN MISSISSIPPI LAKES AND RESERVOIRS

Conditions of Mississippi lakes and reservoirs were assessed by sampling 48 lakes and reservoirs greater than 500 acres during the Fall of 2002, Spring, Summer, and Fall of 2003, and Spring, Summer, and Fall of 2004. Sampling was conducted according to a QAPP developed for the lake and reservoir sampling effort, submitted to and approved by, USEPA Region 4 Quality Assurance/Quality Control (QA/QC) staff. After QA/QC review MDEQ released the data for analysis. Waterbodies included in this analysis are listed in Table 4.1. Analytical method and detection limits for each analyte are presented in Table 4.2.

Table 4.1. Summary of lakes greater than 500 acres sampled from November 2002 through November 2004.

Waterbody Name	Sampling Period			Waterbody Type	Fertilized?
	2002	2003	2004		
Aberdeen Lake	X	X	X	Large reservoir	
Aliceville Park Lake	X	X	X	Reservoir	
Arkabutla Reservoir	X	X	X	Large reservoir	
Bay Springs Lake	X	X	X	Large reservoir	
Bee Lake	X	X	X	Oxbow	
Bluff Lake	X	X	X	Reservoir	
Columbus Lake	X	X	X	Large reservoir	
Dalewood Shore Lake	X	X	X	Reservoir	
Desoto Lake	X	X	X	Oxbow	
Eagle Lake	X	X	X	Oxbow	
Elvis Presley Lake	X	X	X	Reservoir	Yes
Enid Reservoir	X	X	X	Large reservoir	
Flint Creek Reservoir	X	X	X	Reservoir	
Geiger Lake	X	X	X	Reservoir	Yes
Grenada Reservoir	X	X	X	Large reservoir	
Hard Cash Lake	X	X	X	Oxbow	
Horn Lake	X	X	X	Oxbow	

Table 4.1. Continued.

Waterbody Name	Sampling Period			Waterbody Type	Fertilized?
	2002	2003	2004		
Horseshoe Lake	X	X	X	Oxbow	
Kemper County Lake	X	X	X	Reservoir	Yes
Lake Beulah	X	X	X	Oxbow	
Lake Bogue Homa	X	X	X	Reservoir	
Lake Bolivar	X	X	X	Oxbow	
Lake Chotard	X	X	X	Oxbow	
Lake Ferguson	X	X	X	Oxbow	
Lake Lamar Bruce	X	X	X	Reservoir	Yes
Lake Lee	X	X	X	Oxbow	
Lake Lincoln	X	X	X	Reservoir	Yes
Lake Mary	X	X	X	Oxbow	
Lake Tangipahoa	X	X	X	Reservoir	Yes
Lake Washington	X	X	X	Oxbow	
Lake Whittington	X	X	X	Oxbow	
Little Black Creek Res	X	X	X	Reservoir	
Moon Lake	X	X	X	Oxbow	
Natchez St. Park Lake	X	X	X	Reservoir	Yes
Okatibbee Reservoir	X	X	X	Large reservoir	
Pickwick Lake	X	X	X	Large reservoir	
Roebuck Lake	X	X		Oxbow	
Ross Barnett Res.	X	X	X	Large reservoir	
Sardis Reservoir	X	X	X	Large reservoir	
Tchula Lake		X	X	Oxbow	
Tenn-Tom Pools	X	X	X	Reservoir	
Trace State Park Lake	X	X	X	Reservoir	Yes
Tunica Cutoff	X	X	X	Oxbow	
Turkey Fork Creek Res	X	X	X	Reservoir	Yes
Wasp Lake	X	X	X	Oxbow	
Wolf Broad Lake	X	X	X	Oxbow	

“X” indicates that sampling was performed for the period indicated.

Table 4.2. Analytical methods and detection limits used in lake and reservoir sample analyses.

USEPA Analysis Method	Analyte	Method Quantitation Limit
415.2	TOC	1 mg/L
410.4	COD	10 mg/L
365.4	TP	0.01 mg/L
351.2	TKN	0.1 mg/L
350.1	Ammonia	0.1 mg/L
353.2	Nitrate + Nitrite	0.02 mg/L
310.1	Total Alkalinity	10 mg/L
325.2	Chloride	1 mg/L
160.2	Total Suspended Solids	4.0 mg/L
130.1	Hardness	3.0 mg/L
--	Chl-a	0.001 mg/L

4.1 Data Analysis

4.1.1 Objectives and Approach

The primary objective of the data analysis was to evaluate the relationships among parameters to determine if the data indicated "natural" classifications other than large reservoirs, reservoirs, and oxbows. Therefore, as a starting point, the waterbodies were classified as "large reservoirs" (greater than 2000 acres), "reservoirs" (500 to 1999 acres) or "oxbows." The data analysis involved visual examination of patterns among variables and sampling stations. The focus of the analysis was on variables most directly related to nutrient criteria, that is, TP, TN, SD, and Chl-a.

No formal classification procedures such as cluster analysis or descriminant functions analysis were performed. All statistical computations were performed using Systat version 9.01 (Systat 1998).

The steps in the data analysis were as follows:

- Evaluate whether large reservoirs, reservoirs and oxbows were a logical starting point for classifying the large lakes (i.e., Do TP, TN, SD, and Chl-a and other water quality parameters show clear patterns among large reservoirs, reservoirs and oxbows?).
- Assess seasonal differences among the waterbody types to help determine the appropriate season for assessing nutrient status in the large lakes.
- Evaluate water quality characteristics and properties that are relevant to nutrient criteria in Mississippi lakes and reservoirs.

The first step in the data analysis was to evaluate relationships among variables and sampling locations using principal components analysis (PCA). Analysis of the distribution of raw data indicated approximately log normal distributions for all variables except pH. Therefore, all data values except pH were log (10) transformed before analysis. Principle components were calculated using the varimax rotation and the variance associated with each principal component was evaluated visually. Parameter values for each sampling station on each sampling date were converted to principal component scores for evaluating relationships among sampling locations.

PCA results were evaluated to:

- Determine the structure of the overall data set by identifying groups of co varying variables (i.e., factors);
- Identify groupings of sampling stations (in variable space) to evaluate the validity of lake type categories (e.g., reservoir, large reservoir, oxbow); and
- Identify other possible waterbody classifications consistent with the groupings of sampling stations.

Although samples from the surface (1 ft depth), mid depth, and bottom (1 ft from the bottom) were collected from each station on each sampling date and analyzed, the data analysis focused entirely on the surface samples. This is because, due to the interaction between light penetration, nutrients, and Chl-a, surface samples are most likely to reflect the interactions between nutrients, primary production, and clarity.

4.2 Data Analysis Results and Discussion

4.2.1 Variation Among Waterbody Types (Large Reservoirs, Reservoirs, and Oxbows)

Variation among large reservoirs, reservoirs and oxbows in TP, TN, SD, and Chl-a is illustrated in Figure 4.1. The box and whisker plots in Figure 4.1 indicate that there are clear differences in these parameters among these waterbody types. These results indicate that a classification consisting of large reservoirs, reservoirs, and oxbows is a valid means of capturing significant variation in TP, TN, SD, and Chl-a and is a valid starting point for classification of Mississippi lakes and reservoirs.

4.2.2 Seasonal Variation in TP, TN, SD, and Chl-a

Seasonal variation in reservoirs and oxbows in TP, TN, SD, and Chl-a is illustrated in Figures 4.2 and 4.3, which indicate relatively little seasonal variation in TP with highest SD and Chl-a values in the summer. These results indicated that nutrient criteria development should be based on data collected during the summer because changes in the response variables Chl-a and SD were greatest during this season.

4.2.3 Principal Components Analysis

Results of the PCA analysis are presented in Table 4.3. The analysis used data from surface samples collected from June 2003 through September 2004. The results showed that, after rotation, the first 3 principal components accounted for 71% of the total variance (21, 27, and 23% in principal component PC1, PC2, and PC3, respectively).

Relationships Among Variables

Total organic carbon (TOC), chemical oxygen demand (COD), total kjeldahl nitrogen (TKN), and Chl-a showed high correlations with PC1; Conductivity, total alkalinity, chloride, and hardness showed high correlations with PC2; SD, TP, total suspended solids (TSS) and turbidity showed high correlations with PC3 (Table 4.3). These results indicated that over 70 % of the variance in the surface data collected in the summer was accounted for by 3 PC axes that

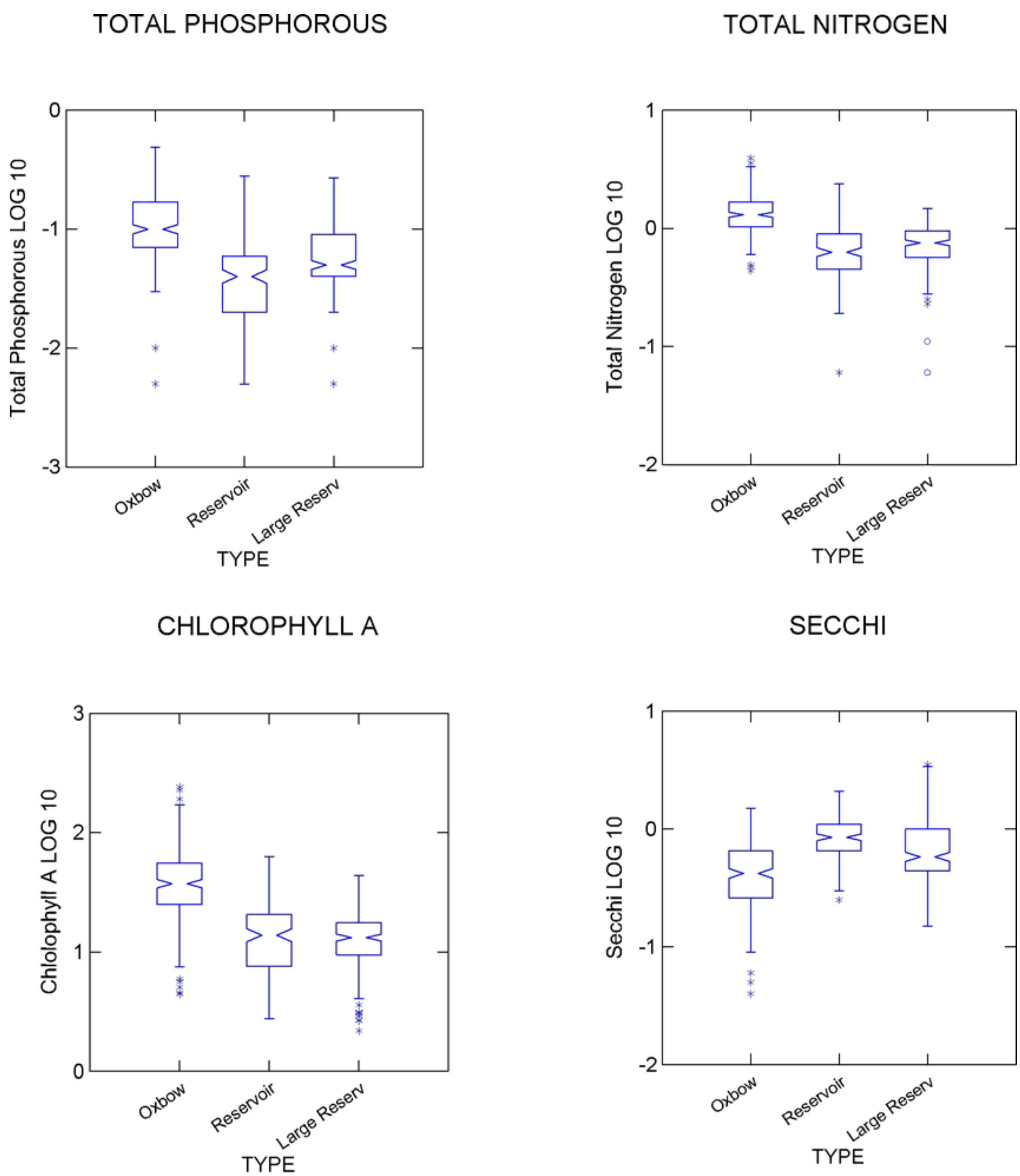


Figure 4.1. Box and whisker plots of TP, TN, SD, and Chl-a in large reservoirs, reservoirs and oxbows in surface samples collected June 2003 through September 2004.

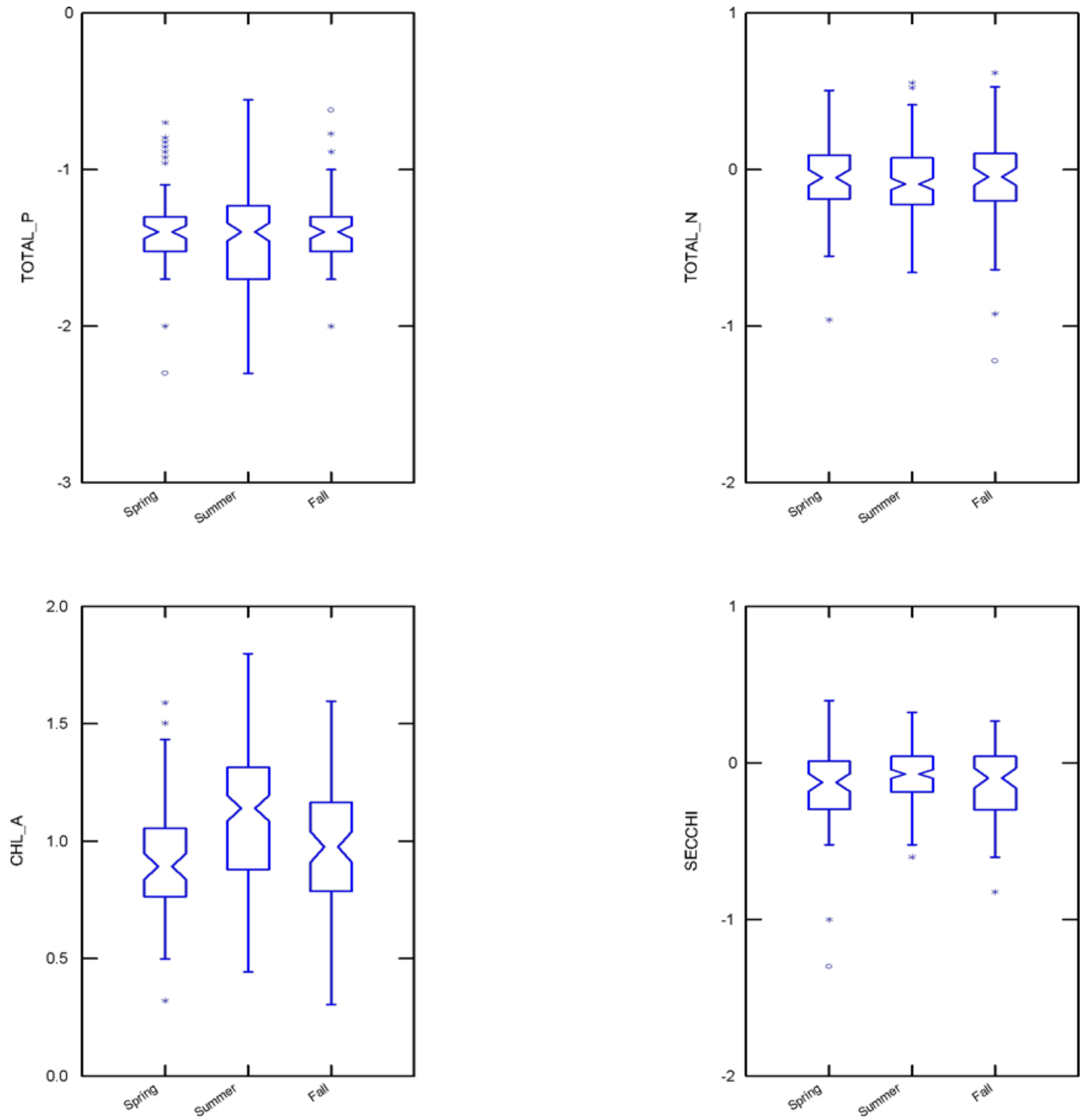


Figure 4.2. Box and whisker comparison of TP, TN, SD, and Chl-a in reservoirs during the spring summer and fall seasons.

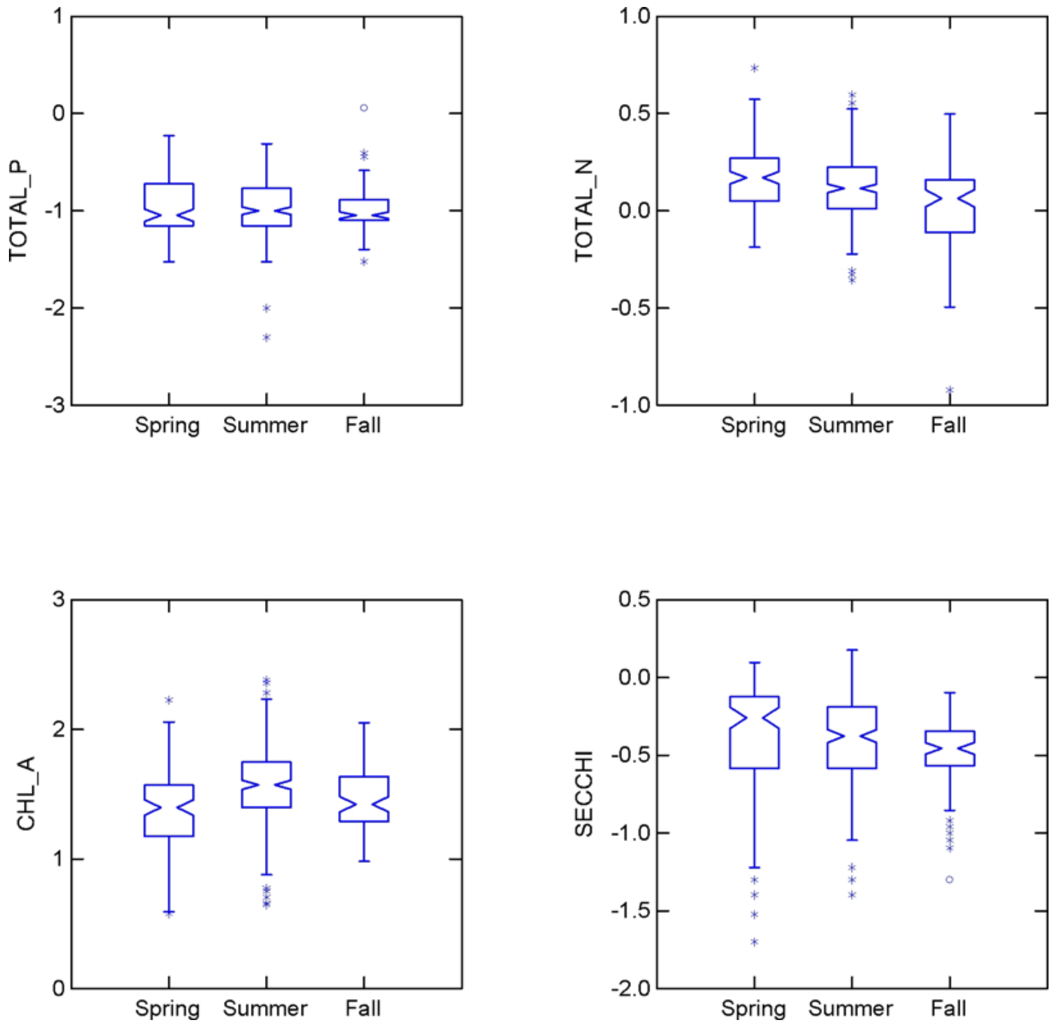


Figure 4.3. Box and whisker plots of TP, TN, SD, and Chl-a from surface samples in oxbows collected during the spring, summer, and fall seasons.

showed a clear pattern of variable loadings. For this data set, each of the 3 principal axes can be readily interpreted by examining, which variables load onto each axis. These interpretations are summarized as follows:

- PC1 had high loadings from TOC, COD, TKN, and Chl-a. This axis represented increasing primary productivity and organic content.
- PC2 had high loadings from conductivity, total alkalinity, chloride, and hardness. This axis represented increasing ionic strength.
- PC3 showed high loadings from SD, TP, TSS, and turbidity. This axis represented increasing TP and decreasing water clarity.

Table 4.3. Summary of results of principal components analysis on surface samples collected June through September.

Variable	PC1	PC2	PC3
Conductivity	0.050	0.976	0.093
Total alkalinity	0.096	0.932	0.160
Chloride	0.076	0.773	0.113
Hardness	0.056	0.961	0.130
COD	0.772	0.009	0.193
TOC	0.866	-0.006	0.173
TKN	0.727	0.262	0.363
Chl-a	0.706	0.437	0.328
TP	0.442	0.303	0.672
SD	-0.260	-0.116	-0.881
TSS	0.225	0.213	0.771
Turbidity	0.150	0.015	0.927
Percent of Total Variance Explained	21	27	23
Interpretation of PC Axis	Overall productivity	Ionic strength	TP and clarity

The patterns of variable loadings on the 3 axes (Table 4.3) and the scatter plots provided in Figures 4.4 and 4.5 indicate that TP covaries with SD ($R^2 = 0.48$) but not with Chl-a ($R^2 = 0.18$). Therefore the best nutrient related predictor of Chl-a in the Mississippi data set was TKN or TN rather than TP (Figure 4.5). This result suggests that in Mississippi lakes and reservoirs, the causative variables (TP and TN) and response variables (SD and Chl-a) are not as tightly linked as might be expected in a classical limnological setting. For example, Carlson's trophic state index (TSI, Carlson 1977), a widely used indicator of trophic condition in lakes and reservoirs, depends on very strong correlations among SD, TP, and Chl-a. The likely cause of this decoupling in Mississippi waterbodies is the presence of non-algal turbidity that characterizes many Mississippi lakes and reservoirs. The implications of this partial decoupling among causative and response variables for setting nutrient criteria are discussed below.

Light Attenuation in Mississippi Lakes and Reservoirs

To illustrate the prevalence of non-algal turbidity in Mississippi lakes and reservoirs, the relationships among light attenuation (as indicated by SD), TP and Chl-a was examined using response ratios and "residual SD" (Hern et al. 1981). The response ratio (RR) is the ratio of Chl-a to TP. Because this value is known to vary seasonally (Hern et al. 1981) all RR values were computed using summer data. At a RR of approximately 1.0 or above, all of the TP in the system is theoretically associated with cellular Chl-a (Strickland 1960, cited in Hern et al. 1981). Therefore, as RR values decrease below 1.0, more of the TP pool is extracellular and associated with non-algal turbidity.

Residual SD uses the following strong relationship ($r = 0.93$) between SD and Chl-a found by Carlson (1977):

$$\ln(SD) = 2.04 - 0.68\ln(Chl\text{-}a)$$

This relationship forms part of the TSI (Carlson 1977) that was based on lakes that were relatively free of non-algal related particles. Therefore, SD predicted using this equation represents the SD at low levels of non-algal turbidity. Departures of actual SD measurements from this predicted value indicate light attenuation due to non-algal turbidity. Therefore the level of non-algal light limitation can be measured by evaluating the difference between the observed SD and the predicted SD based on the amount of Chl-a present.

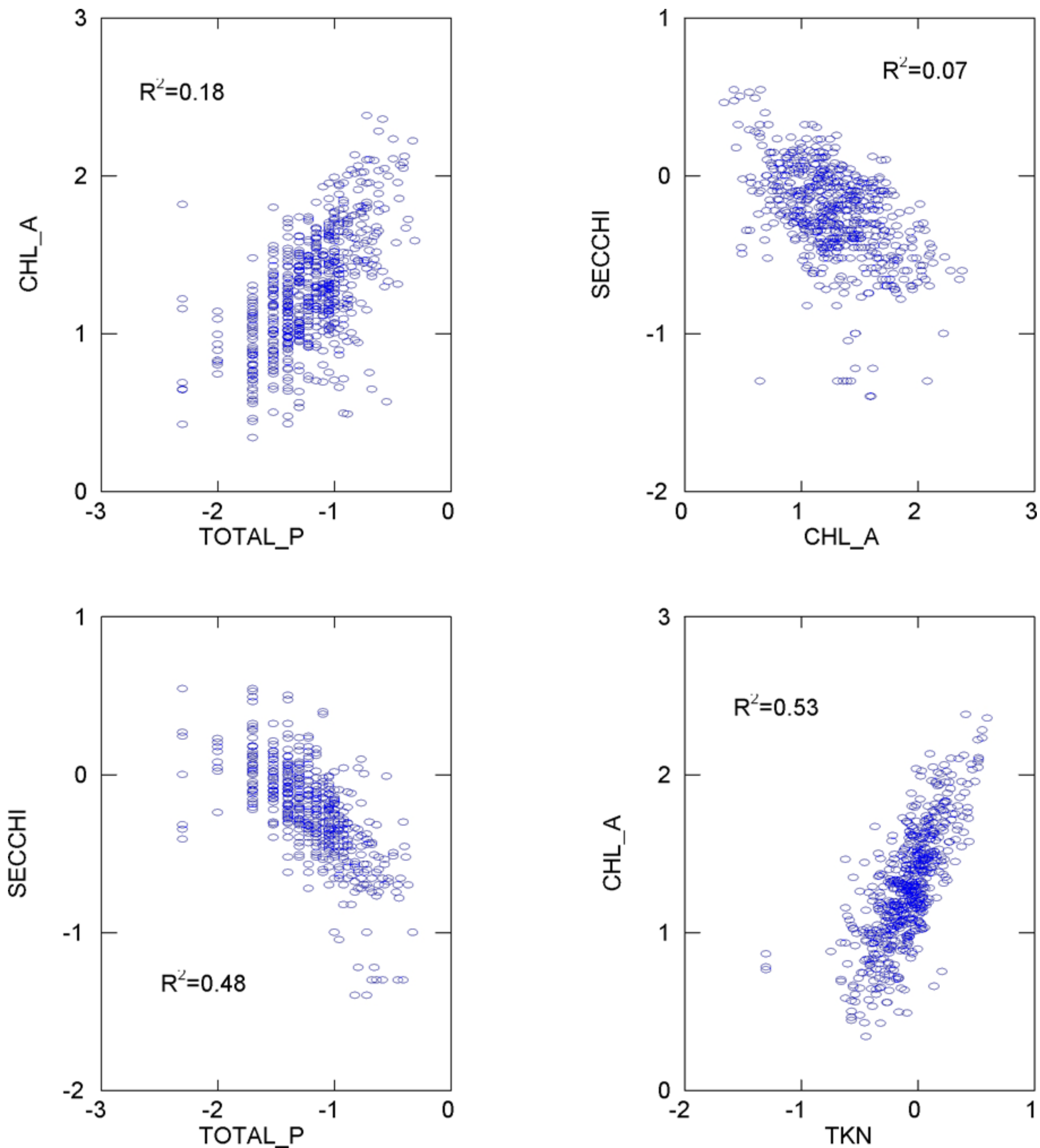


Figure 4.4. Scatter plots showing relationships among TKN, TP, SD, and Chl-a.

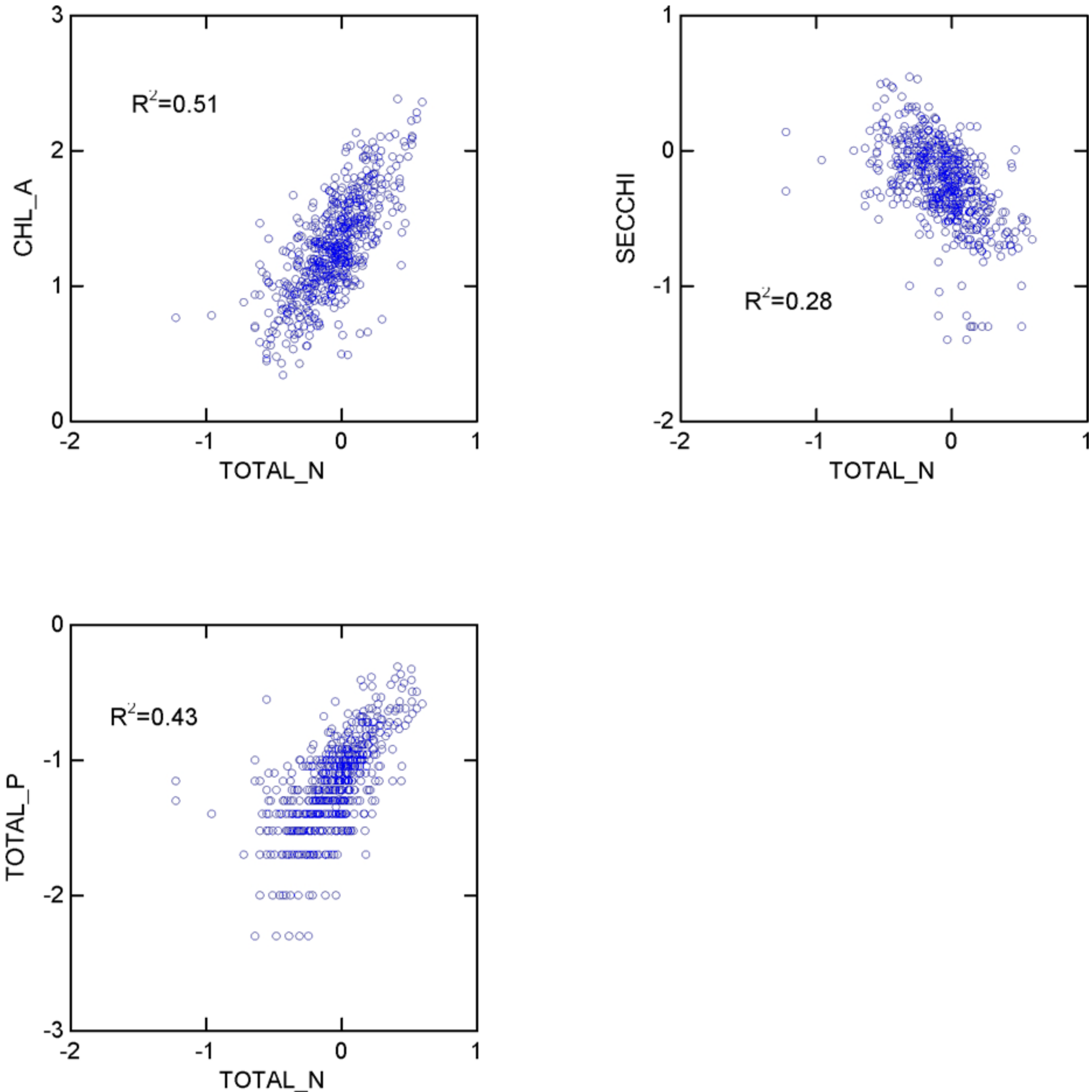


Figure 4.5. Scatter plots of TN vs. Chl-a, SD, and TP.

This quantity is referred to a "Residual SD" (RS) and is computed as:

RS = PS – OS

Where RS = residual SD, which is an index of non-Chl-a related light attenuation.

PS = predicted SD determined by substituting the Chl-a value into Carlson's regression equation.

OS = observed SD value.

As RS increases, light attenuation due to non-algal turbidity increases. Since low RR can also be caused by high amounts of extracellular phosphorus (e.g., phosphorus associated with clays) a plot of RR vs. RS for each sampling point on each sampling date can indicate the prevalence of light limitation due to non-algal turbidity among the sampling locations.

A plot of RR vs. RS is provided in Figure 4.6. Hern et al. (1981) suggest that RS values greater than 0.46 and RR values less than 0.5 indicate the influence of non-algal turbidity on light attenuation. Examination of Figure 4.6 indicates that a large proportion of the data points from the MDEQ data set show RS values greater than 0.46 and/or RR values less than 0.5. This finding indicates that the presence of relatively high levels of non-algal turbidity is a general property of Mississippi lakes and reservoirs. This property is a result of geomorphology and soil types prevalent in Mississippi.

This finding also indicates that the effects of nutrients on Mississippi lakes and reservoirs cannot be inferred from generalizations and relationships based on waterbodies that are dissimilar with respect to factors affecting light attenuation. USEPA's Nutrient Criteria Technical Guidance Manual (USEPA 2000a) relies heavily on Carlson's TSI approach to interpret measurements of nutrients, Chl-a, and water clarity in lakes and reservoirs. The TSI approach is a well developed and useful approach to assessing nutrients and their effects, but it relies on strong correlations among SD, TP, and Chl-a. The analyses presented above shows that recommendations or conclusions based on Carlson's TSI approach should be used cautiously

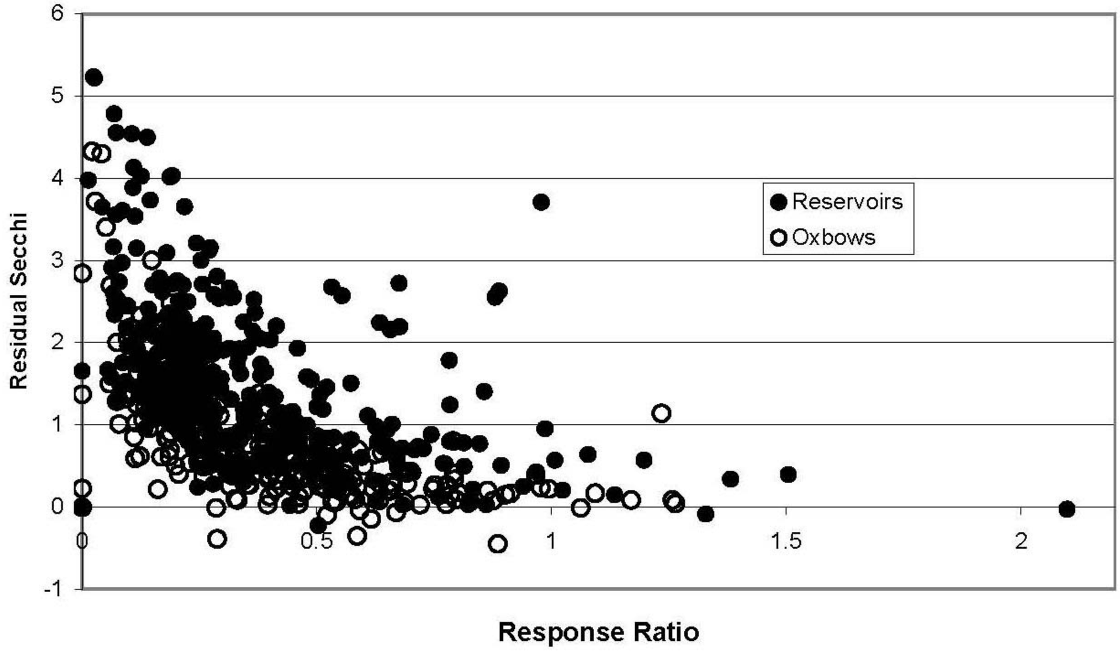


Figure 4.6. Plot of Residual SD and RR for Mississippi lakes and reservoirs.

with Mississippi lakes and reservoirs because these correlations are not present. For example, USEPA (2000a, pg. 76) states, "The light limited condition of hypereutrophy (TSI 70, TP of 0.1 mg/L) is characterized by dense algal and macrophyte communities and should be considered undesirable under all circumstances. It is recommended that no criterion ever be set higher than this value, regardless of designated use, unless it can be demonstrated that the natural reference condition is high."

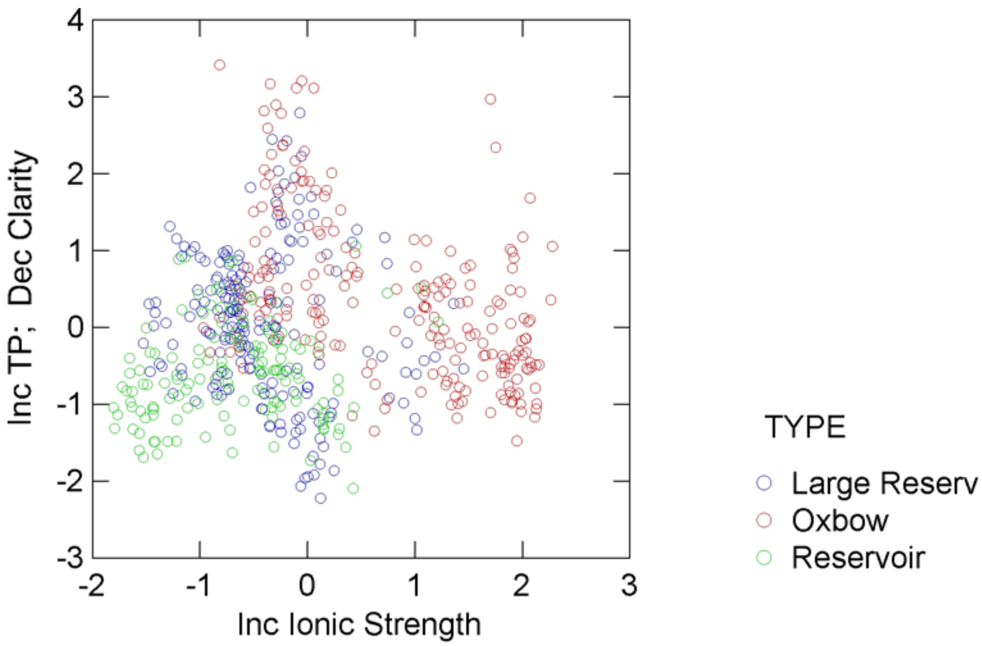
The recommendation that no TP criterion be higher than 0.1 mg/L is probably valid when the assumptions of Carlson's TSI are met but it is not, in general, valid for Mississippi lakes and reservoirs. In addition, although MDEQ has not identified "reference" lakes or reservoirs, the information presented in Figure 4.6 suggests a high natural reference condition for non-algal turbidity. *Therefore the USEPA recommendation that TP criteria, based on Carlson's TSI, never exceed 0.1 mg/L should not apply to Mississippi lakes and reservoirs.*

Relationships Among Sampling Locations (Lake Classification)

The PCA analysis allowed an examination of the data for potential “natural” classifications in addition to the reservoir/large reservoir/oxbow classification used as a starting point. This evaluation involved converting the raw data values from each sampling location on each sampling date into PC scores. The PC scores can then be plotted on each PC axis resulting in a scatter plot using any two or three PCs as axes. A scatter plot using PC1 and PC2 provides a view of how the data set maps onto space defined by overall productivity (PC1) vs. ionic strength (PC2); A scatter plot using PC1 vs. PC3 provides a view of how the data map onto space defined by overall productivity (PC1) and TP/water clarity. All three axes can be combined to form a 3 dimensional view of the data set. These scatter plots, presented in Figures 4.7 and 4.8 can then be examined for indications of natural groupings within the whole data set or for sub groupings within the preliminary reservoir/large reservoir/oxbow classification.

Examination of Figures 4.7 and 4.8 indicates only two distinct groups present in the data set. The smaller of the two groups is made up of a subset of oxbow lakes.[3] The remaining larger group is made up of a combination of oxbows, reservoirs, and large reservoirs. The scatter plots in Figure 4.7 and the three-axis plot in Figure 4.8 indicate that there may be a gradation in waterbody type from “pure” reservoir to a mixture of reservoirs and large reservoirs to a mixture of reservoirs, large reservoirs, and oxbows to “pure” oxbows. This pattern could form the basis of more refined classification such as that summarized in Table 4.4. Box and whisker plots of the waterbody classes given in Table 4.4 are provided in Figure 4.9. These plots show that there are clear differences in TP, TN, SD, and Chl-a among these alternative waterbody classes. It should be noted that there is no formal process for identifying sub groups within the PCA scatter plots and that there is no unique “best” classification. The primary result of the analysis is that while there is no clear alternative classification beyond “oxbows” and “reservoirs”, the data could support other classifications that are based on less distinct overlapping groups such as the “reservoir/large reservoir/oxbow” and “reservoir/large reservoir” groups identified in Table 4.4.

[3] Closer examination of this distinct set of oxbows shows that they all lie in the western Delta along the Mississippi River while the “reservoir like” oxbows are located in the central and eastern portions of the Delta.



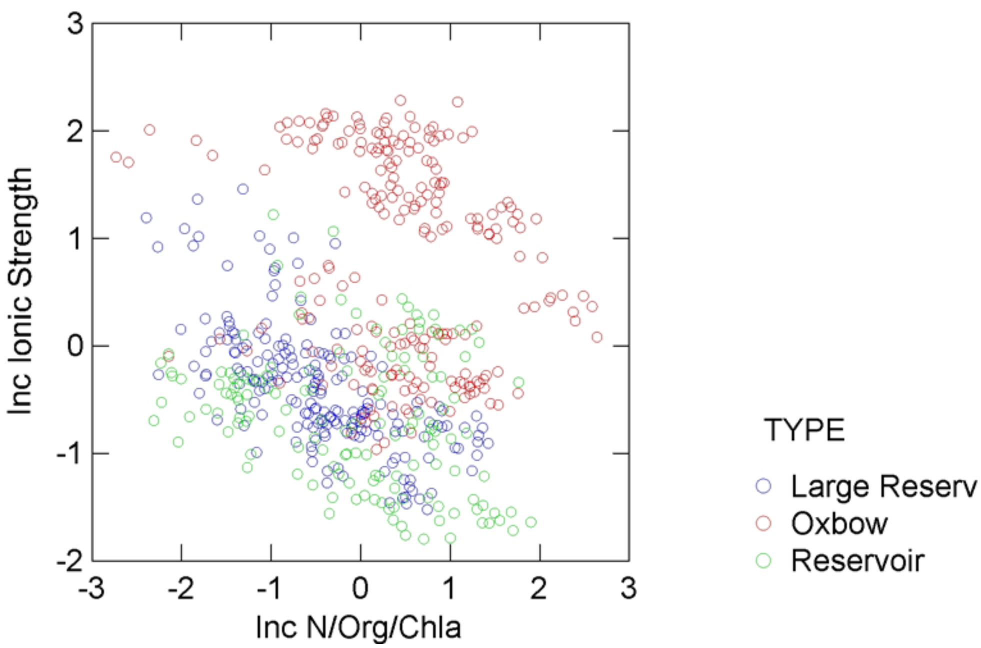


Figure 4.7. PCA plots: Upper figure PC1 (overall productivity) vs. PC2 (ionic strength); Lower figure – PC2 (ionic strength) vs. PC3 (TP/clarity).

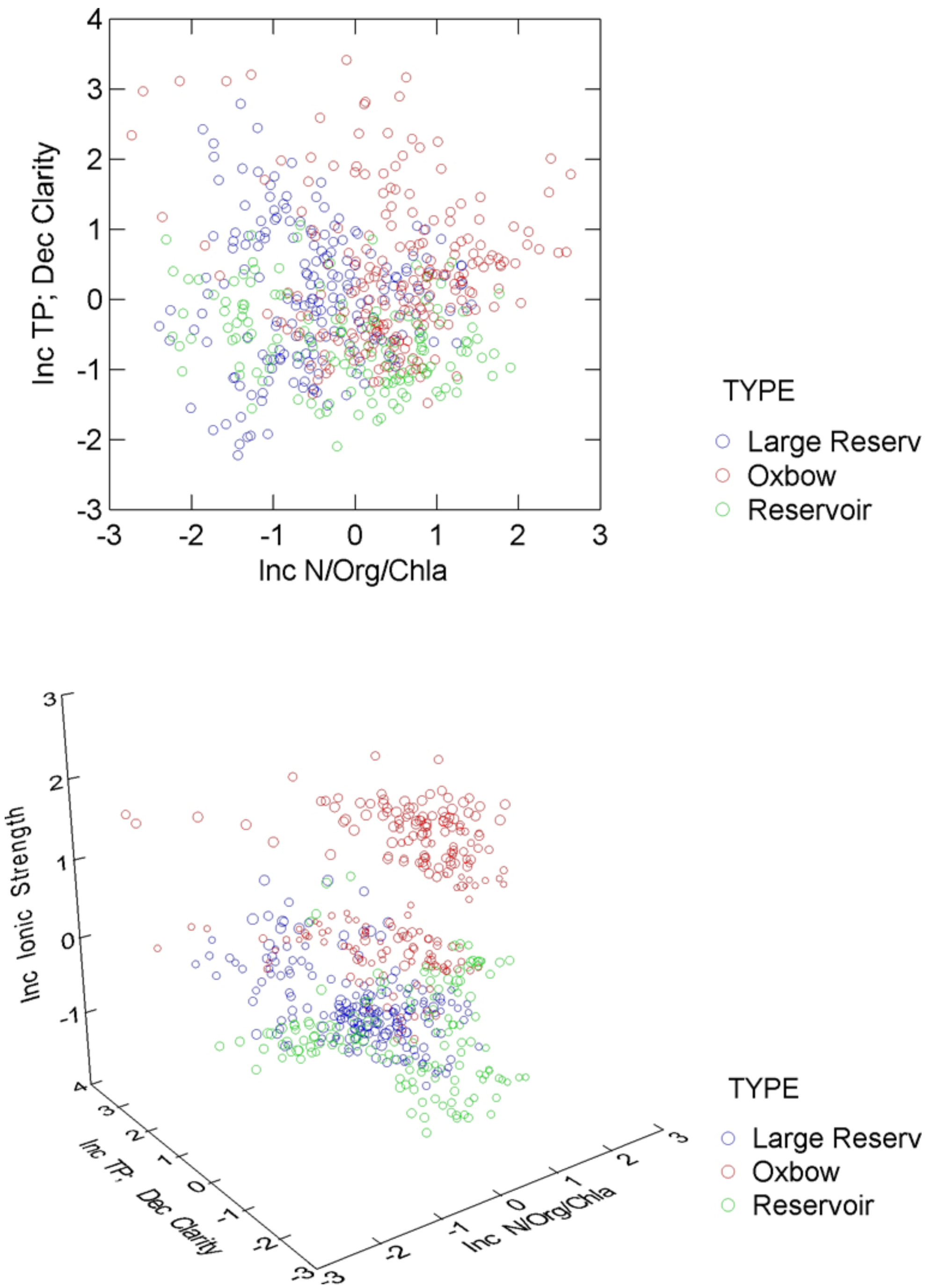


Figure 4.8. PCA plots: Upper figure PC1 (overall productivity) vs. PC3 (TP/clarity); Lower figure – PC1 (overall productivity) vs. PC2 (ionic strength) vs. PC3 (TP/clarity).

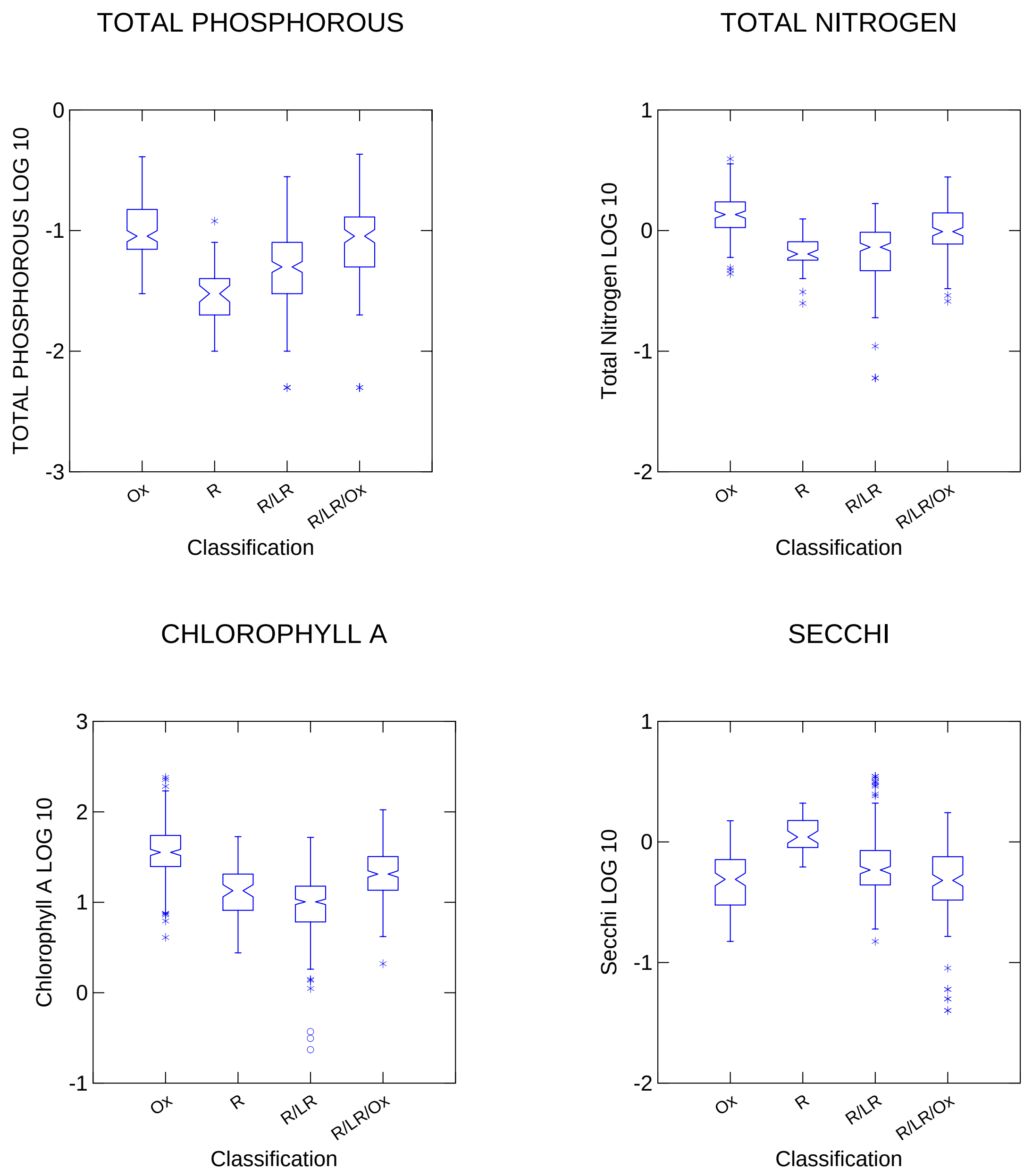


Figure 4.9. Box and whisker comparison of TP, TN, SD, and Chl-a in alternative classification described in text (OX = Oxbow; R = Reservoir; R/LR = Reservoir/Large Reservoir; R/LR/OX = Reservoir/Large Reservoir/Oxbow).

Table 4.4. Alternative waterbody classification based on evaluation of PCA scatter plots.

Oxbow	Reservoir/Large Reservoir/Oxbow	Reservoir/Large Reservoir	Reservoir
Beulah	Aliceville Pool	Aberdeen	Dalewood Shores
Chotard	Bogue Houma	Arkabutla	Bluff
DeSoto	Natchez State Park	Bay Spring	Elvis Presley
Eagle	Trace	Enid	Flint Creek
Ferguson	Bee	Grenada	Gieger
Horn	Horseshoe	Okatibee	Kemper County
Lee	Wasp	Ross Barnett	Lamar Bruce
Mary	Wolf Broad	Lamar Bruce	Little Black
Tunica	Hard Cash	Lincoln	Turkey
Washington	Columbus	Tenn-Tom Pool A	
Whittington	Pickwick	Tenn-Tom Pool B	
Bolivar*	Bolivar*	Tenn-Tom Pool C	
Moon*	Moon*	Tenn-Tom Pool D	
Bluff*	Bluff*	Tenn-Tom Pool E	
	Tangipahoa*	Tangipahoa*	

*Asterisks indicate waterbodies having sampling locations that are placed in 2 different groups.

4.3 Data Analysis Conclusions

The analysis of water quality data collected from Mississippi reservoirs/large reservoirs and oxbows during 2002 through 2004 indicates the following:

1. Sampling for nutrient related issues should take place during June through September;
2. Sampling data support the initial classification of reservoirs, large reservoirs, and oxbows used by MDEQ as well as modifications of the initial classification;
3. Much of the variation (70%) in the water quality parameters can be explained by 3 independent factors: Water clarity/TP, ionic strength, and primary productivity/organic content;
4. Conclusions based on Carlson’s TSI (Carlson 1977) are not valid for Mississippi lakes and reservoirs because TP and SD are only weakly correlated with Chl-a;
5. Light limitation due to non-algal turbidity resulting from geomorphology and soil type is a general property of Mississippi lakes and reservoirs; and
6. USEPA’s recommendation that TP criteria not exceed 0.1 mg/L based on Carlson’s TSI should not apply to Mississippi lakes and reservoirs because TSI approaches are not, in general, valid for Mississippi lakes and reservoirs.

5.0 NUTRIENT CRITERIA DEVELOPMENT

Nutrient concentrations, *per se*, (with the exception of unionized ammonia toxicity and the human health nitrate criterion of 10 mg/L N) convey little information about the condition of aquatic ecosystems or their capacity to support designated uses. It is the biological responses to nutrient concentrations that are relevant in aquatic ecosystems. Therefore, the preferred approach for the development of nutrient criteria was to develop effects-based criteria that focus on the linkage between nutrient concentrations and impairment of designated uses. Numeric criteria were considered for both causative (phosphorus and nitrogen) and response (Chl-a and clarity) variables associated with the prevention and assessment of eutrophic conditions. These nutrient criteria should reflect local conditions and protect specific designated uses as described in the USEPA Technical Guidance Manuals (USEPA 2000, 2001). In addition to an effects-based approach to the development of nutrient criteria, other scientifically defensible methods and appropriate water quality data were considered.

WQS are comprised of designated uses, narrative and numeric criteria, and antidegradation requirements. The preferred approach was to start with the designated uses, identify ecological endpoints that can be associated with these designated uses and then, using conceptual models, develop the linkage among designated uses, ecological endpoints, nutrient concentrations and factors affecting the expression or response of the endpoint to nutrient concentrations. Possible assessment/management endpoints associated with designated uses for MS lakes and reservoirs are shown in Table 5.1. Some of the factors that might moderate endpoint effects or responses to nutrients are shown in Table 5.2.

Table 5.1. Assessment/management endpoints associated with designated uses.

Assessment /Management Endpoint	Designated Use(s)
Biodiversity (Sustainability)	Aquatic Life
Fish Production	Aquatic Life, Fish and Wildlife
Chl-a Concentrations	Aquatic Life, Drinking Water, Fish and Wildlife
Water Clarity	Recreation, Drinking Water, Fish and Wildlife
Macrophytes	Recreation, Fish and Wildlife
TOC, nitrate	Drinking Water
Harmful Algal Blooms	Aquatic Life, Drinking Water, Fish and Wildlife
Algal Blooms	Aquatic Life, Drinking Water, Fish and Wildlife

Table 5.2. Factors that can moderate nutrient effects on assessment/management endpoints.

Category	Factors
Physical	Different classification perspective (e.g., ecoregions, watersheds) Residence time Land use/land cover Morphometric attributes (mean depth, surface area) Geology Watershed physiography Water temperature Climate (precipitation)
Chemical	Alkalinity pH DO TSS Hardness

In order to identify the most appropriate approach for nutrient criteria development for Mississippi lakes a number of different approaches were evaluated. These approaches included developing criteria based on:

1. USEPA guidance criteria for lakes and reservoirs as given in USEPA (2000b and 2000c),
2. The "percentile" approach given in USEPA (2000b and 2000c) using the data set from Mississippi lakes and reservoirs described above,
3. Least disturbed streams identified as part of the Mississippi Index of Stream Quality (M-BISQ) developed for wadeable streams, and
4. Maintenance of quality sport fisheries.

The approaches were evaluated based on their utility in developing effects based criteria that reflect the linkage between nutrient concentrations and impairment of designated uses. These approaches are discussed separately below.

5.1 Criteria Based on USEPA Guidance Criteria for Lakes and Reservoirs

USEPA guidance criteria (USEPA 2000b, USEPA 2000c) were presented as part of Table 3.1 and are presented again in Table 5.3. Only USEPA Ecoregions IX, X, and XII are present in Mississippi. USEPA has developed guidance criteria for lakes and reservoirs for USEPA ecoregions IX (USEPA 2000b) and XII (USEPA 2000c) but not Ecoregion X. In

Mississippi, ecoregions IX and XII contain primarily reservoirs. Therefore the guidance criteria in Table 5.3 pertain primarily to reservoirs. The percentile value from the MDEQ reservoirs/large reservoirs data set that corresponds to each guidance criterion is also provided in Table 5.3. This summary indicates that the USEPA guidance criteria, in general, represent extremes in the ranges of actual TP, TN, Chl-a, and SD values encountered in Mississippi. Each of the guidance criteria are derived from a selected percentile for TP, TN, Chl-a, and SD (25th percentile for TP, TN, and Chl-a; 75th percentile for SD) from a sample of lakes and reservoirs from each particular ecoregion. This procedure does not consider whether or not adverse effects are associated with the concentrations at the chosen percentiles. Therefore this approach was not selected for deriving nutrient criteria for Mississippi lakes and reservoirs because the resulting guidance values are not effects-based.

Table 5.3. USEPA guidance nutrient criteria for ecoregions in Mississippi.

Parameter	Ecoregion	Guidance Criterion	Percent of Values Exceeding the Guidance Criteria in the Mississippi Reservoir/Large Reservoir Data Set		
			Reservoirs	Large Reservoirs	Oxbows
TP (µg/L)	IX[1]	20	70	99	90
	X[2]	--		--	--
	XII[3]	10	93	99	90
TN (µg/L)	IX[1]	360	88	100	92
	X[2]	--	--	--	--
	XII[3]	600	55	97	70
Chl-a (µg/L)	IX[1]	4.93	91	99	93
	X[2]	--	--	--	--
	XII[3]	2.6	100	100	99
SD[4] (m)	IX[1]	1.53	92	100	93
	X[2]	--	--	--	--
	XII[3]	2.1	100	100	96

1. USEPA (2000b), 2. USEPA criteria for Ecoregion X have not yet been developed,
3. USEPA (2000c), and 4. SD values are the percent of values less than the guidance criteria.

5.1.1 Criteria Based on USEPA Percentile Approach Using Data From Mississippi Waterbodies

As an alternative to USEPA guidance criteria, the USEPA's percentile-based approach (USEPA 2000a) was used with data collected from Mississippi lakes and reservoirs. The results of this approach are provided in Table 5.4. These values are representative of the 25th (or 75th in the case of SD) percentile values of Mississippi lakes and reservoirs. Selection of criteria using this approach implies than approximately 75% of lakes and reservoirs in Mississippi will be found to be impaired due to excess nutrients. However, the actual proportion of Mississippi lakes and reservoirs that are, impaired, is unknown and may be higher or lower than 75%. Therefore this method bases criterion levels on an unwarranted assumption regarding the number of impaired Mississippi lakes and reservoirs. In addition, this method suffers from the same deficiency as the USEPA guidance criteria. That is, it does not consider whether or not adverse effects occur at the concentrations corresponding to the chosen percentiles. Therefore this approach was not selected to derive nutrient criteria for Mississippi lakes and reservoirs.

Table 5.4. Potential criteria based on USEPA's percentile approach using data from Mississippi waterbodies.

Parameter	Reservoirs	Large Reservoirs	Oxbows
TP (µg/L; 25th percentile)	20	40	70
TN (µg/L; 25th percentile)	450	565	1030
Chl-a (µg/L; 25th percentile)	7.6	9.5	25
SD (m; 75th percentile)	1.1	1.0	0.65

5.2 Criteria Development Based on Nutrient Conditions in M-BISQ Reference Streams

MDEQ has developed and implemented the M-BISQ for wadeable streams based on a benthic macroinvertebrate index of biotic integrity. As part of the M-BISQ development reference streams were identified based on watershed land use. Biological sampling of these streams included collection of water samples for nutrient analysis. Additional quarterly samples were collected from these streams and others to support nutrient criteria development for Mississippi streams. Quarterly samples and samples collected as part of biological sampling were collected as grab samples according to the QAPP developed for the M-BISQ project (MDEQ 2001).

Nutrient data from these reference streams is potentially useful for nutrient criteria development in reservoirs. A "least disturbed" or "best attainable" condition in a reservoir could be thought of as that condition resulting from inflows from reference streams. Therefore, nutrient conditions in the reference streams should indicate best attainable conditions in reservoirs. This approach is supported by Dodds et al. (2006) who observed that nutrient levels in reference rivers and streams in Missouri were generally similar to levels in Missouri reference lakes and reservoirs.

Although nutrient sampling of selected M-BISQ streams has been conducted quarterly since approximately 2001, the entire quarterly sampling data set was not available for this analysis. The majority of the available data were collected between the months of August through April in 2001 and 2004 and do not include samples taken during the summer months. In addition approximately 50% of the nutrient samples in the available data set were collected concurrently with biological sampling which generally avoids elevated flows. Given these factors, the nutrient data from the M-BISQ reference streams provide a biased estimate of potential inflow concentrations from least disturbed watersheds. Since many of the sampling events purposely avoided elevated flows, the bias likely favors low rather than high TP and TN concentrations.

TP and TN data collected from the M-BISQ streams for each river basin in Mississippi are summarized in Table 5.5. Data are aggregated at the basin level to provide adequate sample sizes for calculation of percentile values. Inspection of Table 5.5 indicates generally uniform 75th percentile values for TP and TN for the Big Black, Pascagoula, Pearl, South Independent, Tennessee, and Tombigbee basins. Average 75th percentile values for TP and TN were 58 μg/L and 561 μg/L, respectively for these basins. The values for the North Independent basin were not included in these averages because there were only 4 observations from that basin. Yazoo basin values are presented separately because of this basin's unique geomorphology and soils, and because the percentile values from the Yazoo basin appeared to be somewhat higher than the other basins as a group.

The information summarized in Table 5.5 suggests TN and TP concentrations that could represent potential criteria values for hypothetical "reference" reservoirs (i.e., a lake or reservoir fed entirely by streams from least disturbed watersheds). Lake and reservoir criteria based on M-BISQ reference streams could represent a lower limit to any final criteria because they would represent the best attainable TP and TN values. General reservoir models (e.g., BATHTUB; Walker 1987) can be used to predict in-lake TP and TN concentrations using inflow and data and waterbody morphometry and thereby estimate the best attainable in-lake TP and TN concentrations for Mississippi lakes and reservoirs. However, this approach was not evaluated with the Mississippi data set because the available data probably do not represent an unbiased representation of the distribution of TP and TN concentrations in the reference streams.

Information provided in Table 5.5 indicates that M-BISQ reference streams in the Yazoo Basin carry higher concentrations of TP and TN than other basins. This difference indicates that Yazoo Basin reservoirs should experience higher background loading of TN and TP which should, in turn, be reflected in higher TN and TP criteria values for Yazoo Basin reservoirs.

5.2.1 Conclusions Based on Analysis of M-BISQ Reference Streams

Nutrient conditions in M-BISQ reference streams represent the best theoretically attainable conditions for reservoirs. However the M-BISQ reference stream data are probably biased in favor of low values. Therefore this approach was not used to establish nutrient criteria for Mississippi lakes and reservoirs. TN and TP criteria in Yahoo Basin Reservoirs should reflect higher background TN and TP concentrations indicated by the M-BISQ reference streams.

Table 5.5. Percentile values of TP and TN from M-BISQ least disturbed streams.

	Percentile Values							
		TP (μg/L)				TN (μg/L)		
Basin	**N**	**25%**	**50%**	**75%**	**N**	**25%**	**50%**	**75%**
Big Black	23	40	50	60	23	330	390	530
Pascagoula	85	30	40	60	84	410	530	690
Pearl	25	20	30	40	25	450	540	670
South Independent	15	20	40	60	15	220	270	345
Tennessee	10	20	30	50	10	260	330	530
Tombigbee	42	40	50	80	42	350	450	600
Average		28	40	58		337	418	561
North Independent	4	30	55	120	4	495	520	755
Yazoo	32	40	65	125	32	415	475	725

6.0 CRITERIA DEVELOPMENT BASED ON SPORT FISHERIES

6.1 Overview of Approach

As noted above, the literature clearly establishes a link between primary productivity and fish production. Therefore, primary productivity is directly linked to the fishable uses of a lake or reservoir. The approach presented herein proposes to use a quantitative measure of the potential quality of the sport fishery as an indicator of aquatic life use support. A measure of the potential of the sport fishery is provided by data analysis conducted by the Bureau of Fisheries of the MDWFP on fisheries data from selected lakes and reservoirs in Mississippi. The data collection and analysis were conducted as part of the development of the MsFish index. MsFish is an index used to provide estimates of relative fishing quality potential for lakes and reservoirs and is based on the Sport Fishing Index developed by the Tennessee Valley Authority (TVA). The index "…allows anglers to objectively compare waters across the state in terms of potential fishing success" (MDWFP 1996). Scores are based on sport fish population quality (fish abundance, size, structure, and condition) of black bass, crappie, and "bream" and angler results (catch rate, fish sizes, targeted effort). Procedures for calculating the MsFish Index from raw data are provided in Appendix C.

The approach combines the MsFish index with data describing nutrients (TP and TN), water clarity (SD), and primary productivity (Chl-a) collected by MDEQ for the development of nutrient criteria in Mississippi lakes and reservoirs. The MsFish index is used as an indicator of aquatic life designated use attainment. For purposes of nutrient criteria development a lake is considered to be meeting its aquatic life use if any of its three fisheries, (black bass, crappie, or other sunfish) rank high according to MsFish. The distribution of TP, TN, Chl-a, and SD for lakes with high MsFish scores (i.e., meeting their aquatic life designated use) is then considered to represent the range of levels of nutrients, clarity and primary productivity that supports, and does not impair, aquatic life use.

This approach is conceptually similar to that used by the ADEM. According to ADEM's Nutrient Criteria Implementation Plan (ADEM 2006) nutrient criteria are targeted to preserve reservoirs conditions that support all designates uses, including high quality fisheries and other aquatic communities. It should be noted that, for these purposes, nutrients are not being used to predict an MsFish index or vice versa. Rather, the MsFish index is being used to identify that range of nutrients that supports, and does not impair, the sport fishery. This approach is in contrast to the ADEM approach that used reservoir fishery studies (Maceina et al. 1996) to identify a lower bound of nutrient levels (as indicated by Chl-a concentrations) that does not limit sport fishery production in the sense of limitation of productivity due to low nutrient levels. Therefore the Chl-a criteria adopted by ADEM indicate levels of primary production required to maintain quality sport fisheries while still supporting primary contact recreation.

In contrast, the objective herein is to identify nutrient conditions that do not impair sport fish production or primary contact recreation. Nutrient levels that do not impair a designated use due to various phenomena associated with cultural eutrophication (e.g., DO depletion, toxic algae blooms, decreased clarity) can be expected to be higher than minimum levels needed to maintain quality sport fisheries. Therefore, criteria values for nutrients and Chl-a recommended herein will represent the upper range of values that support and do not impair designated uses. As a corollary to this approach it should be noted that the majority of nutrient and Chl-a measurements taken from an attaining waterbody should reflect attainment. That is, criteria values should be such that the majority of nutrient and Chl-a measurements taken from an attaining waterbody will be less than the criteria.

The MsFish index focuses only on sport fisheries and does not directly address other aquatic communities. However, the three types of fisheries that the MsFish index addresses include generalist opportunistic predators (black bass), zooplankton feeders (crappie), and generalist insectivores (other sunfish i.e., “bream”; Robison and Buchanan 1984). A high quality fishery potential depends on a number of factors including adequate food base, water quality, habitat (for adults, juveniles, larvae, and spawning), and appropriate harvest rates. Therefore sport fish populations are indicators of the integrity of the food web and biological aspects of the habitat. Nutrient impairment adversely affects habitat (e.g., overabundance or decline in macrophytes), water quality (episodes of DO depletion, algal toxins), and the food base (shifting species composition of primary producers to dominance by blue green algae which are less usable to primary consumers). High levels of productivity resulting from high nutrients might support high levels of total fish production. However excessive nutrient enrichment often results in a shift in fish species composition in favor of species (e.g., shad, carp) that are less desirable. Therefore while overall fish production may be high in the presence of excess nutrients, sport fish production is expected to be lower. Accordingly, a high quality sport fishery is not compatible, in the long term, with nutrient impairment. The presence of a high quality sport fishery indicates a waterbody that is not impaired by nutrients.

Of the 42 lakes and reservoirs sampled by MDEQ, 30 were also sampled by MDWFP for MsFish development. Of these 30 waterbodies there were 24 reservoirs greater than 500 acres in surface area and eight oxbow lakes. MDWFP sampled selected waterbodies in Mississippi from 2000 through 2005. However, the same set of waterbodies was not visited each year. Therefore any given lake or reservoir sampled by both MDWFP and MDEQ will have from 1 to 6 years of fisheries data. MsFish indices were calculated (Appendix C) for three sport fisheries: Black bass (largemouth, spotted, and smallmouth bass combined), crappie (black crappie and white crappie combined), and “bream” (bluegill, redear, and longear sunfish combined; referred to herein as “other sunfish”).

6.2 Analysis of Fisheries Data

The analysis of the MsFish information was based on the following assumptions:

1. Because of various factors that can affect sampling efficiency, average scores across years (in contrast to maximum or minimum scores) provide the best indication of the potential fishery quality for a waterbody. Therefore, if data from multiple years were available, scores for each fishery were averaged across years for each lake or reservoir.
2. High quality fisheries exist in at least some of the lakes and reservoirs sampled by MDWFP and the highest MsFish scores should indicate the highest quality fisheries. Accordingly, the scores for each fishery were scaled such that the score for a particular fishery at a particular waterbody was expressed as a percentage of the highest score from all waterbodies for that fishery. The resulting data scaled all scores to range between 0 and 100 for each fishery. The result of this scaling was to assure that a particular waterbody could be rated as high (or low) based on any of the three fisheries. The waterbodies were classified as either “oxbows” or “reservoirs”. The unscaled and scaled scores for each waterbody sampled by MDWFP are presented in Appendix D.
3. For each waterbody, the fishery with the highest score (i.e., the waterbody’s “strong suit” with respect to its sport fishery) represents the aquatic life attainment status of the waterbody. This analysis assumes that water quality that supports one type of fishery will support either or both of the other two types of fisheries. Furthermore it is not reasonable to expect that, as a prerequisite to aquatic life use attainment, a particular water body support a high level of attainment for all three

fisheries (although some waterbodies do). This is because the type of fishery that a particular waterbody best supports is affected by a number of factors other than water quality including habitat, fishing pressure, and hydrology. Therefore, the highest scaled index value among the three fisheries was used as a final index value to indicate the aquatic life use attainment status of a particular water body.

After averaging and scaling as described above, the waterbodies within each classification and their accompanying final indices were sorted by the value of the final index. The index values were then divided into upper, middle, and lower tri-sections and rated as high, medium, and low, respectively. Lakes sampled by both MDWFP and MDEQ were then divided into oxbow and reservoir classifications. The results of the data analysis through this step are provided in Table 6.1.

The data analysis presented in previous sections indicated that oxbows, as a group, differ from reservoirs and large reservoirs more than reservoirs and large reservoirs differ from one another. Therefore MsFish data presented in Table 6.1 were analyzed separately for oxbows. In order to have a larger sample size, MsFish scores and accompanying nutrient data from both reservoirs and large reservoirs were pooled.

6.3 Analysis of MsFish and Water Quality Data

A conceptual model illustrating the expected relationship between sport fish production and habitat, nutrients, Chl-a, and clarity in lakes and reservoirs is presented in Figure 6.1. The figure illustrates how aquatic life use as indicated by sport fish production can be limited by low nutrients, habitat, or impairment due to excess nutrients. Although the shape of the boundary in Figure 6.1 is unknown, it is clear that sport fish production must be low at either extreme of the curve. At the far left hand portion of the figure, low overall productivity caused by low nutrient levels limits fish production. As nutrient levels, Chl-a and productivity increase (and clarity decreases) nutrients become less limiting. However, fish production can range from low to high depending on habitat or other factors such as exploitation or recruitment. As nutrients increase further (in the far right of the figure), impairment of sport fish production can occur (even though overall fish production may be high) due to factors typically associated with eutrophication (low dissolved oxygen, toxic algae blooms, habitat changes due to increases, or decreases in vascular

Table 6.1. Final MsFish index values for oxbows and reservoirs (reservoirs + large reservoirs).

Lake Name	Waterbody Type	Final MsFish Index		
		Score	Rank	Category
Beulah	Oxbow	58	3	Low
Whittington	Oxbow	53	3	Low
Eagle	Oxbow	68	3	Low
Washington	Oxbow	70	2	Med
DeSoto	Oxbow	71	2	Med
Tunica Cutoff	Oxbow	75	2	Med
Moon	Oxbow	84	2	Med
Bee	Oxbow	89	1	High
Lock A Tenn Tom	Reservoir	45	3	Low
Lock C Tenn Tom	Reservoir	49	3	Low
Elvis Presley	Reservoir	60	3	Low
Pickwick	Large Reservoir	62	3	Low
Bogue Homa	Reservoir	63	3	Low
Bay Springs	Large Reservoir	64	3	Low
Lock B Tenn Tom	Reservoir	69	3	Low
Lock D Tenn Tom	Reservoir	70	2	Med
Ross Barnett Reservoir	Large Reservoir	71	2	Med
Grenada	Large Reservoir	74	2	Med
Natchez State Park	Reservoir	76	2	Med
Aberdeen	Large Reservoir	76	2	Med
Aliceville	Reservoir	81	2	Med
Kemper	Reservoir	83	2	Med
Tangipahoa	Reservoir	87	1	High
Columbus	Large Reservoir	89	1	High
Lincoln	Reservoir	89	1	High
Geiger	Reservoir	90	1	High
Arkabutla	Large Reservoir	96	1	High
Enid	Large Reservoir	97	1	High
Sardis	Large Reservoir	100	1	High
Trace State Park	Reservoir	100	1	High

plants) or to light limitation due to non-algal suspended solids. The model illustrates how low fish sport production can be associated with either low or high nutrients depending on whether the nutrients are limiting or impairing sport fish production. Low sport fish production associated with low nutrients (left-hand portion of Figure 6.1) does not represent “nutrient impairment.” In contrast low sport fish production associated with high nutrients (right-hand portion of Figure 6.1) might represent nutrient impairment. This conceptual model can be used to interpret the observed relationships between the final MsFish index and TP, TN, Chl-a, and SD distributions.

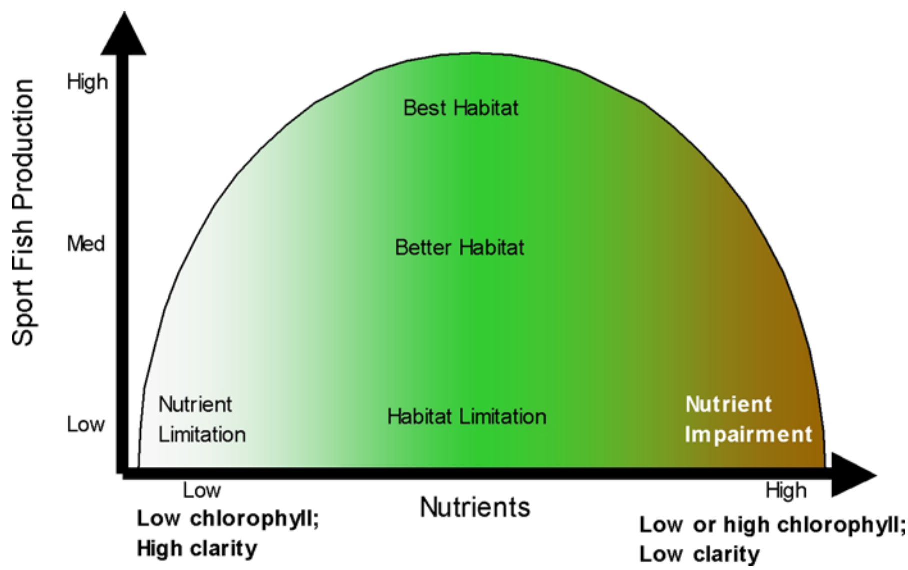


Figure 6.1. Conceptual model illustrating the expected relationship between sport fish production, habitat, nutrients, chlorophyll, and clarity.

6.3.1 Reservoirs and Large Reservoirs

The following analysis of “reservoirs” pertains to reservoirs and large reservoirs together as a group. Distributions of TP, TN, Chl-a, and SD were examined for reservoirs for the high, medium, and low final MsFish index categories.

6.3.1.1 Comparison with Conceptual Model

TP, TN, SD, and Chl-a distributions are examined for each MsFish category in Figures 6.2 and 6.3. For each figure the boxes labeled as “High,” “Medium,” and “Low” indicate the distributions of MsFish values and associated TP, TN, SD, and Chl-a distributions. The vertical dimension of each box indicates the 95% confidence interval for the MsFish scores and the horizontal dimension indicates the upper and lower quartiles for each parameter (TP, TN, SD, Chl-a). If the “High” MsFish category represents an approximate “best attainable” range of MsFish scores then the range of TP, TN, SD, and Chl-a might represent a range of those parameters that is near optimal for the production of sport fish. If this is the case, then TP, TN, SD, and Chl-a values to the right or left of the “High” MsFish box should be associated with lower MsFish scores. This is what appears to happen in Figures 6.2 and 6.3 when the data distributions are superimposed on the conceptual model. This analysis indicates that the “Low” MsFish category in reservoirs is best seen as an indication of nutrient limitation whereas the “Medium” category represent either variation due to other factors such as habitat or movement away from the optimum towards enrichment.

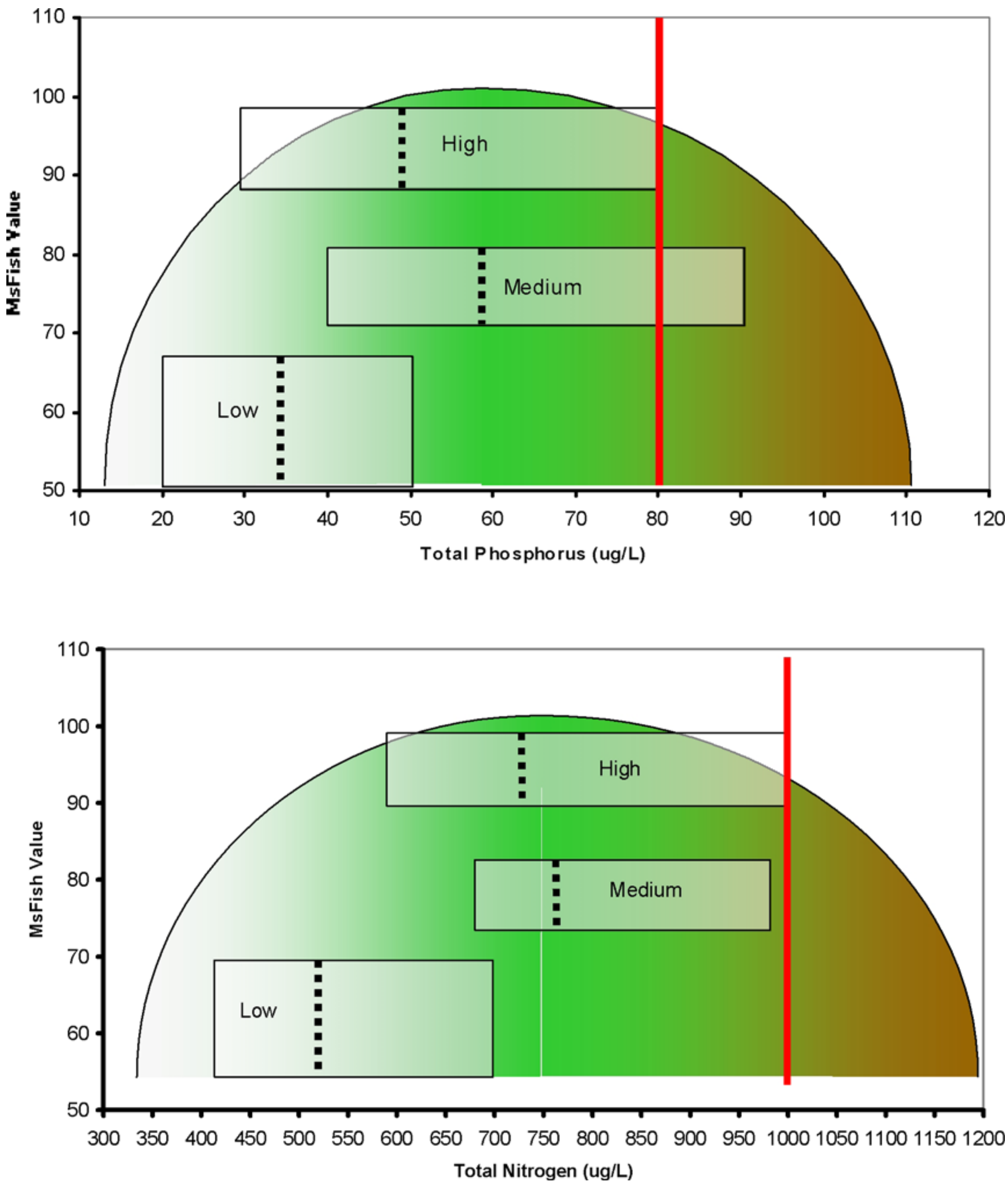


Figure 6.2. TP (top figure) and TN (bottom figure) vs. Reservoir MsFish values in relation to the conceptual model. Red lines indicate recommended criteria levels. Vertical dimension of each MsFish Category (box) indicates 95% confidence interval of mean MsFish value. Horizontal dimension of each box indicates upper and lower quantities of the parameter values (TP, TN, SD, or Chl-a) and vertical dotted line indicates mean parameter value associates with each box.

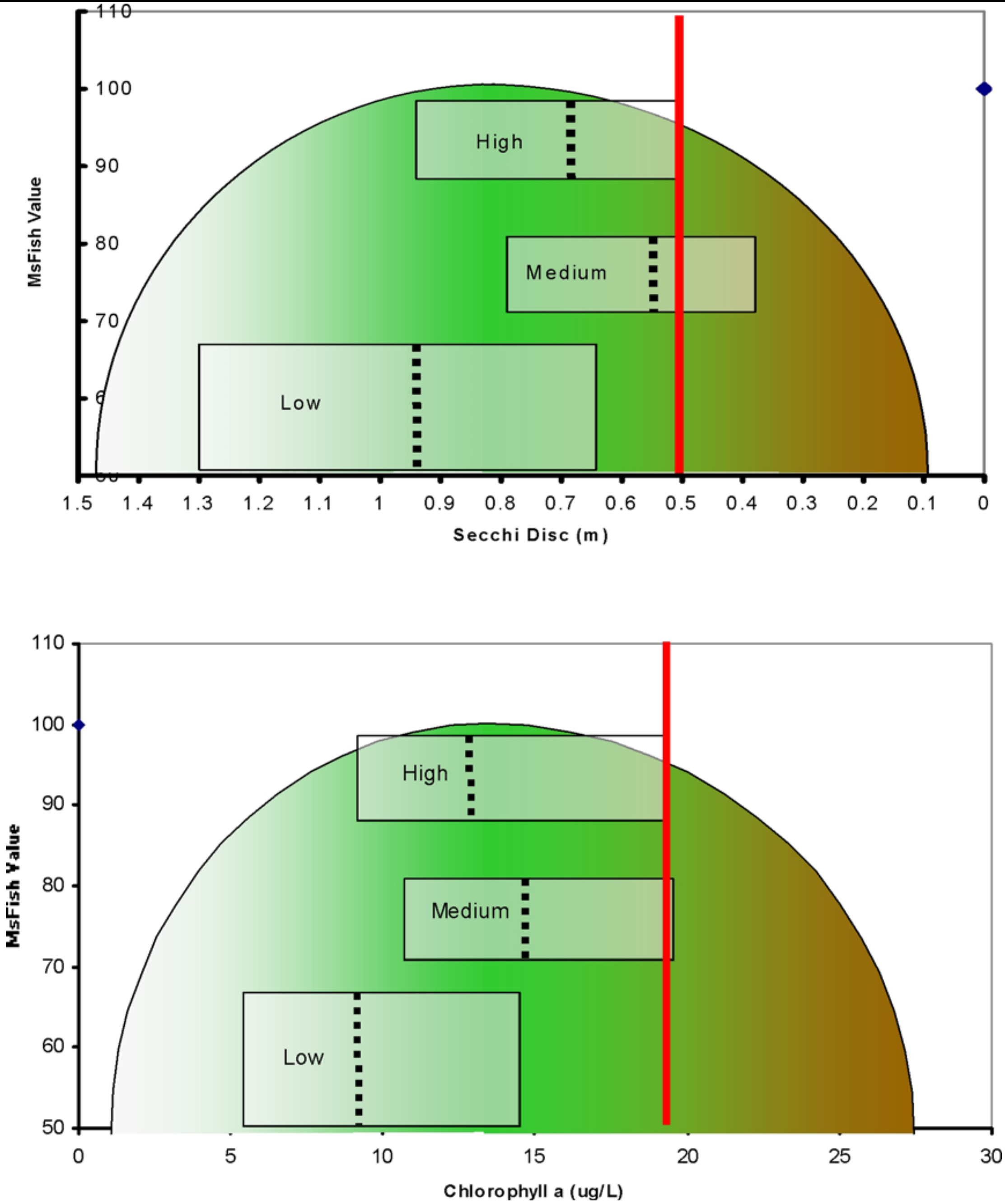


Figure 6.3. SD (top figure) and chlorophyll a (bottom figure) vs. Reservoir MsFish values in relation to the conceptual model. Red lines indicate recommended criteria levels. Vertical dimension of each MsFish Category (box) indicates 95% confidence interval of mean MsFish value. Horizontal dimension of each box indicates upper and lower quantities of the parameter values (TP, TN, SD, or Chl-a) and vertical dotted line indicates mean parameter value associates with each box.

6.3.1.1.1. Nutrient, Clarity, and Chlorophyll Values Supporting Aquatic Life Uses in Reservoirs

The selection of nutrient, clarity, and Chl-a values that support aquatic life uses in reservoirs was based on the following principles:

- Criteria values for nutrients and Chl-a should be established such that they represent the upper range of values that support and do not impair designated uses;
- Criteria values for nutrients, clarity, and Chl-a should be established such that the majority of nutrient, clarity, and Chl-a measurements in an attaining waterbody reflect attainment; and
- Due to variability in the linkage among nutrients, primary production, clarity, and fish production, and because the criteria are intended to represent the upper range of levels that support the aquatic life use, *a precautionary principal should be applied to assure that criteria are protective of uses*.

Distributions of TP, TN, SD, and Chl-a values for reservoirs are summarized in the box and whisker plots for reservoirs provided in Figure 6.4. The distribution of each water quality parameter indicates the range of values that support particular levels of aquatic life use attainment as indicated by the final MsFish index values.

Figure 6.4 indicates that the low category of MsFish is associated with lower nutrient and Chl-a concentrations and higher SD transparency than the medium and high categories. One way analysis of variance (ANOVA) was performed to evaluate the statistical significance of differences in the mean TP, TN, SD, and Chl-a values among the low, medium, and high MsFish categories. Results of this analysis, provided in Table 6.2, indicates statistically significant differences among the TP, TN, SD, and Chl-a concentrations with respect to MsFish category. These differences are also reflected in non-overlapping “notches” in the box and whisker plots in Figure 6.4. This result, as discussed above in the context of the conceptual model, suggests a classic nutrient limitation enrichment response in which the low MsFish category is associated with lower nutrient levels, while the medium and high MsFish categories indicate higher sport fishery potential in response to higher nutrient levels.

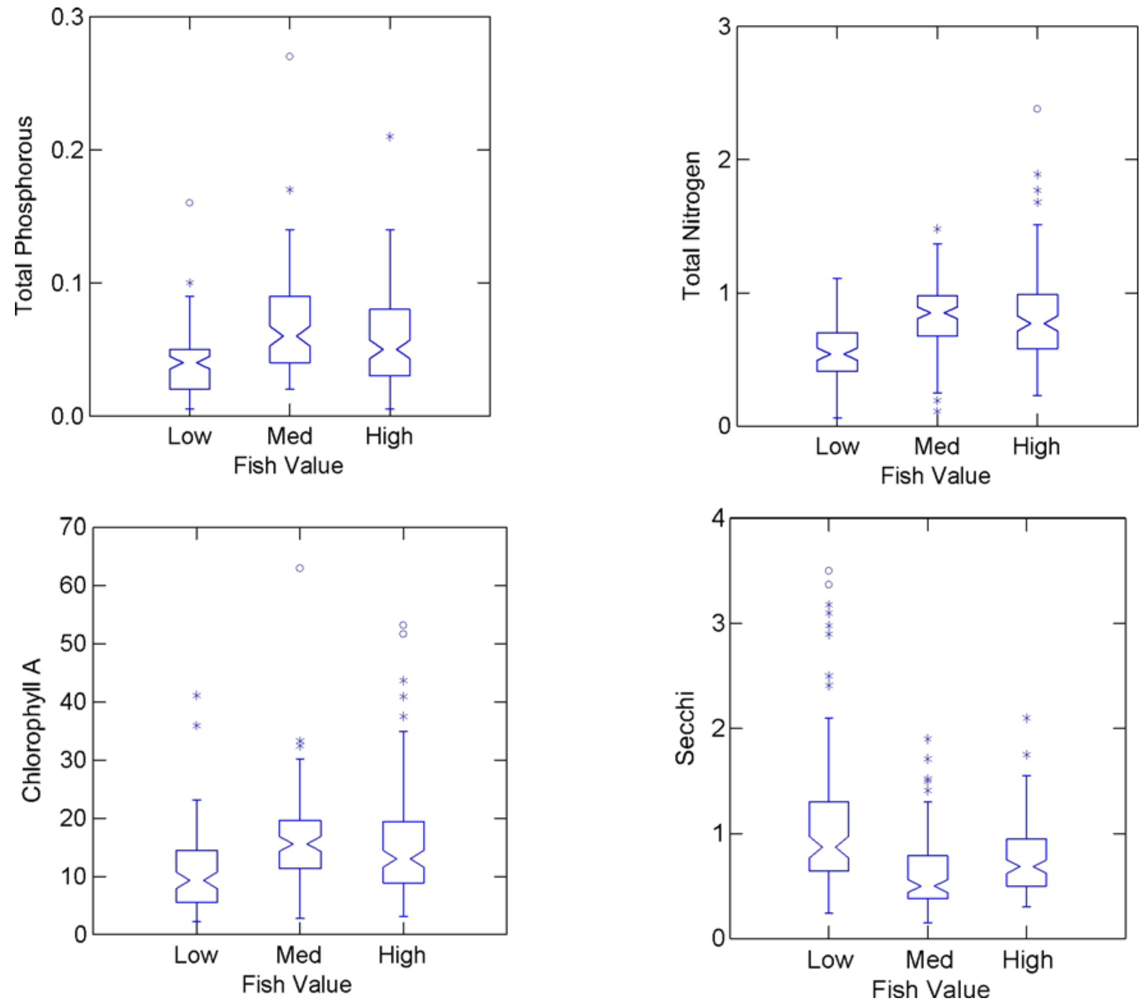


Figure 6.4. Box and whisker plots comparing distributions of TP (mg/L), Chl-a (g/L) and SD (m) among Low, Medium, and High final MsFish index categories in reservoirs and large reservoirs combined."

Table 6.2. Summary of statistical comparison of mean TP, TN, SD, and Chl-a values among MsFish categories (Low, Medium, and High) in reservoirs (reservoirs and large reservoirs combined).

Parameter	MsFish Category		
	Low (7)	**Med (7)**	**High (8)**
TP (µg/L)	34[a] (99)	57[b] (113)	49[b] (247)
TN (µg/L)	513[a] (99)	755[b] (113)	732[b] (245)
SD(m)	0.93[a] (99)	0.55[b] (113)	0.68[c] (239)
Chl-a (µg/L)	8.9[a] (96)	14[b] (108)	13[b] (242)

Values in parentheses following mean values indicate number of samples collected.
Values in parentheses following MsFish categories indicate number of waterbodies in category.
Values for a particular parameter having the same superscript are not statistically (a, b, or c) different (P greater than 0.05)

TP, TN, Chl-a, and SD values associated with the high MsFish category provide values for those parameters that support and do not impair aquatic life use as indicated by the quality of the sport fishery. Therefore the majority of measurements of TP, TN, SD, and Chl-a should reflect attainment of the designated use in those attaining waterbodies. Accordingly, the 75th percentile values of TP, TN, and Chl-a and the 25th percentile SD value might be used to indicate attainment of aquatic life use. Table 6.3 summarizes selected percentile values for each MsFish category for TP, TN, Chl-a, and SD.Table 6.3. Selected percentile values for TP, TN, Chl-a, and SD in relation to MsFish categories in reservoirs.

MsFish Category	Percentile	Parameter			
		TP (ug/L)	TN (ug/L)	Chl-a (ug/L)	SD (m)
Low	25th	20	410	5.5	0.64
	50th	40	540	9.3	0.87
	75th	50	700	14.5	1.30
	n	99	99	96	99
Medium	25th	40	678	11.3	0.38
	50th	60	850	15.6	0.50
	75th	90	980	19.6	0.79
	n	113	113	108	113
High	25th	30	580	9.0	0.50
	50th	50	770	13.0	0.68
	75th	80	990	19.4	0.95
	n	130	129	127	126

n = the number of data points on which the percentiles are based.

The 75th percentile values of TP, TN, and Chl-a and the 25th percentile SD values taken from Table 6.3 are summarized as recommended criteria values in Table 6.4. These draft criteria values are consistent with the principles listed at the beginning of this section because:

- Nutrient, clarity, and Chl-a values in the subset of data from "high" MsFish category represent values that support and do not impair aquatic life uses. The 75th percentile for TP, TN, and Chl-a and the 25th percentile for SD therefore represent the upper range of values that support and do not impair designated uses.
- The draft criteria values are such that the majority of nutrient, clarity and Chl-a measurements in attaining waterbodies reflect attainment (i.e., are lower than the criteria).
- Since 25% of the measurements from the "high" MsFish category indicate impairment, there is a significant chance of "false positive" determinations of impairment. *Therefore this approach is conservative (i.e., precautionary) and protective of aquatic life uses.*

Reservoir criteria recommendations in Table 6.4 include recommendations based on the analysis presented in Section 5.3 that indicated minimum TP and TN criteria for Yazoo Basin reservoirs.

Table 6.4. Recommended criteria values for TP, TN, Chl-a, and SD in reservoirs.

Basis	TP (μg/L)	TN (μg/L)	Chl-a (μg/L)	SD (m)
Recommended Criteria	80	990	19.4	0.50

6.3.1.2 Site-specific Modifications of Recommended Reservoir Criteria

In the course of assessing attainment in reservoirs, it is possible that a reservoir may be found to exceed the recommended criteria while still supporting a high quality fishery. In such cases, site-specific criteria for TP, TN, SD, and Chl-a may be chosen that reflect the existing nutrient, clarity and productivity of that reservoir in order to preserve that high level of use attainment.

6.3.2 Oxbows

Distributions of TP, TN, Chl-a, and SD were examined for the high, medium, and low final MsFish index categories in oxbows.

6.3.2.1 Comparison with Conceptual Model

TP, TN, SD, and Chl-a distributions are examined for each MsFish category in Figures 6.5 and 6.6. For each figure the boxes labeled as "High," "Medium," and "Low" indicate the distributions of MsFish values and associated TP, TN, SD, and Chl-a distributions. As in the preceding analysis of reservoir data the vertical dimension of each box indicates the 95% confidence interval for the MsFish scores and the horizontal dimension indicates the upper and lower quartiles for each parameter (TP, TN, SD, Chl-a)[4]. If the "High" MsFish category represents an approximate "best attainable" range of MsFish scores, then the range of TP, TN, SD, and Chl-a might represent a range of those parameters that is near optimal for the production

[4] Since there was only 1 oxbow lake in the "High" MsFish, a 95% confidence interval equal to that of the "Medium" category was assumed. The 95% confidence intervals for the categories overlap due to low sample sizes.

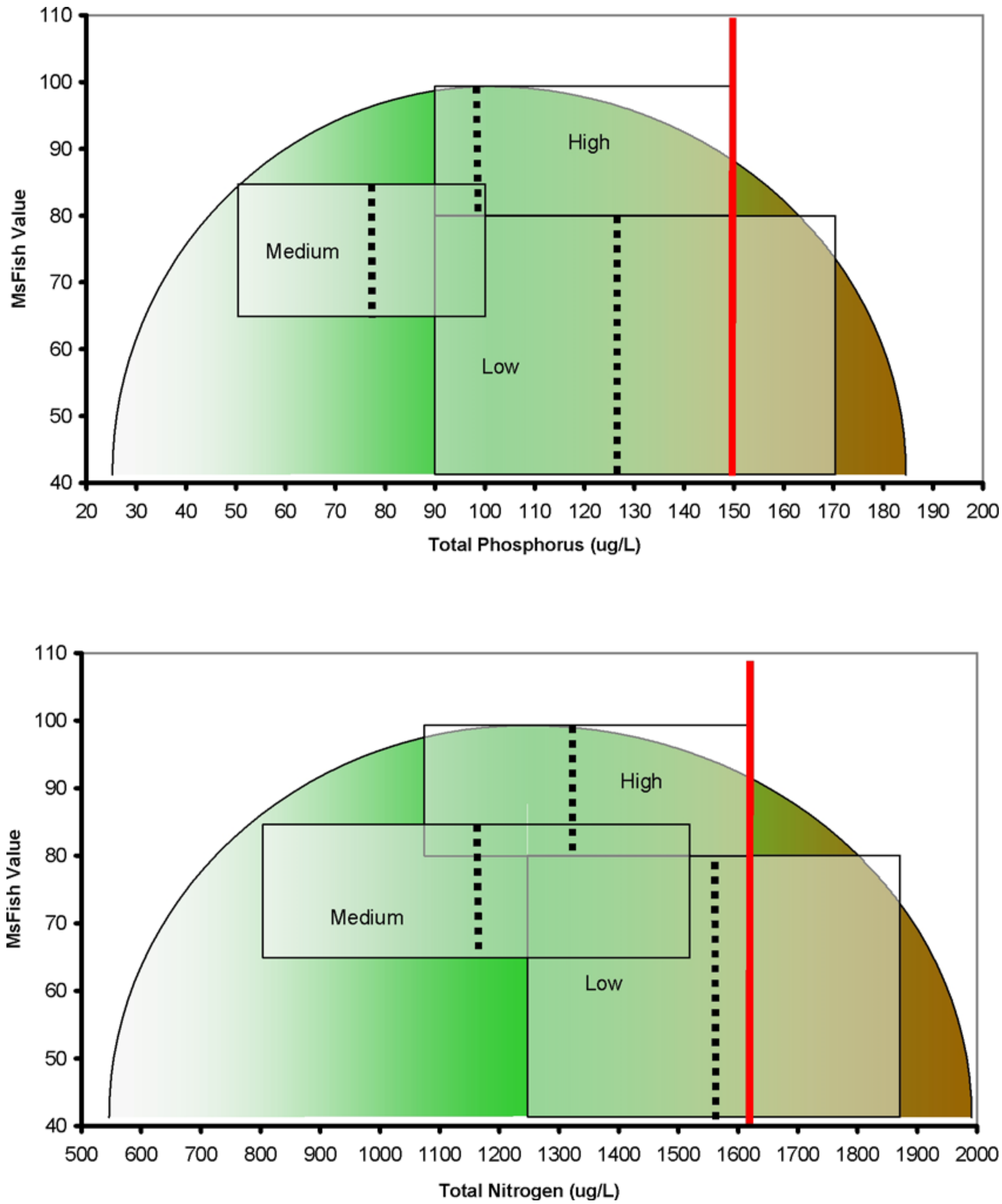
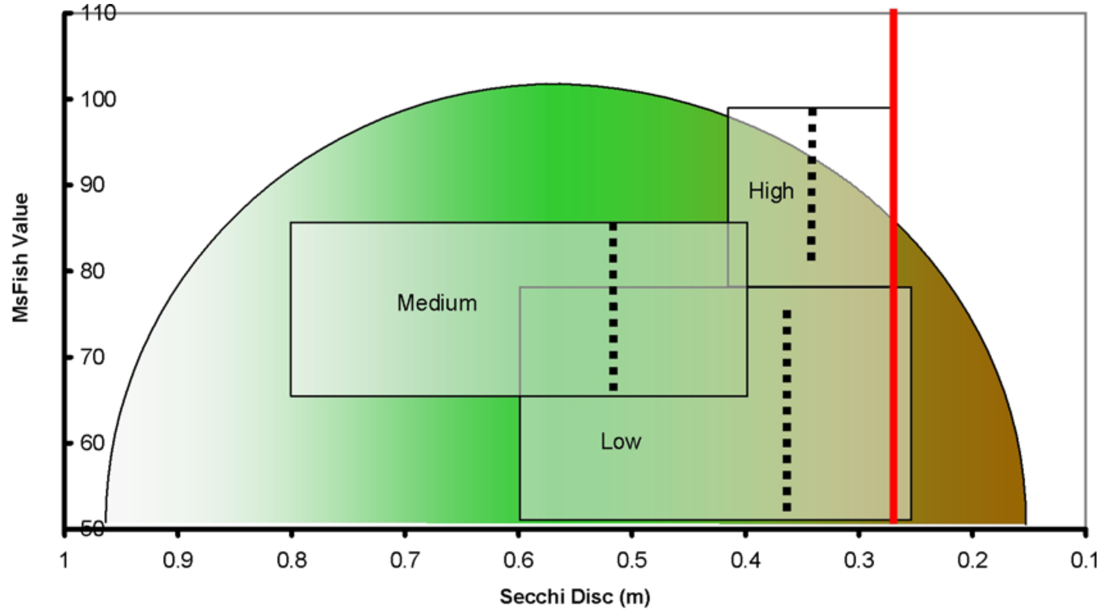


Figure 6.5. TP (top figure) and TN (bottom figure) vs. Oxbow MsFish values in relation to the conceptual model. Red lines indicate recommended criteria. Vertical dimension of each MsFish Category (box) indicates 95% confidence interval of mean MsFish value. Horizontal dimension of each box indicates upper and lower quantities of the parameter values (TP, TN, SD, or Chl-a) and vertical dotted line indicates mean parameter value associates with each box.



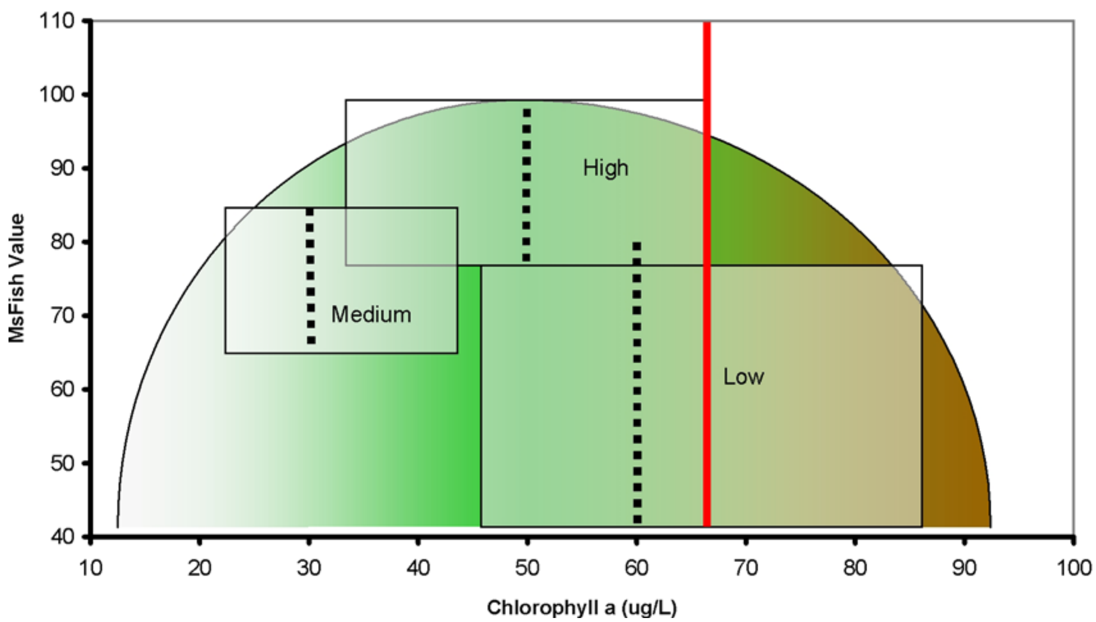


Figure 6.6. SD (top figure) and chlorophyll a (bottom figure) vs. Oxbow MsFish values in relation to the conceptual model. Red lines indicate recommended criteria. Vertical dimension of each MsFish Category (box) indicates 95% confidence interval of mean MsFish value. Horizontal dimension of each box indicates upper and lower quantities of the parameter values (TP, TN, SD, or Chl-a) and vertical dotted line indicates mean parameter value associates with each box.

of sport fish in oxbow systems. If this is the case, then TP, TN, SD, and Chl-a values to the right or left of the “High” MsFish box should be associated with lower MsFish scores. This analysis indicates that the “Medium” MsFish category in oxbows might be viewed as an indication of nutrient limitation whereas the “Low” category represents movement away from the optimum towards enrichment and might indicate conditions that impair oxbow lakes.

It should be emphasized that there were a total of only eight oxbow lakes in this analysis. Only one lake is present in the “High” MsFish category. Therefore, any conclusions for oxbows are tentative. However, the general patterns agree with expectations based on the conceptual model.

6.3.2.1.1. Nutrient, Clarity and Chlorophyll Values Supporting Aquatic Life Uses in Oxbow lakes

The selection of nutrient, clarity, and Chl-a values that support aquatic life uses in oxbows was based on the same principles applied to reservoirs, that is:

- Criteria values for nutrients and Chl-a should be established such that they represent the upper range of values that support and do not impair designated uses;
- Criteria values for nutrients, clarity, and Chl-a should be established such that the majority of nutrient, clarity, and Chl-a measurements in an attaining waterbody reflect attainment; and
- Due to variability in the linkage among nutrients, primary production, clarity and fish production, and because the criteria are intended to represent the upper range of levels that support the aquatic life use, a precautionary approach should be applied to assure that criteria are protective of uses.

Distributions of TP, TN, SD, and Chl-a values for oxbows are summarized in the box and whisker plots for reservoirs provided in Figure 6.7. The distribution of each water quality parameter indicates the range of values that support particular levels of aquatic life use attainment as indicated by the final MsFish index values.

One-way ANOVA was performed to evaluate the statistical significance of differences in the mean TP, TN, SD, and Chl-a values among the low, medium and high MsFish categories. Results of this analysis, provided in Table 6.5, indicate statistically significant differences among the TP, TN, SD, and Chl-a concentrations with respect to MsFish category. These differences are also reflected in non-overlapping "notches" in the box and whisker plots in Figure 6.7. This result, as discussed above in the context of the conceptual model, is in contrast to the patterns seen in the reservoir data. The oxbow data show low clarity, high nutrients and high Chl-a associated with both high and low MsFish categories. As illustrated by the conceptual model (Figure 6.1) high nutrient concentrations (within limits) can result in a highly productive aquatic ecosystem with high-quality sport fishery or an impaired system with lower quality sport fishery. Figures 6.5 through 6.7 indicate that both situations may be occurring in Mississippi oxbows.

Figure 6.7 indicates that the medium MsFish category is associated with the lowest nutrient levels and highest clarity among oxbows while both the low and high MsFish categories are associated with high nutrient and Chl-a and low clarity levels. This result suggests that, although they have similar levels of nutrients, Chl-a and clarity, oxbow lakes in the high and low MsFish categories might represent TP, TN, Chl-a, and SD levels associated with attaining and impaired lakes, respectively.

According to the reasoning and principles applied to the reservoirs, nutrient, Chl-a and clarity conditions associated with the high MsFish category represent levels of those parameters that support aquatic life use as indicated by quality of the sport fishery. Therefore, the 75th percentile values of TP, TN, and Chl-a and the 25th value of SD represent levels of those parameters that support aquatic life use attainment in Mississippi oxbows. Using this approach the 75th percentile values of TP, TN, and Chl-a and the 25th value of SD from Table 6.6 are 150 µg/L, 1020 µg/L, 67.8 µg/L, and 0.27 m, respectively. The difficulty with using these values to indicate levels of nutrient, Chl-a, and clarity that support aquatic life use attainment is that a large portion of the values in the low MsFish category are below these percentile values even though the low MsFish category might represent impaired conditions.

An alternative approach could be based upon the distribution of values, (e.g., 25th percentile values for nutrients and Chl-a, and the 75th percentile value for SD) in the "Low" MsFish category. Using this approach the 25th percentile values of TP, TN, and Chl-a and the 75th value of SD from Table 6.6 are 90 µg/L, 1250 µg/L, 45.6 µg/L, and 0.60 m, respectively. This approach would identify levels of nutrients, Chl-a and SD that are associated with non-attainment of the aquatic life use. The difficulty with using this approach is that it

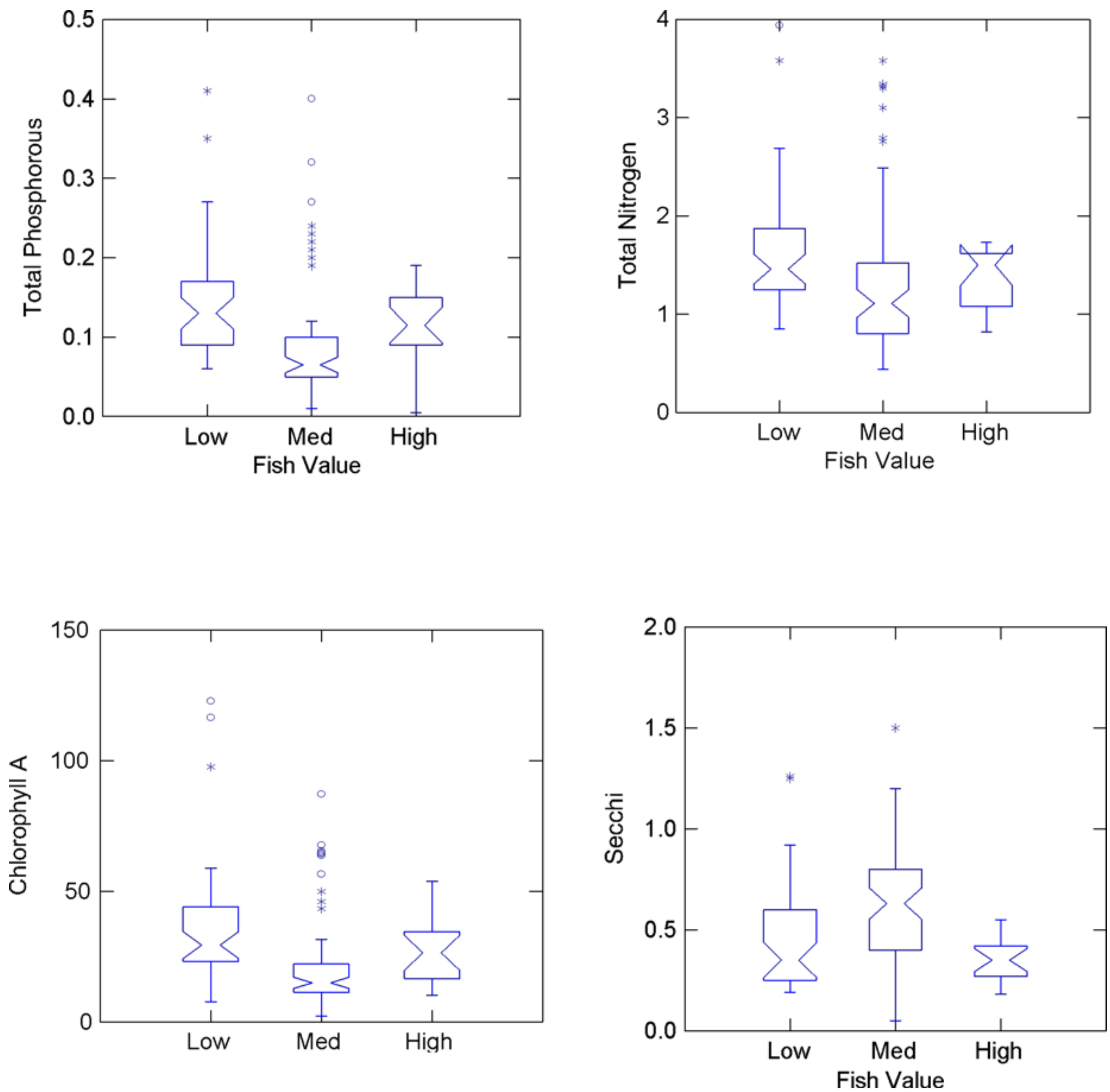


Figure 6.7. Box and whisker plots comparing distributions of TP (mg/L), TN (mg/L), Chl-a (µg/L), and SD (m) among Low, Medium, and High final MsFish index categories in Oxbow lakes.

Table 6.5. Summary of statistical comparison of mean TP, TN, SD, and Chl-a values among MsFish categories (Low, Medium, and High) in oxbows.

Oxbows	MsFish Category		
	Low (3)	Med (4)	High (1)
TP (μg/L)	127[a] (41)	77[b] (64)	99[b] (36)
TN (μg/L)	1566[a] (41)	1171[b] (64)	1316[b] (34)
SD(m)	0.38[a] (41)	0.52[b] (64)	0.33[a] (34)
Chl-a (μg/L)	60[a] (41)	30[b] (67)	49[a] (36)

Values in parentheses following mean values indicate number of samples collected.
Values in parentheses following MsFish categories indicate number of waterbodies in comparison.
Values for a particular parameter having the same superscript are not statistically (a, b, or c) different (P greater than 0.05).

Table 6.6. Selected percentile values for TP, TN, Chl-a, and SD in relation to MsFish categories in oxbows.

MsFish Category	Percentile	Parameter			
		TP (μg/L)	TN (μg/L)	Chl-a μ(g/L)	SD (m)
Low	25th	90	1250	45.6	0.25
	50th	130	1460	57.7	0.35
	75th	170	1870	86.2	0.60
	n	41	41	41	41
Medium	25th	50	805	22.3	0.40
	50th	65	1110	29.4	0.63
	75th	100	1520	43.4	0.80
	n	64	64	63	65
High	25th	90	1080	32.6	0.27
	50th	115	1500	51.9	0.35
	75th	150	1620	67.8	0.42
	n	18	17	18	17

n = the number of data points on which the percentiles are based.

would classify virtually all of the nutrient, Chl-a and clarity levels in the high MsFish category as not supporting the aquatic life use. Resolving these difficulties requires a basis for a site-specific evaluation of aquatic life use attainment. This basis follows the approach for site-specific modification of nutrient criteria described previously for reservoirs and is provided below.

Recommended criteria values for oxbow lakes are provided in Table 6.7. The criteria values given in Table 6.7 are based on percentiles from the "Low" MsFish category as explained above. These values are highly conservative because:

- They are lower than a large portion of values that are associated with "Medium" or "High" MsFish categories.
- In the case of TP and SD, these values are comparable to recommended criteria values for reservoirs. This similarity to reservoirs ignores the overall tendency for oxbow lakes to have higher levels of nutrients and productivity and lower clarity than reservoirs.

Table 6.7. Recommended criteria values for TP, TN, Chl-a, and SD in oxbow lakes.

Basis	Recommended Criteria			
	TP (µg/L)	**TN (µg/L)**	**Chl-a (µg/L)**	**SD (m)**
Recommended Criteria	90	1250	45.6	0.60
Demonstrated Attainment (Example: Bee Lake)	150	1620	67.8	0.27

Because of the highly conservative nature of the recommended oxbow lake criteria, the values should be subject to site-specific modifications as described below.

6.3.2.1.2. Site-specific Modifications of Recommended Oxbow Criteria

As noted previously in reservoirs, during the course of assessing attainment in oxbow lakes it is possible that a lake may be found to exceed the recommended criteria while still supporting a high level of use attainment. For example, a high MsFish index score or an established, documented reputation for outstanding sport fishing provides strong evidence of aquatic life use attainment as defined herein. An example of this situation is found with Bee Lake. Bee Lake is the single oxbow lake in the available data set that has a "High" MsFish score indicating a high level of aquatic life use attainment in that waterbody (Table 6.1). The data distribution for Bee Lake is indicated by the "High" MsFish category in Figures 6.5 through 6.7. This data distribution provides a basis for a site-specific modification of the recommended default criteria values as summarized in Table 6.7. In the case of Bee Lake, site-specific criteria for TP, TN, SD, and Chl-a may be chosen that reflect the existing nutrient, clarity, and productivity of that reservoir in order to preserve that high level of use attainment. Accordingly, criteria values for a lake, such as Bee Lake, that shows "demonstrated attainment" of its aquatic life use by virtue of its "High" MsFish score are provided by the 75th percentile values for TP, TN, Chl-a, and SD from that waterbody. These values are provided as an example of a site-specific criteria modification in Table 6.7.

6.3.3 Nutrient Criteria for MDWFP Managed Lakes

MDWFP fertilizes selected reservoirs[5] as part of its fisheries management program to enhance fishery production. The MDEQ data set was evaluated to determine if these managed lakes required special consideration for establishing nutrient criteria. Figure 6.8 shows box and whisker plots comparing TP, TN, SD, and Chl-a in fertilized vs. un-fertilized reservoirs. The plots indicate that MDWFP management activities result in no or only modest increases in TP levels or reduced clarity relative to un-fertilized lakes. However, the fertilized lakes do exhibit elevated TN and Chl-a levels. Elevated TN levels are somewhat surprising since lake fertilization programs generally seek to increase productivity by increasing available phosphorus. This result suggests that TN concentrations in the fertilized lakes may be controlled by factors other than fertilization.

Further examination of Figure 6.8 indicates that the majority of TP and SD values (97% and 90%, respectively) in fertilized lakes comply with draft criterion values for those parameters. Since lake fertilization typically seeks to increase phosphorus concentrations, MDWFP should not have to curtail lake fertilization activities as a result of implementation of a TP criterion at or near the recommended criterion value of 80 µg/L. However, a substantial portion of the Chl-a values (59%) from fertilized lakes are higher than the draft criterion value of 19.4 µg/L (Figure 6.8). This result indicates that MDWFP fertilization activities might have to consider existing Chl-a levels in lakes before implementing management activities involving fertilization. Since the Chl-a criterion recommended herein is based on sport fishery quality, this restriction might aid fishery management activities by identifying lakes that are not likely to benefit from fertilization.

[5] MDWFP does not fertilize large reservoirs. Therefore this analysis focuses on reservoirs between 500 and 2000 ac. in surface area.

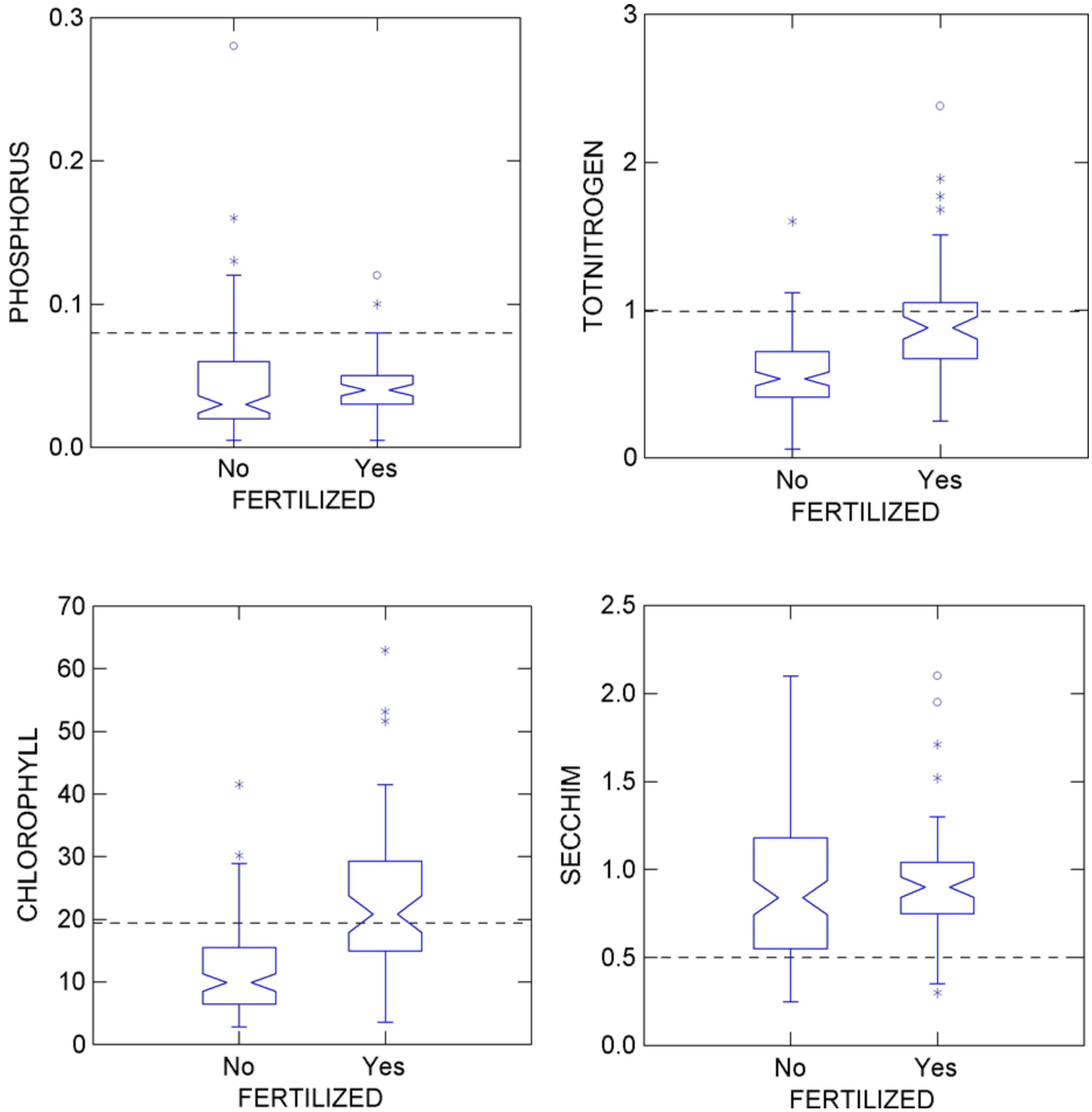


Figure 6.8. Box and whisker plots comparing TP, TN, Chl-a, and SD in fertilized vs. un-fertilized reservoirs.

7.0 SUMMARY OF NUTRIENT CRITERIA RECOMMENDATIONS FOR MISSISSIPPI LAKES AND RESERVOIRS

The following recommendations apply to lakes and reservoirs greater than 500 acres in surface area.

1. Elevated levels of non-algal turbidity are a general property of Mississippi lakes and reservoirs. Therefore a TSI approach to evaluating the effects of nutrients on primary production and clarity should be used with caution in Mississippi water bodies. Accordingly, the USEPA recommendation that no TP criterion be higher than 0.1 mg/L is, in general, not valid for Mississippi lakes and reservoirs.
2. Criteria development based on USEPA guidance (USEPA 2000a) is not appropriate for Mississippi lakes and reservoirs because it is not effects based and it incorporates unsupported assumptions about the number of impaired lakes and reservoirs in Mississippi.
3. The quality of sport fisheries is a valid indicator of aquatic life use in Mississippi lakes and reservoirs.
4. Nutrient criteria should be based on levels that do not impair sport fisheries.
5. Recommended criteria for nutrients, clarity, and Chl-a in reservoirs based on the analysis of sport fishery and water quality data are provided in Table 7.1.
6. Recommended criteria for nutrients, clarity, and Chl-a in oxbow lakes based on the analysis of sport fishery and water quality data are provided in Table 7.2.
7. Refinement of criteria for oxbows might require additional information regarding designated use attainment.
8. Additional paired water quality and MsFish data sets are needed for oxbows in order to clarify the sport fishery response to nutrient enrichment in those systems.
9. Lake management activities might have to consider Chl-a levels in lakes before implementing management activities involving fertilization.

Table 7.1. Recommended criteria values for TP, TN, Chl-a, and SD in reservoirs.

Basis	**TP (μg/L)**	**TN (μg/L)**	**Chl-a (μg/L)**	**SD (m)**
Recommended Criteria	80	990	19.4	0.50

Table 7.2. Recommended criteria values for TP, TN, Chl-a, and SD in oxbow lakes.

Basis	Recommended Criteria			
	TP (μg/L)	TN (μg/L)	Chl-a (μg/L)	SD (m)
Recommended Criteria	90	1250	45.6	0.60
Demonstrated Attainment (Example: Bee Lake)	150	1620	67.8	0.27

7.1.1 Recommendations for Further Development of Nutrient Criteria Mississippi Lakes and Reservoirs

Relationships between nutrient regimes and sport fishery quality provide a sound basis for evaluating the effects of nutrients on aquatic life. The response of the sport fishery to nutrient conditions conforms to expectations based on how nutrients are thought to affect productivity in aquatic ecosystems. The response of the sport fishery to nutrients in reservoirs is based on a reasonably large dataset (seven to eight waterbodies per MsFish category). Although, there are only a total of eight oxbow lakes in the analysis, the response of the oxbow fisheries seems to conform to expectations based application of the conceptual model. However, the small sample size results in a lower level of confidence in recommended criteria values for oxbows. Because of the promising result using this approach in reservoirs, additional collection of oxbow fishery data appears warranted. It is therefore recommended that fishery data be collected for additional oxbow lakes to clarify the sport fishery response to nutrients in these systems.

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USEPA. 2002. Guidance for Quality Assurance Project Plans (USEPA QA/G-5, USEPA/240/R-02/009) US Environmental Protection Agency, Office of Environmental Information, Washington, D.C., December 2002.

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APPENDIX A:

QUALITY ASSURANCE PROJECT PLAN

SECTION A: PROJECT MANAGEMENT

A.1 TITLE AND APPROVAL SHEET

Title: Data Analysis for Lakes/Reservoirs Nutrient Criteria Development

Revision 1
May 31, 2006

This quality assurance project plan (QAPP) has been prepared according to:

Guidance for Quality Assurance Project Plans (EPA QA/G-5, EPA/240/R-02/009) U.S. Environmental Protection Agency, Office of Environmental Information, Washington, D.C., December 2002;
*EPA Requirements for Quality Assurance Project Plans, (*EPA QA/R-5, EPA/240/B-01/003) U.S. Environmental Protection Agency, Office of Environmental Information, Washington, DC, March 2001; and
QAPP Requirements for Secondary Data Research Projects, U.S. Environmental Protection Agency, National Risk Management Research Laboratory, Washington, DC, July 1999

These documents will be used to ensure that that the data analysis is scientifically sound and defensible, and that the data used for this project are of the type, quantity, and quality required for their intended purpose.

Approvals:

Kent Thornton — Date
Project Administrator
FTN Associates, Ltd.

Jim Malcolm — Date
Project Quality Assurance Coordinator
FTN Associates, Ltd.

Natalie Guedon — Date
Project Administrator
MDEQ

Doug Upton — Date
Quality Assurance Officer
MDEQ

Ed Decker — Date
Project Administrator
US EPA Region IV

Marilyn Thornton — Date
Quality Assurance Official
US EPA Region IV

A.2 TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

A.3 DISTRIBUTION LIST

This document will be distributed to the following: United States Environmental Protection Agency (US EPA) Region IV, Mississippi Department of Environmental Quality (MDEQ), and FTN Associates, Ltd. (FTN) staff involved in this project. The FTN Project Leader will be responsible for distributing the QAPP to all technical personnel involved in this project.

Individual	Phone Number	Mailing Address
Kent Thornton FTN Project Administrator	(501) 225-7779	FTN Associates, Ltd. 3 Innwood Circle, Suite 220 Little Rock, AR 72211
Jim Malcolm FTN Quality Assurance Coordinator	(501) 225-7779	FTN Associates, Ltd. 3 Innwood Circle, Suite 220 Little Rock, AR 72211
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Doug Upton MDEQ Quality Assurance Officer	(601) 664-3959	MDEQ Field Services Division 1542 Old Whitfield Road Pearl, MS 39208
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Marilyn Thornton US EPA Quality Assurance Official	(706) 355-8553	US EPA Region IV Science and Ecosystem Support Division 980 College Station Road Athens, GA 30605

A.4 PROJECT ORGANIZATION

This section describes the overall organization of the project that will be conducted by FTN for MDEQ. The project management, quality program, and activities included in this QAPP are for data analysis. Duties and responsibilities of personnel for various aspects of the data analysis and reporting process are described.

The organizational aspects of a project provide the framework for conducting tasks. The organizational structure and function can also facilitate project performance and adherence to quality control (QC) procedures and quality assurance (QA) requirements. Key project roles are filled by those persons responsible for overseeing the data analysis and ensuring that it is technically sound and scientifically defensible, as well as the persons responsible for approving and accepting final products and deliverables. The project organizational chart is presented in Figure A1 and includes relationships and lines of communication among participants. The responsibilities of these persons are described in Table A1.

A.5 PROBLEM DEFINITION/BACKGROUND

On March 24, 1998, the President's Clean Water Action Plan was presented in the Federal Register. The Clean Water Action Plan specifically states that US EPA will establish nutrient criteria that reflect the different types of water bodies and different ecoregions of the country and will assist States and Tribes in adopting numeric water quality standards based on these criteria. In June 1998 US EPA published the National Nutrient Strategy for Development of Regional Nutrient Criteria, outlining the approach US EPA is following to develop and implement nutrient water quality criteria.

MDEQ has established a Nutrient Criteria Task Force to assist it in formulation of nutrient criteria for Mississippi waters, and developed a draft implementation plan for nutrient criteria development (*Mississippi's Plan for Nutrient Criteria Development*, Submitted to US EPA Region IV, November 14, 2003). As part of this plan, water quality data was collected from Mississippi lakes with surface area >500 acres, to fill data gaps related to nutrients for Mississippi's lakes and reservoirs. That monitoring program was conducted from 2002 to 2004.

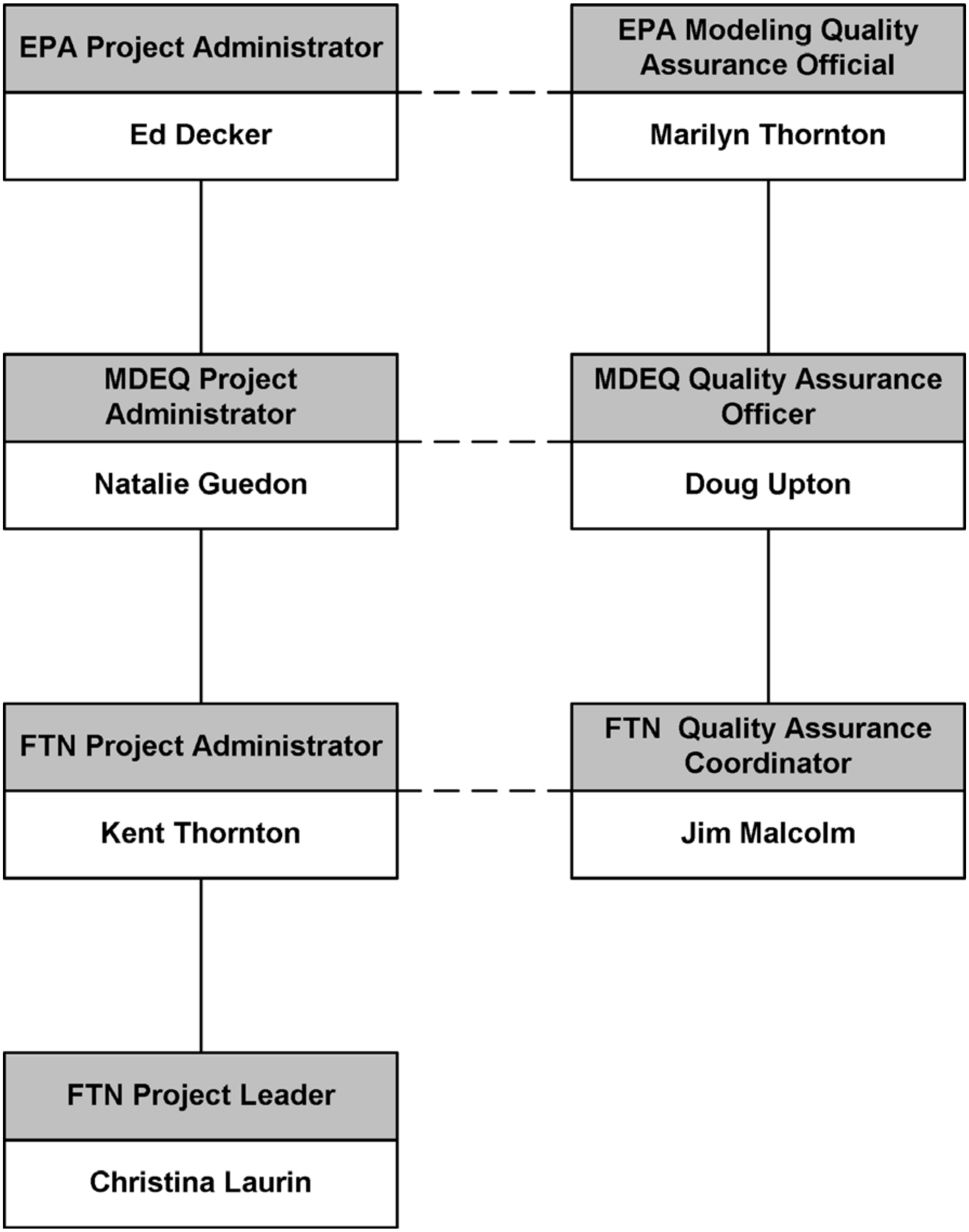

Figure A1 Project organization (dashed lines indicated communication only, solid lines indicated authority).

Table A1. Key positions and areas of responsibilities.

Title	Description of Duties/Responsibilities
EPA Region IV Project Administrator	Establishes the requirements for technical work for the project and reviews project deliverables to determine that standards have been met.
MDEQ Project Administrator	Oversees work performed by the subcontractor for this project to meet EPA project requirements.
FTN Project Administrator	Supervises the assigned project personnel (scientists, technicians, and support staff) in providing for their efficient utilization by directing their efforts either directly or indirectly on projects. Other specific responsibilities include: coordinate project assignments in establishing priorities and scheduling; facilitate the completion of projects within established budgets and time schedules; provide guidance and technical advice to those assigned to projects by evaluating performance; implement corrective actions and provide professional development to staff; prepare and/or review preparation of project deliverables; and interact with clients, technical reviewers, and agencies to ensure technical quality requirements are met in accordance with contract specifications.
FTN Project Leader	Oversees and supervises details of data gathering, data analysis and report preparation and checks work of others to confirm that all aspects of data analysis are done correctly and appropriately.
EPA Region 4 QA Official	Reviews and approves the QAPP. Participates in QA oversight for EPA as required by the contract.
MDEQ QA Officer	Reviews and approves the QAPP. Performs QA oversight of the subcontractor for this project.
FTN QA Coordinator	Is independent of the data analysis for this project. Maintains the official approved project QAPP. Monitors QC activities to determine conformance, distributes quality-related information, trains personnel on QC requirements and procedures, reviews QA/QC plans for completeness and notes inconsistencies, and signs off on the QAPP and reports.

The overall objective of this project is to perform analyses of these and other existing data for these lakes and reservoirs to identify and evaluate:

1. The designated uses for these waterbodies and appropriate management and assessment endpoints for these designated uses;
2. Nutrient criteria approaches and lake/reservoirs classes or categories being used by other US EPA Region IV States;
3. Water quality conditions for Mississippi lakes and reservoirs; and
4. Quantitative relationships linking designated uses, assessment/management endpoints, stressors, and hydrogeomorphic modifiers for Mississippi reservoirs and oxbows, by strata, with 2-Tier thresholds for indicators.

A.6 PROJECT/TASK DESCRIPTION

The data collection and analysis for this project has been divided into six tasks, which are described below. The schedule for completion of these tasks is shown in Table A2.

Table A2. Project schedule.

Completion Date	Task
June 16, 2006	Compile existing data
June 21, 2006	Meeting with Lakes & Reservoirs Nutrient Task Force
July 14, 2006	Identify management endpoints
July 14, 2006	Evaluate class structures for lake nutrient criteria
September 16, 2006	Data analysis
October 27, 2006	Develop criteria recommendations

A.6.1 Gather Existing Water Quality Data

FTN will work with MDEQ to gather the existing water quality databases needed to perform the work under this contract. MDEQ will furnish existing water quality data from MDEQ databases and files to supplement and update its existing data FTN already has on Mississippi lakes and reservoirs.

A.6.2 Meet with Lakes and Reservoirs Nutrient Task Force

FTN will meet and coordinate with the MDEQ Lake and Reservoir Nutrient Task Force (LRNTF) to discuss the scope and approach of this study. This meeting will serve to obtain input and recommendations from the LRNTF. MDEQ will coordinate this meeting. FTN has facilitated previous meetings not only with the LRNTF but also with the combined MDEQ Nutrient Task Force. These combined meetings are critical to developing stream and river criteria that will be protective of lake, reservoir, estuarine and coastal water quality.

A.6.3 Review Designated Uses and Identify Assessment/Management Endpoints

FTN will review the applicable designated uses and assess conditions of lakes included in this project. Reservoir and oxbow lake designated uses are available for Mississippi waterbodies and will be compiled to determine the relative proportion of waterbodies that have identical, as well as different, designated uses. Mississippi designated use categories will be compared with those of other southern states (AL, AR, FL, GA, KY, LA, MO, NC, OK, SC, TN, and TX) to determine the relative proportion of designated use categories for southern lakes and reservoirs. Assessment and management endpoints shall be identified for each of the designated use categories. Some endpoints can be used to assess multiple designated uses. Chlorophyll concentrations, for example, relate to drinking water, recreational and aquatic life uses.

A.6.4 Evaluate Nutrient Criteria and Waterbody Classes or Strata

FTN shall contact Water Quality Coordinators and personnel in state agencies regulating water quality, in US EPA Region IV States of AL, GA, TN, KY, NC, and SC, as well as the neighboring US EPA Region VI States of LA and AR to determine the approaches being used by these states to develop nutrient criteria for their lakes and reservoirs. In addition, approaches used to classify waterbodies or develop waterbody specific criterion, such as are in use in Alabama, will be evaluated. Preliminary classification of reservoirs and oxbows using exploratory statistical procedures has been initiated in Mississippi. These exploratory analyses will be complemented by considering Classification and Regression Tree (CART), and change-point analyses. These statistical procedures were useful in identifying water quality and biological thresholds for Mid-Atlantic watersheds and coastal ecosystems. This classification considers factors such as:

- Lake Surface Area,
- Watershed Area,
- Watershed Drainage Area: Lake Surface Area Ratio,
- Watershed Land Use (Percent Forest, Agricultural, Urban),
- Mainstream vs. Tributary Reservoir,
- Transparency,
- Chlorophyll Concentrations,
- Nutrient Concentrations,
- Suspended Solids Concentrations, and
- N: P Ratio.

Additional factors that will be included in the analyses for this project are ecoregions and geology.

Factors such as residence time and mean depth, which have been used to describe various classes of lakes, are not readily available for many waterbodies. However, where available, this information will be obtained. FTN will consider factors such as reservoir residence time by compiling watershed and morphometric information from different sources to allow a more complete consideration of physical factors such as surface area, and watershed drainage area: surface area ratios.

FTN will explore approaches for assessing the effects of nutrients in light-limited (e.g., sediment dominated) systems using statistical tools such as quantile regression and other approaches (e.g., “residual Secchi disc” analysis).

A.6.5 Data Analyses (Reference Sites and Condition)

The following approaches, among others, may be used for analyzing the data to support nutrient criteria recommendations. The results from the four approaches described below will be integrated to identify reference conditions. Those sites that are coincident with all four approaches will receive higher ranks as reference sites with reference conditions.

- Best professional judgment will be used to identify sites that are considered to be least impaired based on either land use or on best attainable land management (where the most appropriate best management practices have been implemented). The Mississippi Delta is 90% agricultural, and every waterbody is affected by agricultural land use. However, some watersheds have a high level of implementation of best management practices and represent the best attainable condition for this land use. Reservoirs and oxbows in the Delta with this level of watershed management may be identified as candidate reference sites and reference conditions.
- A list of lakes and reservoirs meeting designated uses will be identified and the conditions associated with these waterbodies will be documented. Waterbodies considered to be attaining designated uses, by definition, may serve as reference sites for waterbodies that are not attaining designated uses.
- FTN may use a statistical approach to evaluate the distribution of conditions occurring in various classes of reservoirs and oxbows. Reference sites may be obtained by considering the distributional attributes for various constituents and their relation to designated uses.
- FTN shall evaluate the cross-sectional attributes of lakes and/or reservoirs exhibiting desired endpoint water quality conditions, that were used to develop quantitative relationships for southern lakes and reservoirs. The cross-sectional data will be obtained and reviewed to evaluate the hydrogeomorphological factors associated with these waterbodies and their relationship to Mississippi waterbodies.

A.6.6 Develop Criteria Recommendations

FTN shall use water quality from Mississippi lakes and reservoirs, available lakes and reservoirs water quality quantitative empirical relationships, and other data and approaches that support nutrient criteria recommendations. These recommendations will be both tested and refined using data from the various classes of Mississippi lakes. These quantitative relationships may be used to evaluate the response of these systems to various stressors and hydrogeomorphological factors, and assess uncertainty in predicting system response. While monitored data may be preferred for assessing the status of lake and reservoir condition, empirical relationships, with known confidence, might also be useful in evaluative assessments of lake and reservoir condition for those systems that are not part of the ambient monitoring program. In addition to evaluating the response of these systems to various stressors and hydrogeomorphological factors, the attributes of those systems attaining designated uses and with desired assessment endpoint levels will be noted and used in delineating reference sites and conditions for nutrient criteria recommendations.

A.7 QUALITY OBJECTIVES AND CRITERIA

The quality requirements for the secondary data to be used in this task order reflect the quality that is needed to achieve the desired outcome for the task order. Quantitative data used for data analysis, will be obtained primarily from MDEQ. Qualitative information, which will be used to enhance and guide the data analyses, will be obtained from various sources. Table A3 lists these secondary data and their sources, technical requirements, and quality requirements. The sources of data were selected based on availability (no other readily available sources of these data are known). The sources of the secondary data will be identified in the final report.

FTN will attempt to evaluate the quality of the secondary data in terms of whether the data sets meet the requirements stated in Table A3. The final report will document any use of secondary data of unknown quality. FTN will review all secondary data for reasonableness.

Table A3. List of secondary data and associated quality requirements.

MDEQ Lakes and Reservoirs Nutrient Criteria Sampling Data	
Required or optional	Required
Source of data	MDEQ
Technical requirements	Parameters needed include total nitrogen, nitrate+nitrite, total kjeldahl nitrogen, total phosphorus, soluble reactive phosphorus, total suspended solids, total organic carbon, chlorophyll *a*, temperature, pH, dissolved oxygen, and Secchi transparency.
Quality requirements	Must have met MDEQ's field and laboratory QA/QC requirements for accuracy, precision, bias, and comparability, and the requirements for completeness and representativeness set out in the field QAPP under which this data was collected (MDEQ 2002).
MDEQ Routine Surface Water Sampling Data	
Required or optional	Required
Source of data	MDEQ
Technical requirements	Parameters needed include total nitrogen, nitrate+nitrite, total kjeldahl nitrogen, total phosphorus, soluble reactive phosphorus, total suspended solids, total organic carbon, chlorophyll *a*, temperature, pH, dissolved oxygen, and Secchi transparency.

Table A3 (Contd.)

MDEQ Routine Surface Water Sampling Data (Contd.)	
Quality requirements	Must have met MDEQ's field and laboratory QA/QC requirements for accuracy, precision, bias, and comparability (MDEQ 1998). Requirement for representativeness is that the data must be for lakes/reservoirs with surface area >500 ac, and no more than 10 years old. There is no requirement for completeness, whatever data is available and meets the other specified quality requirements will be used.
Water Body Characteristics Data	
Required or optional	Required
Source of data	Primarily MDEQ, with input from MDWFP, USFS, and USGS
Technical requirements	Parameters needed include latitude and longitude of sampling points, counties in which sampling points are located, water body surface area, watershed area, watershed land use, ecoregion in which sampling points are located, water body type classification, major river basin in which water body is located, mean depth, use classifications, designated uses, if water body is fertilized and by what agency/group, national forest in which sampling points are located, if water body is listed on Mississippi 2004 303(d) list
Quality requirements	Information must have been verified by MDEQ to the extent possible. The requirement for completeness is that the information must be available for at least 95% of the sampling stations. There is no requirement for representativeness.
Designated Uses for Lakes and Reservoirs in Other Southern States	
Required or optional	Required
Source of data	State agencies regulating water quality in AL, AR, FL, GA, KY, LA, MO, NC, OK, SC, TN, and TX
Technical requirements	Information needed includes designated uses for public lakes/reservoirs with surface area > 500 ac in the states listed above.
Quality requirements	Requirement for representativeness is that the information be from the most recent water quality regulations. Requirement for completeness is that information be obtained for at least 95% of the public lakes/reservoirs in all of the states contacted.
Information About Nutrient Criteria Development Approaches in EPA Region 4 and Near States	
Required or optional	Required
Source of data	US EPA Water Quality Coordinators of AL, GA, TN, KY, NC, SC, LA, and AR
Technical requirements	Information on the approaches being used to develop state nutrient criteria for lakes and reservoirs, including any statistical relationships, water body classes for criteria application, and indicators being developed/used.
Quality requirements	There are no requirements for representativeness or completeness, however, more current information is expected to be most useful.
Fisheries Data	
Required or optional	Required
Source of data	MDWFP annual freshwater fisheries reports available from MS Museum of Natural Science Library; Freshwater fisheries summary reports and the MS Fishery Index (MS Fish) produced by the MDWFP.
Technical requirements	Information needed include results from creel and electrofishing surveys conducted on MS public lakes/reservoirs with surface area > 500 acres.
Quality requirements	Must have met MDWFP field QA/QC requirements. Requirement for representativeness is that data must be less than 10 years old. There is no requirement for completeness.

A.8 SPECIAL TRAINING/CERTIFICATION

Personnel performing data analysis for this project will have previous experience with advanced statistical analysis, and be familiar with statistical software packages used. No special certifications are necessary for the analyses in this project.

A.9 DOCUMENTATION AND RECORDS

FTN shall provide oral and written reporting for project activities as required by MDEQ. FTN reporting will include the following:

1. Monthly progress reports shall be submitted with invoices;
2. Meeting with LRNTF to discuss study approaches;
3. Final written report on recommendations for lakes and reservoirs criteria, which will include documentation of data sources, analyses, and resulting equations; and
4. Assistance to MDEQ in communicating defensible technical assessments of criteria recommendations, which will consist of up to two PowerPoint presentations.

The schedule for data reporting activities is shown in Table A4.

Table A4. Report schedule.

Completion Date	Task
June 9, 2006	May progress report to MDEQ
June 22, 2006	Meeting with Lakes & Reservoirs Nutrient Task Force
July 7, 2006	June progress report to MDEQ
August 8, 2006	July progress report to MDEQ
September 8, 2006	August progress report to MDEQ
October 9, 2006	September progress report to MDEQ
November 9, 2006	October progress report to MDEQ
December 8, 2006	November progress report to MDEQ
To be determined	Assistance to MDEQ in communicating defensibility of criteria recommendations
October 27, 2006	Draft project report submittal
November 27, 2006	Receive comments on draft project report
December 21, 2006	Final project report submittal

A.9.1 QAPP Distribution

Upon approval of the QAPP by MDEQ and US EPA, the FTN Project Leader will distribute the QAPP to the individuals listed in Section A3. If any revisions to the QAPP are required afterwards, the revisions will be summarized by FTN and routed to all individuals listed in Section A1 for their approval. After the revisions are approved, the revised QAPP and the summary of the changes will be distributed to the individuals listed in Section A3 with instructions to discard the previous version of the QAPP and replace it with the revised QAPP.

A.9.2 Information in Final Report Package

The final report will include summaries of the data and information gathered and used in this project, documentation of data sources, and documentation of how data was gathered, selected, and used, and the results of the analyses performed. As appropriate, summary statistics, graphs, and tables will be used to summarize information.

A.9.3 Documentation Control and Management

It is anticipated that nearly all internal documentation and record transfer within the project team while the project is ongoing will be done electronically. Hardcopy and electronic submittals of deliverables will be made to MDEQ. The FTN Project Leader, or his designee, will be responsible for electronic and hardcopy documentation version control, updates, storage, tracking, distribution, and disposition. Because existing software will be used for all phases of this project, there is no need to develop any new file types or protocols.

Spreadsheet, database, and word processing files will be stored in the format appropriate for the software. Current and widely used software packages will be used for electronic spreadsheets (Microsoft Excel 2000) and word processing (Microsoft Word).

While the project is ongoing, FTN will store all electronic documentation and data on a central network server with weekly full backups and daily incremental backups (daily backups of files that have been created or modified that day). The backup data are archived on digital tape or optical disc for easy retrieval or recovery.

A.9.4 Disposition of Records and Documents

The governmental authority for storage, access, and disposal of all records after the task order is complete is MDEQ. All relevant records and data pertaining to the project will be sent to MDEQ when MDEQ has approved the final report. MDEQ will control access, storage, and disposal of those records according to its internal procedures.

B. DATA GENERATION AND ACQUISTION

B.1 SAMPLING PROCESS DESIGN

Not relevant

B.2 SAMPLING METHODS

Not relevant

B.3 SAMPLE HANDLING AND CUSTODY

Not relevant

B.4 ANALYTICAL METHODS

Not relevant

B.5 QUALITY CONTROL

Not relevant

B.6 INSTRUMENT/EQUIPMENT TESTING, INSPECTION, AND MAINTENANCE

Not relevant

B.7 INSTRUMENT/EQUIPMENT CALIBRATION FREQUENCY

Not relevant

B.8 INSPECTION/ACCEPTANCE OF SUPPLIES AND CONSUMABLES

Not relevant

B.9 NON-DIRECT MEASUREMENTS

B.9.1 Data Sources

MDEQ will be the primary source for lake and reservoir water quality data needed to establish nutrient criteria (see Table A3). For the past 3 years, MDEQ has sampled 41 oxbow lakes and reservoirs with surface area greater than 500 acres for water quality constituents needed to establish nutrient criteria. These data were collected specifically for use in developing nutrient criteria for Mississippi lakes and reservoirs, so it is an appropriate data set to use. In addition, MDEQ conducts routine ambient water quality monitoring of additional lakes and reservoirs, which will be another good source of data between 3 and 10 years old.

Lake and reservoir fisheries data (Annual Freshwater Fisheries Reports and fisheries summary reports prepared by the Mississippi Department of Wildlife, Fisheries, and Parks) will be obtained from the Mississippi Museum of Natural Science Library in Jackson, MS and from the Mississippi Department of Wildlife, Fisheries, and Parks. In addition, consultation will occur with selected staff of the United States Department of Agriculture (USDA) Agricultural Research Service (ARS) Sedimentation Laboratory concerning their work with oxbow lakes.

Water Quality Coordinators and personnel in state agencies regulating water quality, in US EPA Region IV States of AL, GA, TN, KY, NC, and SC as well as the neighboring US EPA Region VI States of LA and AR will be contacted for information regarding the approaches being used by these states to develop nutrient criteria for their lakes and reservoirs. Designated use categories for lakes and reservoirs in other southern states will be obtained from state environmental agency websites, or through direct contact with personnel from those agencies. Since these agencies are responsible for developing and maintaining this information, they are appropriate sources for this information.

All project deliverables will identify the sources of secondary data used in the deliverable.

B.9.2 Quality of Secondary Data

Acceptance criteria for secondary data to be used in this project are described in Section A6. If the quality of secondary data used in a project deliverable cannot be determined, the deliverable shall contain a disclaimer that identifies where such data are used and how their use may affect the validity of the conclusions. The disclaimer shall be added as a footnote and shall read "Due to the unavailability of QA/QC information the data used in this analysis are of unknown quality." A discussion of how the use of the data affects the study conclusions will be included in the text.

B.10 DATA MANAGEMENT

Water quality data collected from lakes and reservoirs by MDEQ include profiles of in-situ measurements and lab results for grab samples at one to two depths. Data to be used in analyses for this project will be combined into a single database. The primary program to be used to manage and analyze data in this project is Systat v9.01. Data are readily imported into Systat from Excel files. For those waterbodies and dates where both profiles and grab samples were taken, results for grab samples will be associated with in-situ data measured at or near the reported grab sample depths. The analysis file will consist of grab sample results with their associated in-situ measurements.

The grab samples are classified as "top," "bottom," and "mid" samples. For analysis it is preferred to have only two depth classifications, "top" and "bottom," representing eplimnion and hypolimnion conditions. When only one sample is collected ("mid" samples), these samples will be re-classified as "top" samples when they are associated with a dissolved oxygen concentration greater than or equal to 1 mg/L, and as "bottom" samples when they are associated with a dissolved oxygen concentration less than 1 mg/L.

The primary method for combining the water quality results will be electronic file merges in Systat. The resulting merged file will be checked to ensure that data are associated with the correct waterbody and depth classification. In addition, min/max summaries will be examined to identify unusual data values.

Analysis results will be checked by the FTN QA Officer and the MDEQ QA Officer. A description of how electronic data files are stored is included in Section A9.

C. ASSESSMENT AND OVERSIGHT

C.1 ASSESSMENTS AND RESPONSE ACTIONS

Throughout the course of this project, the FTN Project Leader will review and assess the results of each task being performed, including data analysis, or documentation. This review and assessment will occur on a routine, day-to-day basis and will not be formally documented. No special testing methods will be necessary for this assessment due to the nature of the work being performed (e.g., no computer programming that must be tested by running it with a certain set of data). The FTN Project Leader will point out any deficiency (i.e., any error or needed improvement) to the person performing the work; that person will then make the appropriate revision and the FTN Project Leader will confirm that the revision sufficiently addresses the deficiency. The criterion for success in this routine, day-to-day review and assessment is compliance with applicable quality requirements listed in this QAPP.

C.2 REPORTS TO MANAGEMENT

The routine, day-to-day assessments described in Section C1 will not be formally documented for submittal to management. However, FTN will keep MDEQ informed of the status of the task order, including QA/QC issues and activities, through monthly progress reports and routine correspondence (mostly e-mail). The primary detailed reporting of QA/QC activities will be through the QA/QC assessment discussed in Section D.

D. DATA VALIDATION AND USABILITY

D.1 DATA REVIEW, VERIFICATION, AND VALIDATION

Secondary data obtained from previously discussed sources, and analysis results will be reviewed for reasonableness based on best professional judgment of FTN Project Manager and other data analysis personnel.

D.2 VERIFICATION AND VALIDATION METHODS

At a minimum, summary statistics (i.e. min, mean, max) will be examined to determine if the data sets include any unusual values to ensure that data have been entered correctly into the Systat database, and that the reported data are reasonable and useable. Appropriate statistical procedures will be used to determine if data characteristics meet the requirements for application of planned statistical procedures (i.e. normal distribution, lack of bias). Data will be validated prior to its use in analyses.

Before the draft project report is submitted to MDEQ, the FTN QA Coordinator (or his designee) will conduct a QA/QC assessment of the work being documented in the report. This assessment will consist of reviewing data analyses, other calculations, and documentation to see if each quality requirement and criterion in this QAPP has been met. A checklist will be developed to conduct the assessment and document the results. The results of this assessment will be presented to the FTN Project Leader, who will be responsible for correcting any deficiencies noted in the assessment. After any deficiencies are corrected, the FTN QA Coordinator (or his designee) will review the corrections and make notes on the assessment checklist indicating that the deficiencies have been corrected. Any deficiencies that can not be corrected to meet applicable criteria in this QAPP will be documented with an explanation of why the criteria can not be met and what impact the deficiency has on achieving the desired outcome for the project.

D.3 RECONCILIATION WITH USER REQUIREMENTS

The assessment discussed in Section D2 will be conducted with the ultimate purpose of achieving the desired outcome for this project (stated in Sections A6 and A7.1). Secondary and generated data will be assessed in terms of their acceptability for achieving the desired outcome for this task order. In general, results that meet validation criteria (acceptance criteria and performance criteria specified in this QAPP) will be deemed acceptable for achieving the desired outcome for this project.

If validation criteria are not met, the FTN Project Leader and FTN QA Coordinator will document the cause of the criteria not being met and the impact it has on achieving the desired outcome for the project (as noted in Section D2). This documentation will be submitted to MDEQ and will include a recommendation to MDEQ as to whether or not the results of the project should be accepted without limitations, accepted with limitations, or rejected. The results of the project will not automatically be rejected just because a validation criterion was not met; the reason for the deficiency and its impact on the project outcome must be considered. The MDEQ Project Administrator will ultimately decide whether the project results should be accepted without limitations, accepted with limitations, or rejected.

REFERENCES

MDEQ. 1998. Quality Management Plan. Mississippi Department of Environmental Quality. Revised January, 2004.

MDEQ. 2002. Quality Assurance Project Plan for Water Quality Sampling and Analysis for Lakes/Reservoirs Nutrient Criteria Development. Mississippi Department of Environmental Quality, Field Services Division.

APPENDIX B:

LITERATURE REVIEW OF RELATIONSHIP BETWEEN NUTRIENT AND BIOLOGICAL ENDPOINT

COMPILATION OF LAKE AND RESERVOIR NUTRIENT CRITERIA AND NUTRIENT-ENDPOINT RELATIONSHIPS

Prepared for

Mississippi Department of Environmental Quality
PO Box 20305
Jackson, MS 39289-1305

Prepared by

FTN Associates, Ltd.
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June 17, 2003

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

(Note: The Appendices for this document are not included herein.)

1.0 INTRODUCTION

Mississippi Department of Environmental Quality (MDEQ) has established a Nutrient Criteria Task Force to assist it in formulation nutrient criteria for Mississippi waters. The Task Force has three subcommittees: Estuarine, Streams, and Lakes and Reservoirs. The Lakes and Reservoirs Subcommittee has requested that MDEQ summarize information on nutrient criteria developed by other State or Federal Agencies and relationships between nutrients and desired endpoints such as drinking water, fisheries production, aquatic life use, recreation, and similar desired uses. A literature review was conducted to obtain the requested information.

The objective of the review was to identify literature on lakes and reservoirs, with particular emphasis on:

1) Quantitative relationships between nutrients and biological endpoints (e.g., chlorophyll, fish production), and information on Trihalomethane Precursors (THMP) for lakes and reservoirs, and
2) State water quality standards and federal criteria for nutrients, including associated designated uses (e.g., aquatic life use, recreation, fish production, etc.).

2.0 METHODS

The search of the available literature on lakes and reservoirs was performed primarily at the University of Arkansas Mullins Library. Searches were performed on InfoLinks (University of Arkansas electronic library catalog of books) and Biological Abstracts. Searches were limited to the southern United States and focused on nutrients, phosphorus, nitrogen, fish and trihalomethane precursors within lakes or reservoirs. Additionally, several leading researchers were contacted to identify additional relevant reports or articles (see Personal Communications Appendix A).

2.1 Nutrient/Biological Endpoint Linkages and Trihalomethane Precursors

The literature search on nutrient/biological endpoint linkages and trihalomethane precursors focused on the following:

1) Linkages between nutrients or parameters closely related to nutrients (e.g., chlorophyll) and biological parameters (i.e., quantitative or semi-quantitative descriptions of community/population abundance, relative abundance, production, harvest rates, etc.);
2) Published studies specifically addressing linkages between nutrients and trihalomethane Precursors (THMP) for lakes and reservoirs;
3) Published studies specifically addressing effects of suspended sediments on the relationship between nutrients and biological production;
4) Published nutrient or biological criteria related to eutrophication; and
5) Unpublished reports or monitoring programs that include collection of necessary data types (e.g., concurrent collection of nutrient, and biological parameters).

Additional information summarized from relevant studies included information on waterbody type, size, location and morphometery that might be useful in developing general categories of lakes/reservoirs. The emphasis was on published studies or readily available reports. However, readily available unpublished sources were also compiled.

2.2 State and Federal Nutrient Criteria

State and federal nutrient criteria were compiled from state water quality criteria documents and EPA nutrient criteria guidance available on state and EPA websites. This information is intended to supplement state criteria that might not be available on state websites, rather than provide an exhaustive review of state and federal development of nutrient criteria.

3.0 RESULTS AND DISCUSSION

A list of references found to contain pertinent information on nutrients, suspended sediments and TMPH is provided in Appendix B.

3.1 Nutrients and Biological Endpoints

A search of the literature revealed 2,844 papers discussing nutrients in lakes or reservoirs. Of these 354 also dealt with fish production or fish communities. These 354 papers formed the core of the literature review. Papers were reviewed if the lakes were within the southern tier of states (AR, AL, FL, GA, KY, LA, MS, NC, OK, SC, TN, TX). Of approximately 70 reports and journal articles reviewed, 53 sources described quantitative or qualitative relationships between nutrients and biological endpoints. A total of 149 quantitative equations or qualitative relationships linking biological endpoints to water quality parameters were identified. A summary of the information in each of these relationships is provided Appendix C.

Eighteen univariate quantitative equations were compiled describing relationships between phosphorus and chlorophyll a (an additional five multivariate equations are included in the MS Excel spreadsheet). Figure 1 shows these eighteen equations plotted on one graph as well as EPA chlorophyll a and phosphorus guidance criteria for three Mississippi Nutrient Ecoregions (and one from neighboring Arkansas and Alabama) and the nutrient criteria approved by EPA for Georgia and South Carolina (see Table 1). The plotted line from the 18 equations represents the range of empirical chlorophyll-phosphorus relationships found in the literature review. The plotted points indicate how EPA guidance criteria and state water quality criteria compare to these empirical relationships. The figure indicates that the EPA guidance and South Carolina criteria are in general agreement with published empirical relationships. The Georgia criteria show less agreement.

3.2 Nutrients, Suspended Solids and Biological Endpoints

Of the 70 reports and journal articles reviewed, 12 sources provided quantitative or qualitative relationships among suspended sediments and nutrients or biological endpoints. These sources describe primarily the relationships between secchi depth and parameters such as chlorophyll a or suspended sediments. A summary of the information in each of these relationships is provided Appendix D.

3.3 Trihalomethane Precursors

A search of the literature revealed 331 papers pertaining to trihalomethane. Of these, only 9 discussed THMP. Of the original 331 reports and journal articles, 28 dealt with lakes or reservoirs and none were within the southern tier of states. Most of these articles addressed drinking water treatment and removal of trihalomethane but five papers had relevant results which are summarized in Appendix E. Evidence indicates that biological parameters (primary production) are related to THMP production.

3.4 State and Federal Nutrient Criteria

EPA's website (http://www.epa.gov/waterscience/standards/states/) was used to obtatin nutrient criteria from water quality standards regulations for 13 southern states (Appendix F). If regulations did not discuss nutrients, phosphorus, nitrogen, or chlorophyll a, the responsible state agency was contacted to determine if a state had numeric nutrient criteria. State water quality criteria for nutrients and related parameters are summarized for the southern tier of states in Appendix G.

EPA's website (http://www.epa.gov/waterscience/criteria/nutrient/ecoregions/lakes/index.html) was reviewed to download EPA nutrient ecoregion criteria for the three ecoregions within Mississippi (Ecoregions IX, X, and XII) and one from neighboring Alabama and Arkansas (Ecoregion XI) (Appendix H).

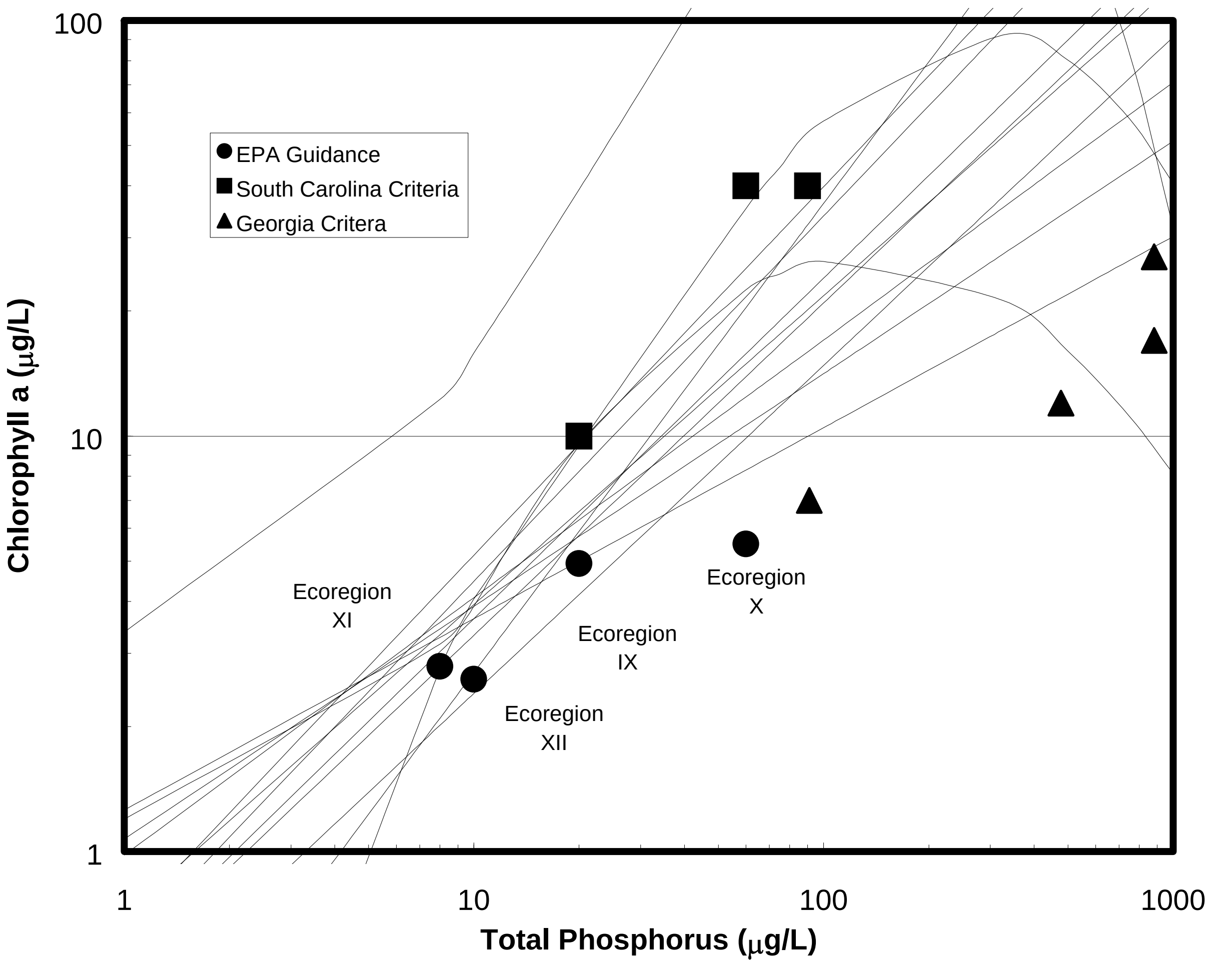
Four states had approved numeric criteria for chlorophyll a, three states had numeric criteria for phosphorus, and two states had numeric criteria for nitrogen (Table 1). Alabama and Georgia have developed numeric criteria for specific lakes, North Carolina for specific designated uses (trout waters and non-trout waters), South Carolina for ecoregions within the state, and Arkansas for the entire state.

Table 1. Numeric Standards adopted by southern states and EPA guidance criteria for related ecoregions. States with approved standards for more than one lake or ecoregion are represented by a range describing their minimum to maximum.

Parameter	Source	State or Ecoregion	Standard or Guidance
Chlorophyll a (□g/L)	State Criteria	AL	5 – 27
		GA	5 – 27
		NC	15 or 40
		SC	10 or [illegible]
	EPA Ecoregion Guidance	IX X XI[1] XII	4.93 5.5 2.79 2.6
Total Phosphorus (□g/L)	State Criteria	AR	50
		GA	91 – 2022
		SC	20 – 90
	EPA Ecoregion Guidance	IX X XI[1] XII	20 60 8 10
Total Nitrogen (mg/L)	State Criteria	GA	3 or 4
		SC	0.35 or 1.5
	EPA Ecoregion Guidance	IX X XI[1] XII	0.36 0.57 0.46 0.60

[1]EPA ECOREGION XI IS NOT FOUND IN MISSISSIPPI (IT IS FOUND IN NEIGHBORING ARKANSAS AND ALABAMA)

FIGURE 1. PLOTS OF EIGHTEEN QUANTITATIVE CHLOROPHYLL A AND



PHOSPHORUS RELATIONSHIPS COMPILED FROM THE LITERATURE. GEORGIA, AND SOUTH CAROLINA WATER QUALITY CRITERIA AND EPA GUIDANCE ARE SHOWN AS POINTS (MORE THAN ONE POINT DENOTES EITHER SEPARATE LAKE OR ECOREGION CRITERIA).

APPENDIX C:

MsFish Index Procedures

Procedures for Calculating the MsFish Index

PROVIDED BY BUREAU OF FISHERIES, MISSISSIPPI

DEPARTMENT OF WILDLIFE, FISHERIES AND PARKS

January 5, 2006

MsFish allows anglers to objectively compare waters across the state in terms of potential fishing success. Scores are based on fish population quality (fish abundance, size structure & condition) and angler results (catch rate, fish sizes, targeted effort). Higher scores along the 100-point scale indicate better fishing potential. MsFish is only a guide and can not be expected to meet all angler expectations and does not indicate the status of a fishery relative to that waterbody's potential. This index is a modified version of the Sport Fishing Index developed by TVA. Anglers and fishery managers may use MsFish for general comparisons and trends.

Data Requirements

Five parameters are scored up to 20 points each and are then added to get a total score for bass (all Micropterus spp.), bream (bluegill, redear, and longear), and crappie (all Pomoxis spp.) in each waterbody meeting sample requirements. Electrofishing (E) and creel (C) are used to obtain data for the five parameters.

1. Population quality (E)
2. Fish abundance (E)
3. Angler catch rate (C)
4. Average size fish kept (C)
5. Target species (C).

Both creel and electrofishing (fall only) are required to compute an index. Data for either electrofishing or creel must be collected during the year for which the MsFish score is calculated. No data can be more than two years old. The most current data must be used if it is available for consecutive years. Tournaments occurring on random sample days are considered part of standard access or roving creel surveys. Separate tournament data may be used for angler catch rate and average size of fish kept in the absence of standard creel data. However, if tournament data is used in the absence of standard creel, at least five tournaments must be reported on a given waterbody and all tournaments reported must be used. All five parameters must be used to compute scores with two exceptions: 1) average size of fish kept may be excluded when passive creel techniques preclude data reliability and 2) target species is omitted when tournament data is used in the absence of standard creel. In the case of these two exceptions, an adjusted index is computed by averaging the four parameters and multiplying by five. Sample sizes and procedures must follow MDWFP Protocols for Inland Fisheries.

Scoring Criteria for Parameters:

Criteria to score the five parameters listed below were developed by fishery managers based on their experiences in Mississippi.

1. **Population quality**: Each of five elements contributes 20% to the score. Four elements (PSD and RSDp,m,t) are based on recognized standards for multi-species fisheries (Gablehouse 1984). Mean Wr is computed for fish ≥ stock sizes only. Stock sizes are: largemouth bass ≥ 20cm; smallmouth & spotted bass ≥ 18cm; black & white crappie ≥ 13cm; bluegill & longear ≥ 8cm; redear ≥ 10cm.

Criteria	Black Bass Score			Crappie Score			Bream Score		
	0	2	4	0	2	4	0	2	4
PSD	<20 or >80	20-39 or 71-80	40-70	<20	20-60	>60	<10 or >80	10-19 or 61-80	20-60
RSDp	0 or >60	1-9 or 41-60	10-40	0	1-30	>30	0 or >40	1-4 or 21-40	5-20
RSDm	0 or >25	1-4 or 11-25	5-10	0	1-10	>10	0 or >25	11-25	1-10
RSDt	0	<1	≥1	0	<1	≥1	0	<1	≥1
Wr	<90	>110	90-110	<90	>110	90-110	<90	>110	90-110

2. **Fish abundance**: Use number of fish ≥ stock size per mile of electrofishing.

	Score		
	0	10	20
Bass	<16	16-40	>40
Crappie	<8	8-13	>13
Bream	<32	32-80	>80

3. **Angler catch rate**: Use average catch/hour for targeted effort only and for all sizes of fish kept and released. Use standard creel data instead of tournament data if both are available. Fish/angler day is used for bass tournament data in the absence of standard creel data.

Criteria	Score		
	0	10	20
Bass/hour	<0.3	0.3-0.6	>0.6
Crappie/hour	<0.6	0.6-1.2	>1.2
Bream/hour	<1.5	1.5-3	>3
Bass/day	<1.1	1.1.-2.3	>2.3

4. **Average size fish kept**: These criteria include average weights (pounds) and lengths (inches) for standard creel data and tournament data (used in the absence of standard creel).

Criteria	Score		
	0	10	20
Bass weight	<1	1-3	3
Bass length	<12	12-17	>17
Crappie weight	<.5	.5-.75	>.75
Crappie length	<10	10-11.5	>11.5
Bream weight	<.3	.3-.5	>.5
Bream length	<7	<7-8.5	>8.5

5. **Target species**: Percentage of anglers targeting certain species is an indicator of popularity and may reflect fishery qualities (fish and environment) that are conducive to fishing success or enjoyment. Skip this parameter if using tournament data only.

	Score		
	0	10	20
Bass	<25	25-50	>50
Crappie	<25	25-50	>50
Bream	<25	25-50	>5

MsFish Calculation Procedure:

Waterbody: ___________________________ Species: _____________________

	Data Value	Score (0,2,4)
PSD		
RSDp		
RSDm		
RSDt		
Wr		
		Score (0,10,20)
Population Quality (Sum of 5 scores)		0
Abundance		
Angler Catch Rate		
Average Size Kept		
Targeted Species		
Total MsFish Score (Sum of 5 Scores)		0

If less than 5 parameters are used, the MsFish score is reported and calculated as follows:

Number of Parameters Used _______
Sum of MsFish Scores _______
Sum/No. of Parameters * 5 _______ (Adjusted MsFish)

Distance Sampling

Based on 305 collections by MDWFP (data file below), a regression between watch time (minutes) and distance (km) was used to develop equations 3 & 4 in Chapter 9 Monitoring Protocols for Inland Fisheries p 220.

On average (equation 4), we travel 1.48 km in 30 min, or almost 1 mile (1 mile = 1.609 km).

MsFish criteria were adjusted as shown below. To convert number/km to CPD (fish/mile of electrofishing): number/km * 1.61.

Abundance	**Bass**		
Scores	0	2	4
Number/hr (box)	<30	30-70	>70
Number/km	<10	10-25	>25
Number/mile	<16	16-40	>40
	Crappie		
Number/hr (box)	<15	15-30	>30
Number/km	<5	5-10	>10
Number/mile	<8	8-13	>13
	Bream		
Number/hr (box)	<60	60-150	>150
Number/km	<20	20-50	>50
Number/mile	<32	32-80	>80

APPENDIX D:

Find MsFish Scores for Waterbodies Sampled by MDQFP

Table D.1. Average unscaled MsFish scores from each waterbody sampled by MDFWP.

Lake Name	Fishery		
	Bass	Crappie	Other sunfish
Aberdeen	49	69	15
Aliceville	34	73	20
Arkabutla	44	86	27
Bee	52	80	38
Clarkco	72	7	25
Columbus	46	80	18
Enid	46	88	27
Geiger	69	28	29
Grenada	33	67	No Score
Lamar Bruce	71	45	59
Lincoln	68	30	38
Lowndes	73	20	66
Moon	40	76	6
Sardis	52	90	44
Tombigbee State Park	71	No Score	58
Trace State Park	76	13	67
Tunica Cutoff	25	68	37
Claude Bennett	65	47	33
Columbia	63	18	46
DeSoto	54	56	42
Jeff Davis	57	33	51
Kemper	63	29	16
Lock B Tenn Tom	42	62	2
Mary Crawford	62	38	39
Monroe	59	51	59
Mossy	23	60	12
Natchez State Park	58	20	30
Paul B. Johnson	67	43	29
Percy Quinn State Park	62	30	2
Pickwick	43	56	26
Ross Barnett Lake	64	19	37
Ross Barnett Reservoir	54	63	25
Tangipahoa	66	10	18
Tippah	63	53	58
Washington	41	63	45
Bay Springs	49	48	33
Beulah	12	52	38
Bogue Homa	48	31	30
Charlie Capps	51	54	11
Eagle	51	48	40
Elvis Presley	No Score	54	No Score
Little Round	22	54	12
Lock A Tenn Tom	35	No Score	2
Lock C Tenn Tom	36	44	4
Lock D Tenn Tom	53	14	12
Mike Conner	36	23	49
Okatibbee	34	56	16
Oktibbeha	52	48	44
Perry	52	37	53
Roosevelt	45	12	46
Simpson	45	16	36
Whittington	39	48	32

Table D.2. Average scaled MsFish scores from each waterbody sampled by MDFW.

Lake Name	Fishery		
	Bass	Crappie	Other Sunfish
Aberdeen	49	69	15
Aliceville	34	73	20
Arkabutla	44	86	27
Bee	52	80	38
Clarkco	72	7	25
Columbus	46	80	18
Enid	46	88	27
Geiger	69	28	29
Grenada	33	67	No Score
Lamar Bruce	71	45	59
Lincoln	68	30	38
Lowndes	73	20	66
Moon	40	76	6
Sardis	52	90	44
Tombigbee State Park	71	No Score	58
Trace State Park	76	13	67
Tunica Cutoff	25	68	37
Claude Bennett	65	47	33
Columbia	63	18	46
DeSoto	54	56	42
Jeff Davis	57	33	51
Kemper	63	29	16
Lock B Tenn Tom	42	62	2
Mary Crawford	62	38	39
Monroe	59	51	59
Mossy	23	60	12
Natchez State Park	58	20	30
Paul B. Johnson	67	43	29
Percy Quinn State Park	62	30	2
Pickwick	43	56	26
Ross Barnett Lake	64	19	37
Ross Barnett Reservoir	54	63	25
Tangipahoa	66	10	18
Tippah	63	53	58
Washington	41	63	45
Bay Springs	49	48	33
Beulah	12	52	38
Bogue Homa	48	31	30
Charlie Capps	51	54	11
Eagle	51	48	40
Elvis Presley	No Score	54	No Score
Little Round	22	54	12
Lock A Tenn Tom	35	No Score	2
Lock C Tenn Tom	36	44	4
Lock D Tenn Tom	53	14	12
Mike Conner	36	23	49
Okatibbee	34	56	16
Oktibbeha	52	48	44
Perry	52	37	53
Roosevelt	45	12	46
Simpson	45	16	36
Whittington	39	48	32

APPENDIX E:

NUTRIENT CRITERIA FOR MISSISSIPPI LAKES AND RESERVOIRS: SMALL LAKES AND RESERVOIRS ADDENDUM

NUTRIENT CRITERIA FOR MISSISSIPPI LAKES AND RESERVOIRS: SMALL LAKES AND RESERVOIRS ADDENDUM

Prepared For

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March 15, 2007

EXECUTIVE SUMMARY

This document is prepared as an addendum to the draft Nutrient Criteria for Mississippi Lake and Reservoirs submitted to the Mississippi Department of Environmental Quality (MDEQ) on February 8, 2007. During November and December 2004 and March, April, June, July, August, September and October of 2005, MDEQ sampled 45 selected lakes and reservoirs between 100 and 500 acres in surface area (Table ES.1). These "small lakes and reservoirs" listed in Table ES.1 were sampled per MDEQ protocols between November 2004 and October 2005 mainly between April and September. The purpose of the analysis presented herein is to provide support for extending the nutrient criteria recommendations presented in the draft Nutrient Criteria for Mississippi Lake and Reservoirs to the small lakes and reservoir data set. Per the analysis presented in the draft Nutrient Criteria for Mississippi Lake and Reservoirs (which focused on reservoirs and oxbow lakes larger than 500 acres in surface area), data collected from the surface during the months of June through September were used in the analysis. This analysis of the small lakes and reservoirs (between 100 and 500 acres in surface area) continues the focus on the application of the MsFish index in the development of nutrient criteria as presented in the draft Nutrient Criteria for Mississippi Lake and Reservoirs.

Data Analysis

The primary objective of the data analysis was to evaluate

- "Natural" groupings of waterbodies within the small lakes and reservoir data set;
- Whether the relationships among parameters in the small lakes and reservoir data set was comparable to the results obtained in the analysis of reservoirs and oxbows larger 500 acres; and
- Whether the small lakes and reservoirs were similar or dissimilar, as a group, from oxbow lakes and reservoirs larger than 500 acres in surface area. The focus of this analysis was on variables most directly related to nutrient criteria, that is, Total phosphorus (TP), Total nitrogen (TN), Secchi depth (SD), and Chlorophyll-a (Chl-a).

Table ES.1. List of lakes and reservoirs between 100 and 500 acres in surface area sampled by MDEQ during November 2004 through October 2005.

Name	Acres	Type	County
Anchor Lake	304	Reservoir	Pearl River
Archusa Creek Water Park	459	Reservoir	Noxube
Artonish Lake	116	Oxbow	Wilkinson
Bailey Lake	124	Reservoir	Carroll
Bonita Reservoir	120	Reservoir	Lauderdale
Butler Lake	130	Reservoir	Adams
Crystal Lake	200	Reservoir	Rankin
Davis Lake	194	Reservoir	Chickasaw
Dump Lake	406	Oxbow	Yazoo
Fields Lake	213	Oxbow	Adams
Filter Lake	107	Oxbow	Issaquena
Flatland Lake	359	Oxbow	Jefferson
Flower Lake	441	Oxbow	Tunica
Gilliard Lake	400	Oxbow	Wilkinson
Halpino Lake	324	Oxbow	Warren
Hennington Lake	203	Reservoir	Lamar
Henry Lake	134	Oxbow	Leflore
Horseshoe Lake (Stovall Lake)	383	Oxbow	Coahoma
Hurricane Lake	111	Reservoir	Lincoln
Jeff Davis Lake	113	Reservoir	Jefferson Davis
Lake Charlie Capps	237	Reservoir	Bolivar
Lake Copiah	149	Reservoir	Copiah
Lake George	307	Oxbow	Yazoo
Lake Hide-A-Way	188	Reservoir	Pearl River
Lake Jackson	163	Oxbow	Washington
Lake Lorman	171	Reservoir	Madison
Lake Lowndes	116	Reservoir	Lowndes
Lake Mary Crawford	149	Reservoir	Lawrence
Lake Mohawk	157	Reservoir	Tippah
Lake Monroe	111	Reservoir	Monroe
Lake Tom Bailey	181	Reservoir	Lauderdale
Little Eagle Lake	191	Oxbow	Humphreys
Loakfoma Lake	458	Reservoir	Clarke
Long Creek Reservoir	231	Reservoir	Lauderdale
Long Lake	108	Oxbow	Sunflower
LT 7 1 Chewalla Reservoir	229	Reservoir	Marshall
LT 7 3 Big Snow Lake	116	Reservoir	Benton
Maynor Creek Water Park	419	Reservoir	Wayne
Neshoba County Lake	225	Reservoir	Neshoba
Oktibbeha County Lake	393	Reservoir	Oktibbeha
Shadow lake	106	Reservoir	Scott
Sixmile lake	121	Oxbow	Leflore
Thornburg Lake	102	Oxbow	Adams
Tippah County Lake	154	Reservoir	Tippah
Walnut Lake	143	Oxbow	Tunica

Data Analysis Conclusions

The following conclusions can be drawn based on the analysis of data from the small lakes and reservoirs.

1. The relationships among variables within the small lakes and reservoirs data set was similar to that of the reservoirs and oxbows larger than 500 acres.
2. Most of the variation in either data set could be explained by groups of variables corresponding to ionic strength, overall productivity and TP/clarity.
3. Levels of TN, TP, SD, and Chl-a were similar among categories of reservoirs.
4. Oxbows between 100 and 500 acres might have a larger tendency for light limitation than larger oxbows as seen in their tendency for higher TP and TN and lower Chl-a and clarity.
5. The analysis of the lakes and reservoirs between 100 and 500 acres supported the general classification of Mississippi lakes into reservoirs and oxbows.

Criteria Development for Small Lakes and Reservoirs

Development of water quality criteria for lakes and reservoirs between 100 and 500 acres focused on the use of the MsFish index as an indicator of aquatic life use attainment as recommended in the draft Nutrient Criteria for Mississippi Lake and Reservoirs. There were five reservoirs within the small lakes and reservoir data set for which MsFish scores were available.

As part of nutrient criteria development, the additional data from the small reservoirs could be combined with the analysis presented in the draft Nutrient Criteria for Mississippi Lake and Reservoirs which was based solely on reservoirs larger than 500 acres. The percentile values resulting from this combined analysis (i.e., reservoirs larger than 100 acres) are presented in Table ES.2. Table ES.2 indicates that percentile values for reservoirs larger than 500 acres vs. those for reservoirs larger than 100 acres are very similar. Therefore, the recommended TP, TN, SD, and Chl-a criteria for reservoirs larger than 500 acres as presented in the draft Nutrient Criteria for Mississippi Lake and Reservoirs can be modified to include reservoirs larger than 100 acres as shown in Table ES.3.

Table ES.2. Comparison of percentile values for TP, TN, Chl-a, and SD in relation to MsFish categories in reservoirs using only data from reservoirs larger than 500 acres (in parentheses) vs. the combined data (reservoirs larger than 100 acres).

MsFish Category	Percentile	Parameter TP (µg/L)	TN (µg/L)	Chl-a (µg/L)	SD (m)
Low	25th	25 (20)	400 (410)	5.8 (5.5)	0.51 (0.64)
	50th	40 (40)	540 (540)	9.5 (9.3)	0.80 (0.87)
	75th	50 (50)	705 (700)	14.7 (14.5)	1.30 (1.30)
	n	135 (99)	135 (99)	130 (96)	135 (99)
Medium	25th	40 (40)	680 (678)	11.1 (11.3)	0.35 (0.38)
	50th	60 (60)	850 (850)	16.1 (15.6)	0.48 (0.50)
	75th	90 (90)	1020 (980)	20.8 (19.6)	0.70 (0.79)
	n	155 (113)	155 (113)	150 (108)	154 (113)
High	25th	40 (30)	590 (580)	8.9 (9.0)	0.45 (0.50)
	50th	50 (50)	760 (770)	12.9 (13.0)	0.65 (0.68)
	75th	90 (80)	1020 (990)	20.3 (19.4)	0.95 (0.95)
	n	162 (130)	161 (129)	159 (127)	158 (126)

n = the number of data points on which the percentiles are based.

Table ES.3. Recommended criteria values for TP, TN, Chl-a, and SD for reservoirs larger than 100 acres.

Basis	TP (µg/L)	TN (µg/L)	Chl-a (µg/L)	SD (m)
Modified Recommended Criteria	90 (90*)	1020 (980*)	20.3 (19.6*)	0.45 (0.50*)

*Recommended criteria for reservoirs longer than 500 acres as presented in the draft Nutrient Criteria for Mississippi Lakes and Reservoirs are given in parentheses for comparison.

Evaluation of Recommended Criteria

The MsFish information from the small reservoirs can be used to evaluate the reservoir criteria presented in Section 6 of the draft Nutrient Criteria for Mississippi Lakes and Reservoirs. Based on that analysis, reservoirs with:

- Levels of TN, TP, SD and Chl-a that exceed recommended criteria should show "Low" MsFish scores;
- Levels of TN, TP, SD, and Chl-a near (slightly above or below) recommended criteria should show "Medium" or "High" MsFish scores depending on habitat; and
- Levels of TN, TP, SD, and Chl-a that are less than the recommended criteria can show "High", "Medium" or "Low" MsFish scores depending on habitat and nutrient limitation.

The comparison of the MsFish categories from the small reservoirs with the recommended criteria for reservoirs larger than 500 acres indicates that the nutrient data from the small reservoirs, in conjunction with the available MsFish data can be used as a test of the recommended criteria based on reservoirs larger than 500 acres.

Although this test data set is small, with only five reservoirs having MsFish data, the small reservoir data set conforms to expectations based on the analysis from reservoirs larger than 500 acres. This result suggests that criteria based on the MsFish index provide robust indicators of aquatic life use attainment that is applicable to a wide range of reservoirs. Therefore, because the data from the small reservoirs conforms to expectations based on the reservoirs larger than 500 acres, the two data sets can be combined to provide TP, TN, SD, and Chl-a data applicable to reservoirs larger than 100 acres as presented in Table ES.3.

Based on the results of the MsFish-based approach in reservoirs, it is recommended that additional data be obtained from oxbow systems to provide a basis for TP, TN SD, and Chl-a criteria in oxbow systems.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

1.0 INTRODUCTION

This document is prepared as an addendum to the draft Nutrient Criteria for Mississippi Lakes and Reservoirs submitted to the Mississippi Department of Environmental Quality (MDEQ) on February 8, 2007. During November and December 2004 and March, April, June, July, August, September and October of 2005, MDEQ sampled 45 selected lakes and reservoirs between 100 and 500 acres in surface area (Table 1.1). These "small lakes and reservoirs" listed in Table 1.1 were sampled per MDEQ protocols three to five times each between November 2004 and October 2005 mainly between April and September. The purpose of the analysis presented herein is to provide support for extending the nutrient criteria recommendations presented in the draft Nutrient Criteria for Mississippi Lake and Reservoirs to the small lakes and reservoirs. Per the analysis presented in the draft Nutrient Criteria for Mississippi Lake and Reservoirs (which focused on reservoirs and oxbow lakes larger than 500 acres in surface area), data collected from the surface during the months of June through September were used in the analysis. This analysis of the small lakes and reservoirs continues the focus on the application of the MsFish index in the development of nutrient criteria as presented in the draft Nutrient Criteria for Mississippi Lake and Reservoirs.

Table 1.1. List of lakes and reservoirs between 100 and 500 acres in surface area sampled by MDEQ during November 2004 through October 2005.

Name	Acres	Type	County
Anchor Lake	304	Reservoir	Pearl River
Archusa Creek Water Park	459	Reservoir	Noxube
Artonish Lake	116	Oxbow	Wilkinson
Bailey Lake	124	Reservoir	Carroll
Bonita Reservoir	120	Reservoir	Lauderdale
Butler Lake	130	Reservoir	Adams
Crystal Lake	200	Reservoir	Rankin
Davis Lake	194	Reservoir	Chickasaw
Dump Lake	406	Oxbow	Yazoo
Fields Lake	213	Oxbow	Adams
Filter Lake	107	Oxbow	Issaquena
Flatland Lake	359	Oxbow	Jefferson
Flower Lake	441	Oxbow	Tunica
Gilliard Lake	400	Oxbow	Wilkinson
Halpino Lake	324	Oxbow	Warren
Hennington Lake	203	Reservoir	Lamar
Henry Lake	134	Oxbow	Leflore
Horseshoe Lake (Stovall Lake)	383	Oxbow	Coahoma
Hurricane Lake	111	Reservoir	Lincoln
Jeff Davis Lake	113	Reservoir	Jefferson Davis
Lake Charlie Capps	237	Reservoir	Bolivar
Lake Copiah	149	Reservoir	Copiah
Lake George	307	Oxbow	Yazoo
Lake Hide-A-Way	188	Reservoir	Pearl River
Lake Jackson	163	Oxbow	Washington
Lake Lorman	171	Reservoir	Madison
Lake Lowndes	116	Reservoir	Lowndes
Lake Mary Crawford	149	Reservoir	Lawrence
Lake Mohawk	157	Reservoir	Tippah
Lake Monroe	111	Reservoir	Monroe
Lake Tom Bailey	181	Reservoir	Lauderdale
Little Eagle Lake	191	Oxbow	Humphreys
Loakfoma Lake	458	Reservoir	Clarke
Long Creek Reservoir	231	Reservoir	Lauderdale
Long Lake	108	Oxbow	Sunflower
LT 7 1 Chewalla Reservoir	229	Reservoir	Marshall
LT 7 3 Big Snow Lake	116	Reservoir	Benton
Maynor Creek Water Park	419	Reservoir	Wayne
Neshoba County Lake	225	Reservoir	Neshoba
Oktibbeha County Lake	393	Reservoir	Oktibbeha
Shadow lake	106	Reservoir	Scott
Sixmile lake	121	Oxbow	Leflore
Thornburg Lake	102	Oxbow	Adams
Tippah County Lake	154	Reservoir	Tippah
Walnut Lake	143	Oxbow	Tunica

2.0 NUTRIENT CONDITIONS IN MISSISSIPPI SMALL LAKES AND RESERVOIRS

2.1 Data Analysis Methods

The primary objectives of the data analysis were to evaluate

- "Natural" groupings of waterbodies within the small lakes and reservoir data set.
- Whether the relationships among parameters in the small lakes and reservoir data set was comparable to the results obtained in the analysis of reservoirs and oxbows larger 500 acres; and
- Whether the small lakes and reservoirs were similar or dissimilar, as a group, from oxbow lakes and reservoirs larger than 500 acres in surface area.

The focus of this analysis was on variables most directly related to nutrient criteria, that is, Total Phosphorus (TP), Total Nitrogen (TN), Secchi Depth (SD), and Chlorophyll-a (Chl-a) concentrations.

No formal classification procedures such as cluster analysis or descriminant functions analysis were performed. All statistical computations were performed using Systat version 9.01 (Systat 1998).

The first step in the data analysis was to evaluate relationships among variables and sampling locations using principal components analysis (PCA). Analysis of the distribution of raw data indicated approximately log normal distributions for all variables except pH. Therefore, all data values except pH were log(10) transformed before analysis. Principle components were calculated using the varimax rotation and the variance associated with each principal component (PC) was evaluated visually. Parameter values for each sampling station on each sampling date were converted to PC scores for evaluating relationships among sampling locations.

PCA results were analyzed to:

- Compare the data structure of the lakes and reservoirs greater than 500 acres, the small lakes and reservoirs and the combined data (lakes and reservoirs greater than 500 acres + small lakes and reservoirs i.e., lakes and reservoirs greater than 100 acres) by identifying and comparing groups of co-varying variables (i.e., factors);and
- Identify groupings (if any) of sampling stations to identify lake type categories in addition to those identified in the analysis of reservoirs and oxbow lakes larger than 500 acres.

As in the analysis of reservoirs and oxbow lakes larger than 500 acres the data analysis focused entirely on the surface samples. PC were calculated using the varimax rotation and the variance associated with each PC was evaluated visually. Parameter values for each sampling station on each sampling date were converted to PC scores for evaluating relationships among sampling locations.

2.2 Data Analysis Results and Discussion

2.2.1 PCs Analysis

Results of the PCA analysis are presented in Table 2.2, 2.3 and 2.4. Results presented in Table 2.2 are from the analysis of the reservoirs and oxbows larger than 500 acres as presented in Table 4.3 of the draft Nutrient Criteria for Mississippi Lake and Reservoirs. Results presented in Table 2.3 are from the PCA analysis of the combined data from reservoirs and oxbows larger than 100 acres. Results presented in Table 2.4 are from the PCA analysis of the data from the small lakes and reservoirs.

Table 2.2. Summary of results of PCs analysis on data from reservoirs and oxbows larger than 500 acres.

Variable	PC1	PC2	PC3
Conductivity	0.050	0.976	0.093
Total alkalinity	0.096	0.932	0.160
Chloride	0.076	0.773	0.113
Hardness	0.056	0.961	0.130
COD	0.772	0.009	0.193
TOC	0.866	-0.006	0.173
TKN	0.727	0.262	0.363
Chl-a	0.706	0.437	0.328
TP	0.442	0.303	0.672
SD	-0.260	-0.116	-0.881
TSS	0.225	0.213	0.771
Turbidity	0.150	0.015	0.927
Percent of Total Variance Explained	21	27	23
Interpretation of PC Axis	Overall productivity	Ionic strength	TP and clarity

Table 2.3. Summary of results of PCs analysis on data from reservoirs and oxbows larger than 100 acres.

Variable	PC1	PC2	PC3
Conductivity	0.120	0.953	0.118
Total alkalinity	0.165	0.894	0.173
Chloride	0.128	0.802	0.141
Hardness	0.116	0.933	0.144
COD	0.791	0.041	0.095
TOC	0.882	-0.028	0.117
TKN	0.784	0.225	0.351
Chl-a	0.619	0.387	0.294
TP	0.435	0.302	0.646
SD	-0.033	-0.114	-0.891
TSS	0.220	0.221	0.773
Turbidity	0.149	0.028	0.924
Percent of Total Variance Explained	20	23	19
Interpretation of PC Axis	Overall productivity	Ionic strength	TP and clarity

Shaded cells indicate groups of variables that load on each PC axis.

Table 2.4. Summary of results of PCs analysis on data from the small lakes and reservoirs.

Variable	PC1	PC2	PC3	PC4
Conductivity	0.948	0.079	0.192	0.020
Total alkalinity	0.879	0.125	0.326	0.002
Chloride	0.849	-0.091	0.083	0.136
Hardness	0.923	0.041	0.225	-0.018
COD	0.264	-0.235	0.770	-0.241
TOC	0.101	-0.150	0.820	-0.056
TKN	0.731	0.269	0.731	0.245
Chl-a	0.453	0.099	0.679	0.159
TP	0.690	-0.134	0.368	0.071
SD	-0.678	0.059	-0.470	-0.360
TSS	0.724	-0.120	0.339	0.339
Turbidity	0.656	-0.209	0.377	0.348
DO	-0.282	0.790	-0.124	0.096
pH	0.193	0.861	0.060	-0.110
Nitrate/nitrite Nitrogen	0.002	0.133	-0.130	0.846
Percent of Total Variance Explained	36	10	21	10
Interpretation of PC Axis	TP, Clarity and Ionic Strength	DO and pH	Overall Productivity	Inorganic Nitrogen

Shaded cells indicate groups of variables that load on each PC axis.

2.2.1.1 Relationships Among Variables

Detailed results from the analysis of the reservoirs and oxbows larger than 500 acres are presented in the draft Nutrient Criteria for Mississippi Lakes and Reservoirs. These results (Table 2.2) indicated that over 70% of the variance in the surface data collected in the summer was accounted for by three PC axes that showed a clear pattern of variable loadings. For this data set, each of the three principal axes can be readily interpreted by examining those variables that load onto each axis. These interpretations are summarized as follows:

- PC1 had high loadings from TOC, COD, TKN, and Chl-a. This axis represented increasing primary productivity and organic content.
- PC2 had high loadings from conductivity, total alkalinity, chloride, and hardness. This axis represented increasing ionic strength.
- PC3 showed high loadings from SD, TP, TSS, and turbidity. This axis represented increasing TP and decreasing water clarity.

The results of the analysis of the combined data (Table 2.3) indicate a pattern of loadings on the PC axes that was very similar to the results from the reservoirs and oxbows larger than

500 acres. A lower portion of the total variance (62% vs. 71%) was explained by the first three PC axes in the analysis of the combined data.

The analysis of the small lakes and reservoirs data set (Table 2.4) showed a slightly different pattern of PC axis loadings when considered separately from the reservoirs and oxbows larger than 500 acres. This data set indicated that the majority of the variance (36%) was accounted for by the first PC axis with variable loadings that corresponded to increasing TP and ionic strength and decreasing clarity. The third PC axis accounted for 21% of the total variance with variable loadings that correspond to overall productivity. The second and fourth PC axes each accounted for 10% of the total variance with variable loadings that correspond to DO and pH (second PC axis) and inorganic nitrogen (fourth PC axis). These results indicate that the structure of the small lakes and reservoir data is similar to the reservoirs and oxbows larger than 500 acres in that the majority of the variance is accounted for by the same groups of correlated variables. An additional similarity is the decoupling of TP and clarity with Chl-a as shown by their loading on different axes.

The primary difference in the structure of the two data sets is that, in the small lakes and reservoirs, variables that correspond to TP, clarity and ionic strength are all correlated. In contrast, variables that correspond to TP and clarity are not strongly correlated with ionic strength in the reservoirs and oxbows larger than 500 acres. This difference might reflect differences in the processes that affect water quality such as loading from watershed or internal nutrient cycling. The small lakes and reservoir data set included only sampling from single year and does not reflect annual variability. Therefore the differences might also reflect the more limited sampling of the small lakes and reservoirs. Additional sampling during other years might show the structure of the two data sets to be more similar.

2.2.1.1.1 Relationships Among Sampling Locations

The PCA analysis allowed an examination of the data for potential “natural” classifications. This evaluation involved converting the raw data values from each sampling location on each sampling date into PC scores. The PC scores can then be plotted on each PC axis resulting in a scatter plot using any two or three PCs as axes. For example, scatter plot using PC1 and PC2 from the combined dots analysis provides a view of how the data set maps onto space defined by overall productivity (PC1) vs. ionic strength (PC2); A scatter plot using PC1 vs.

PC3 provides a view of how the data map onto space defined by overall productivity (PC1) and TP/water clarity (PC3).

Scatter plots were prepared in two ways. First, scatter plots were prepared based on the PCA analysis from the combined data set (i.e., reservoirs and oxbows larger than 100 acres). One analysis compared reservoirs between 100 and 500 acres with reservoirs larger than 500 acres. The purpose of this analysis was to determine if the small reservoirs between 100 and 500 acres formed a group that was distinct from the reservoirs larger than 500 acres (Figures 2.1and 2.3). A similar analysis was performed comparing the oxbows between 100 and 500 acres with oxbows larger than 500 acres (Figures 2.2 and 2.3). Second, scatter plots were prepared that compared reservoirs vs oxbows within the small lakes and reservoir data set. This analysis of the lakes and reservoirs between 100 and 500 acres focused on PC1 and PC3 because most of the variation in the small lakes and reservoir data set was captured by those axes (Figure 2.4).

Box and whisker plots of TP, TN<SD and Chl-a for comparing waterbody category in the combined dataset (i.e., reservoirs, large reservoirs and oxbows all larger than 500 acres and reservoirs and oxbows between 100 and 500 acres) are presented in Figure 2.5.

Examination of Figures 2.1 and 2.3 indicates that the reservoirs between 100 and 500 acres were not distinctly different from reservoirs larger than 500 acres. Any tendency for separation between the data sets was related primarily to ionic strength, TP, and clarity. Variation in TP, TN, SD, and Chl-a is captured in the "Increasing TP and Turbidity" and "Increasing Productivity" axes. There appeared to be only slight differences in the distribution of the small reservoirs vs. those larger than 500 acres on those axes. Figures 2.1 and 2.3 indicate a slight tendency toward greater productivity and clarity and lower TP and ionic strength. There is, however a high degree of overlap in TN, TP, SD, and Chl-a among reservoirs of all sizes shown in Figure 2.4.

There was little tendency for separation between small oxbows and those larger than 500 acres (Figure 2.2 and 2.3). The box and whisker plot comparison (Figure 2.4) indicates that the small oxbows might have slightly higher TP and TN and lower Chl-a and clarity values. This result might indicate a larger tendency for light limitation in the small oxbows.

A comparison of small reservoirs with small oxbows (Figure 2.5) based on PC axes indicates a clear tendency for separation between the two waterbody types, especially with respect to clarity, TP and ionic strength. Within this data set reservoirs showed a clear tendency for lower turbidity, TP and ionic strength.

2.2.2 Comparisons Among Waterbody Types

The analysis presented in the previous section did not indicate strong tendencies for the small lakes and reservoirs to differ greatly from their larger counterparts. Examination of the PC scatter plot in Figure 2.4 and the box and whisker plots in Figure 2.5 indicates that, TP, TN, SD, and Chl-a are consistently different in all oxbows vs. all reservoirs. Small oxbows show a strong tendency towards higher TP, turbidity, and ionic strength (Figure 2.5).

2.3 Data Analysis Conclusions

The following conclusions can be drawn based on the analysis of data from the small lakes and reservoirs.

1. The relationships among variables within the small lakes and reservoirs data set were similar to that of the reservoirs and oxbows larger than 500 acres.
2. Most of the variation in either data set could be explained by groups of variable corresponding to ionic strength, overall productivity and TP/clarity.
3. Oxbows of all sizes tend to have higher TP, TN, Chl-a, and lower SD than reservoirs.
4. Oxbows between 100 and 500 acres might have greater light limitation than larger oxbows as seen in their tendency for higher TP and TN and lower Chl-a and clarity.

The analysis of the lakes and reservoirs between 100 and 500 acres supported the general classification of Mississippi lentic waterbodies into reservoirs and oxbows.

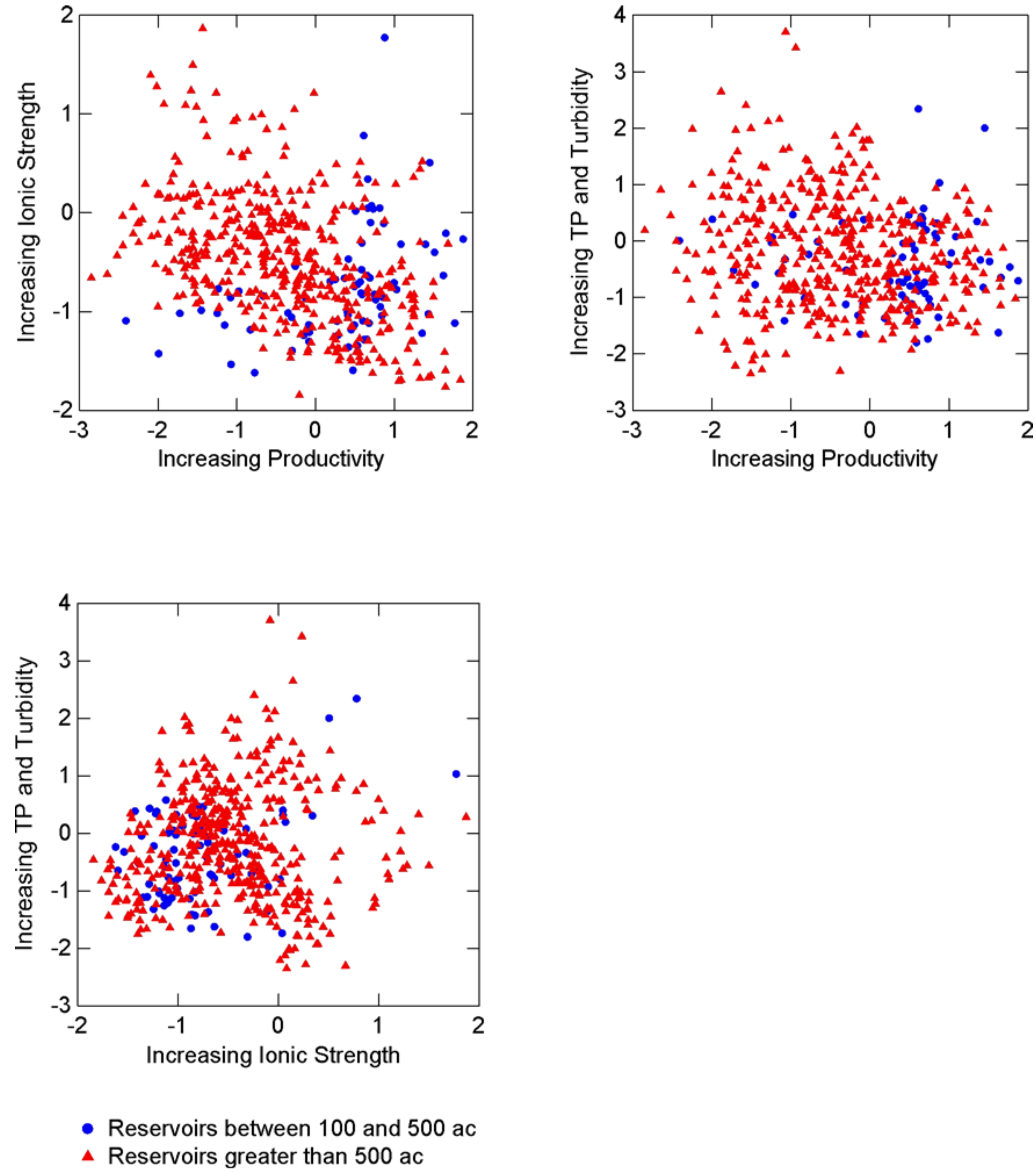


Figure 2.1. Scatter plots of PC axes comparing the distribution of sampling locations in reservoirs greater than 500 acres vs. reservoirs between 100 and 500 acres.

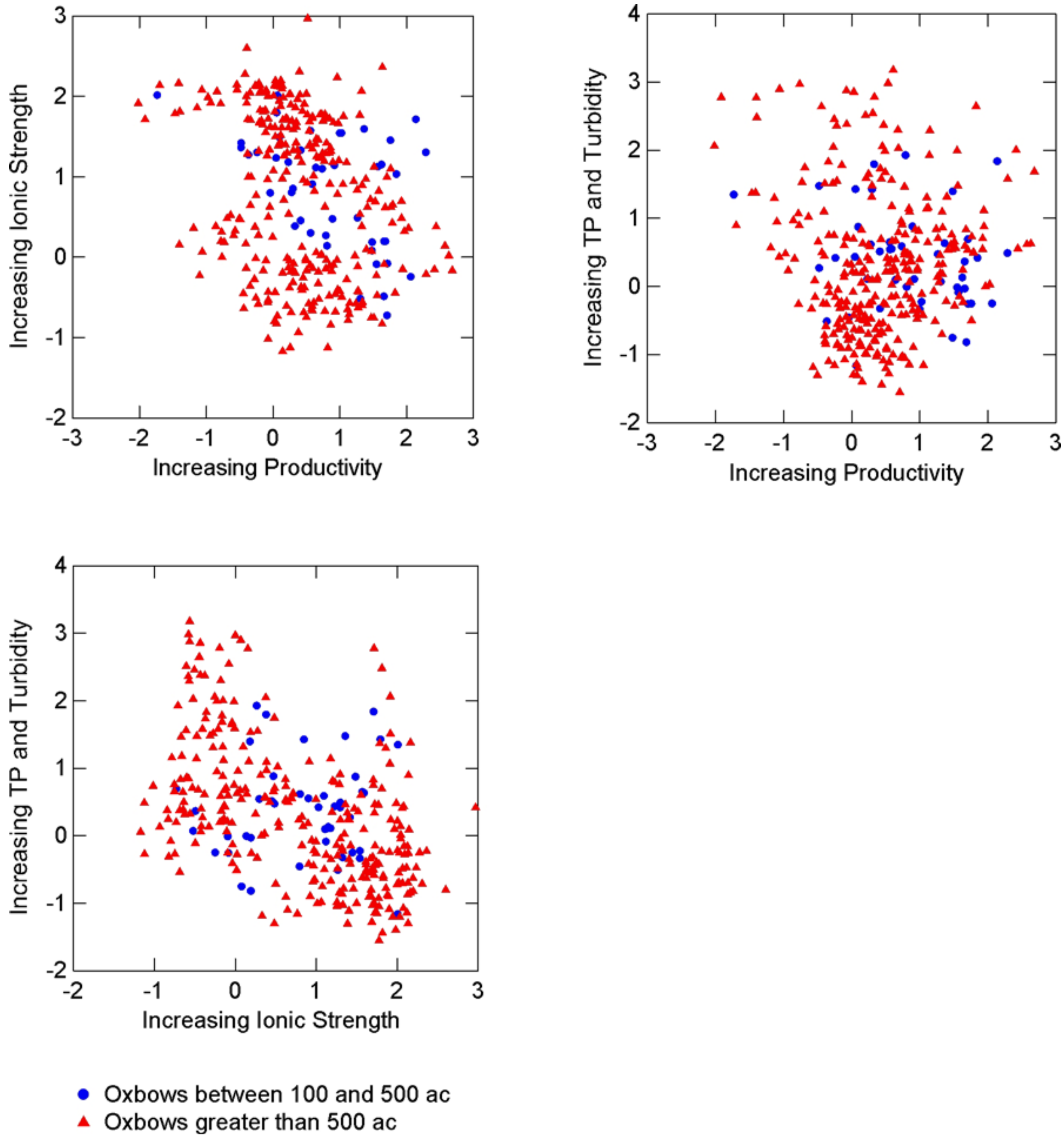
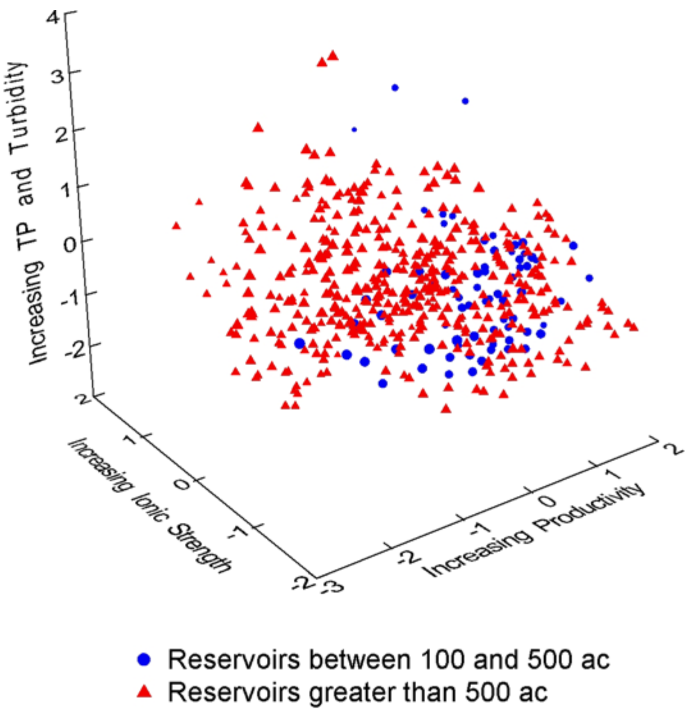


Figure 2.2. Scatter plots of PC axes comparing the distribution of sampling locations in oxbows greater than 500 acres vs. reservoirs between 100 and 500 acres.



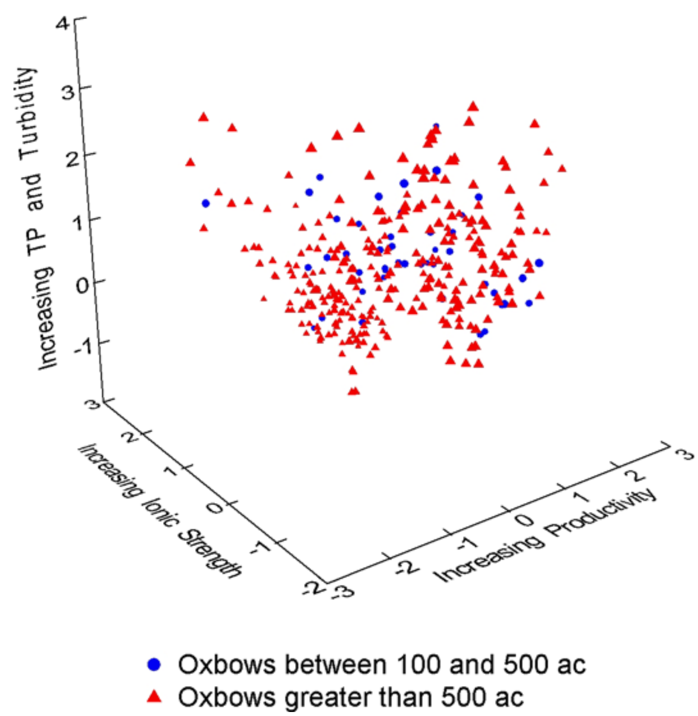


Figure 2.3. Scatter plots of all three PC axes comparing the distribution of sampling locations in waterbodies greater than 500 acres vs. reservoirs between 100 and 500 acres for reservoirs and oxbows.

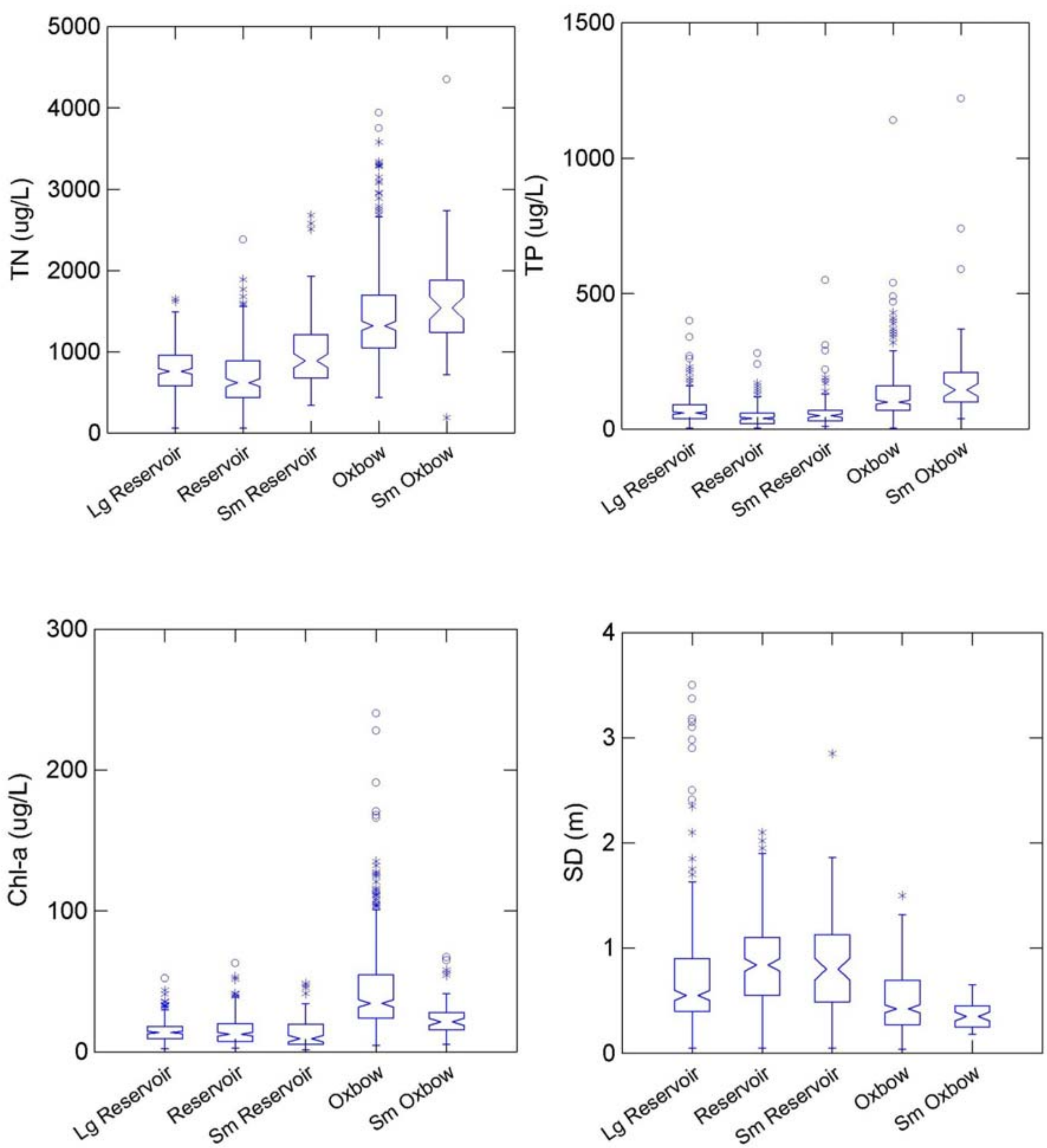


Figure 2.4. Box and whisker plots showing distributions of TP, TN, SD, and Chl-a in reservoirs greater then 2,000 acres (large reservoir), reservoirs between 500 and 2,000 acres (reservoir), reservoirs between 100 and 500 acres (small reservoirs), oxbows greater than 500 acres (oxbow) and oxbows between 100 and 500 acres (small oxbow).

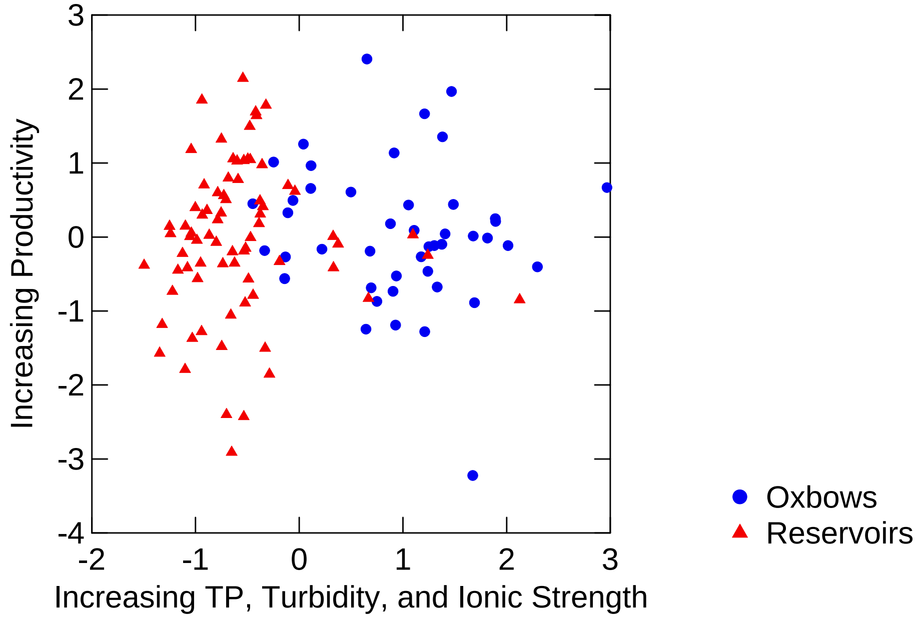


Figure 2.5. Scatter plot of PC 1 (increasing TP, turbidity, and ionic strength) vs. PC 3 (increasing productivity) for oxbows vs. reservoirs between 100 and 500 acres.

3.0 TP, TN, SD, AND CHL-A CRITERIA

3.1 Criteria Development

Development of water quality criteria for lakes and reservoirs between 100 and 500 acres focused on the use of the MsFish index as an indicator of aquatic life use attainment as recommended in the draft Nutrient Criteria for Mississippi Lake and Reservoirs submitted to the Mississippi Department of Environmental Quality on February 8, 2007. There were five reservoirs (Table 3.1) within the small lakes and reservoir data set for which MsFish scores were available. Each of the five reservoirs was assigned an MsFish category (High, Medium of Low) as part of the analysis presented in Section 6 of the draft Nutrient Criteria for Mississippi Lake and Reservoirs. Because there were no MsFish data available for any of the oxbows between 100 and 500 acres, criteria development using the data for lakes and reservoirs between 100 and 500 acres focused on reservoirs.

Table 3.1. MsFish scores (scaled) for each fishery reservoir in the small lakes and reservoirs data set.

Lake Name	Sport Fishery			MsFish Category[1]
	Bass	Crappie	Bream	
Lowndes	96	22	99	High
Mary Crawford	82	42	58	Med
Jeff Davis	75	37	77	Med
Oktibbeha	68	53	66	Low
Charlie Capps	67	60	16	Low

[1] = MsFish category based on the highest sport fishery score.

As part of nutrient criteria development, the additional data from the small reservoirs could be combined with the analysis presented in the draft Nutrient Criteria for Mississippi Lake and Reservoirs which was based solely on reservoirs larger than 500 acres. The percentile values resulting from this combined analysis (i.e., reservoirs larger than 100 acres) are presented in Table 3.2. For purposes of comparison, the percentile values of the analysis using only reservoirs larger than 500 acres is also presented as given in Table 6.3 of the draft Nutrient Criteria for Mississippi Lake and Reservoirs. Table 3.2 indicates that percentile values for each MsFish category for reservoirs larger than 500 acres vs. those for reservoirs larger than 100 acres are very similar. Therefore, the recommended TP, TN, SD, and Chl-a criteria for reservoirs larger than 500 acres as presented in the draft Nutrient Criteria for Mississippi Lake and Reservoirs can be modified to include reservoirs larger than 100 acres as shown in Table 3.3.

Table 3.2. Comparison of percentile values for TP, TN, Chl-a, and SD in relation to MsFish categories in reservoirs using only data from reservoirs larger than 500 acres (in parentheses) vs. the combined data (reservoirs larger than 100 acres).

MsFish Category	Percentile	Parameter			
		TP (µg/L)	TN (µg/L)	Chl-a (µg/L)	SD (m)
Low	25th	25 (20)	400 (410)	5.8 (5.5)	0.51 (0.64)
	50th	40 (40)	540 (540)	9.5 (9.3)	0.80 (0.87)
	75th	50 (50)	705 (700)	14.7 (14.5)	1.30 (1.30)
	n	135 (99)	135 (99)	130 (96)	135 (99)
Medium	25th	40 (40)	680 (678)	11.1 (11.3)	0.35 (0.38)
	50th	60 (60)	850 (850)	16.1 (15.6)	0.48 (0.50)
	75th	90 (90)	1020 (980)	20.8 (19.6)	0.70 (0.79)
	n	155 (113)	155 (113)	150 (108)	154 (113)
High	25th	40 (30)	590 (580)	8.9 (9.0)	0.45 (0.50)
	50th	50 (50)	760 (770)	12.9 (13.0)	0.65 (0.68)
	75th	90 (80)	1020 (990)	20.3 (19.4)	0.95 (0.95)
	n	162 (130)	161 (129)	159 (127)	158 (126)

n = the number of data points on which the percentiles are based.

Table 3.3. Recommended criteria values for TP, TN, Chl-a, and SD for reservoirs larger than 100 acres.

Basis	TP (µg/L)	TN (µg/L)	Chl-a (µg/L)	SD (m)
Modified Recommended Criteria	90 (90*)	1020 (980*)	20.3 (19.6*)	0.45 (0.50*)

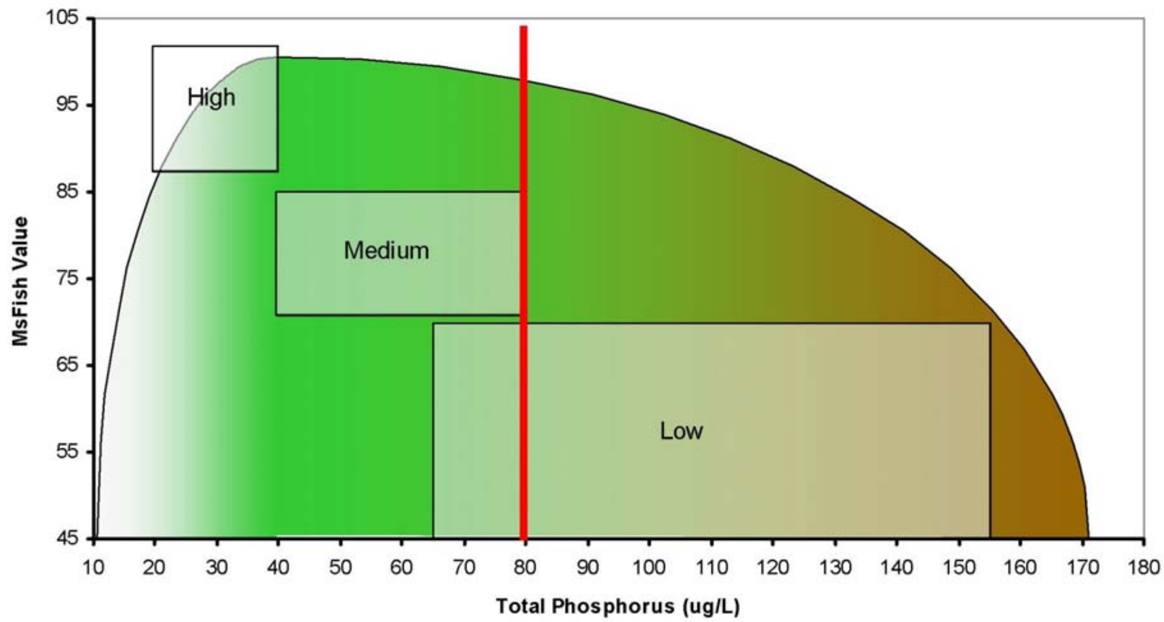
*Recommended criteria for reservoirs longer than 500 acres as presented in the draft Nutrient Criteria for Mississippi Lakes and Reservoirs are given in parentheses for comparison.

3.2 Evaluation of Recommended Criteria

The MsFish information from the small reservoirs can be used to evaluate the reservoir criteria presented in Section 6 of the draft Nutrient Criteria for Mississippi Lake and Reservoirs which were based on reservoirs larger than 500 acres. Based on that analysis, reservoirs with:

- Levels of TN, TP, SD, and Chl-a that exceed recommended criteria should show "Low" MsFish scores;
- Levels of TN, TP, SD, and Chl-a near (slightly above or below) recommended criteria should show "Medium" or "High" MsFish scores depending on habitat; and
- Levels of TN, TP, SD, and Chl-a that are less than the recommended criteria can show "High", "Medium" or "Low" MsFish scores depending on habitat and nutrient limitation.

To compare the small reservoir data with the Conceptual Model and associated recommended criteria, quartile values for TP, TN, SD, and Chl-a for the Low, Medium, and High MsFish categories from the small reservoirs data set were calculated (Table3.4). These values were then compared with the recommended reservoir nutrient criteria presented in Table 6.4 of the draft Nutrient Criteria for Mississippi Lake and Reservoirs. For purposes of illustration the small reservoir values are presented in the context of the Conceptual Model presented in the draft Nutrient Criteria for Mississippi Lake and Reservoirs (Figures 3.1 and 3.2). In Figures 3.1 and 3.2 the x-axis scale has been modified to accommodate the additional data. Also, the boundaries of the response surfaces of the Conceptual Model have been drawn to reflect that the criteria should lie to the right rather than to the left of TN, TP, SD, and Chl-a levels associated with maximum sport fish production. That is, criteria should not represent nutrient levels that limit the sport fishery due to nutrient limitation. In Figures 3.1 and 3.2 the horizontal dimension of each MsFish category box for a given parameter is determined by the upper and lower quartiles as shown in Table 3.4. The vertical dimension of each MsFish category box is the 95% confidence interval of each category using all available MsFish scores.



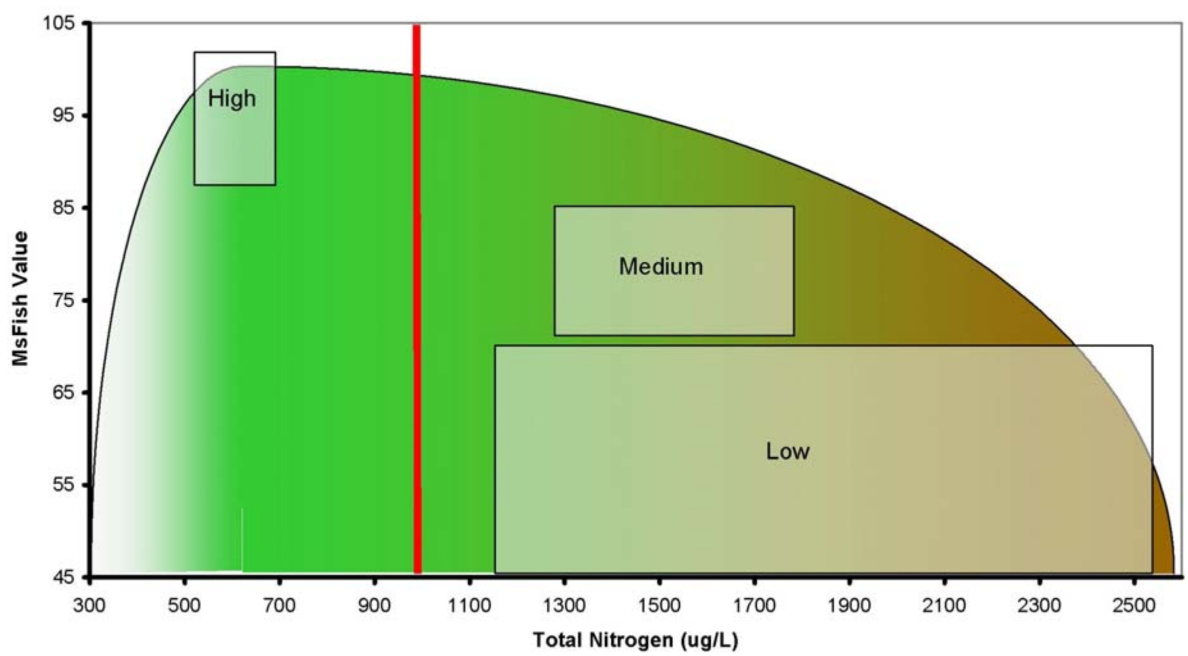


Figure 3.1. TP (top figure) and TN (bottom figure) vs. small reservoir MsFish values in relation to the conceptual model. Red lines indicate recommended criteria based on reservoirs greater than 500 acres. Vertical dimension of each MsFish Category (box) indicates 95% confidence interval of mean MsFish value. Horizontal dimension of each box indicates upper and lower quantiles of the parameter values.

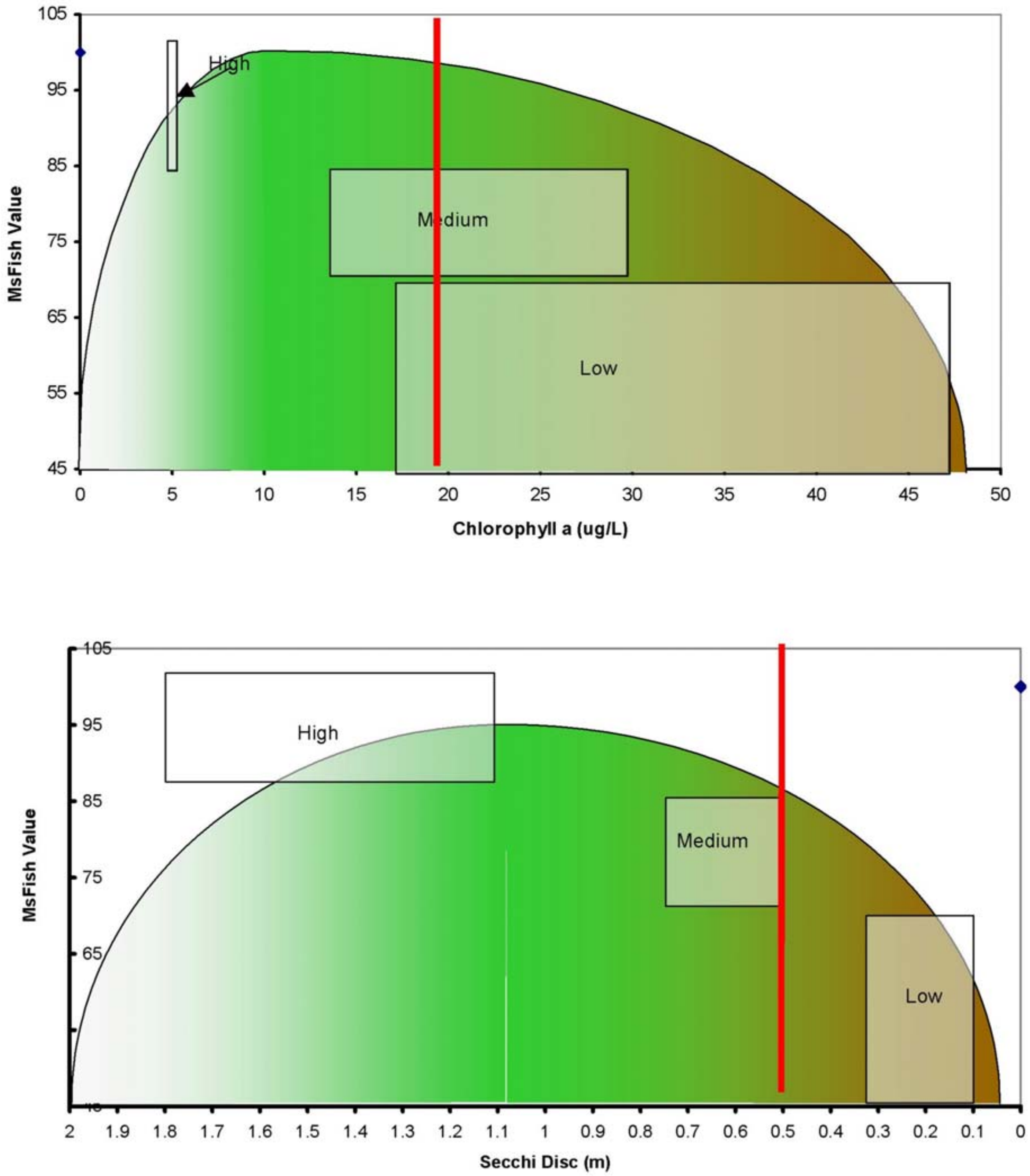


Figure 3.2. Chl-a (top figure) and SD (bottom figure) vs. small reservoir MsFish values in relation to the conceptual model. Red lines indicate recommended criteria greater than 500 acres. Vertical dimension of each MsFish Category (box) indicates 95% confidence interval of mean MsFish value. Horizontal dimension of each box indicates upper and lower quantiles of the parameter values.

The comparison of the MsFish categories from the small reservoirs with the recommended criteria from reservoirs greater than 500 acres (from the draft Nutrient Criteria for Mississippi Lakes and reservoirs, February 8, 2007) indicates that the values of TP, TN, SD, and Chl-a associated with the “High” MsFish category are below the recommended criteria while the values associated with the “Medium” category are near the recommended criteria (Figures 3.1 and 3.2). Most importantly, however, the values of TP, TN, SD and Chl-a associated with the “Low” MsFish category are higher than the recommended criteria. This result indicates that the nutrient data from the small reservoirs, in conjunction with the available MsFish data can be used as a test of the recommended criteria based on reservoirs larger than 500 acres as presented in the draft Nutrient Criteria for Mississippi Lake and Reservoirs.

Although the test data set was small, with only five additional reservoirs having MsFish data, the small reservoir data set conforms to expectations based on the analysis from reservoirs larger than 500 acres. That is, reservoirs having high or medium MsFish scores show levels of TP, TN, SD, and Chl-a that are below or near (respectively) recommended criteria; Reservoirs having low MsFish scores show levels of TP, TN, SD, and Chl-a that exceed recommended criteria. This result suggests that criteria based on the MsFish index provide robust indicators of aquatic life use attainment that are applicable to a wide range of reservoirs. Therefore, the two data sets can be combined to provide TP, TN, SD, and Chl-a data applicable to reservoirs larger than 100 acres as presented in the previous section.

Table 3.4. Selected percentile values for TP, TN, Chl-a, and SD in relation to MsFish categories in reservoirs between 100 and 500 acres.

MsFish Category	Percentile	Parameter			
		TP (µg/L)	TN (µg/L)	Chl-a (µg/L)	SD (m)
Low	25th	65	1150	17.2	0.10
	50th	100	1260	45.6	0.10
	75th	155	2545	47.2	0.33
	n	7	7	5	7
Medium	25th	40	1280	13.6	0.50
	50th	65	1375	25.8	0.50
	75th	80	1780	29.6	0.75
	n	6	6	6	6
High	25th	20	520	4.7	1.10
	50th	30	605	4.9	1.45
	75th	40	690	5.2	1.80
	n	2	2	2	2

n = the number of data points on which the percentiles are based.

4.0 SUMMARY AND CONCLUSIONS

The water quality analysis of the lakes and reservoirs between 100 and 500 acres and Lakes and reservoirs larger than 500 indicated similar structure in the data sets. Both the individual and the combined data set supported the general classification of Mississippi's lentic waterbodies into reservoirs and oxbows.

The MsFish information from the reservoirs between 100 and 500 acres supported the recommended criteria based on the MsFish index based on reservoirs larger than 500 acres presented in the draft Nutrient Criteria for Mississippi Lakes and Reservoirs submitted to MDEQ on February 8, 2007. The results of the analysis presented herein indicate that the use of the sport fishery as an indicator of aquatic life attainment provides a useful basis for nutrient criteria that are protective of designated uses and applicable to a wide variety of lentic waterbodies. Accordingly, the values presented in Table 3.3 are presented as recommended TP, TN SD, and Chl-a criteria for reservoirs larger than 100 acres.

Based on the results of the MsFish-based approach in reservoirs, it is recommended that additional MsFish data be obtained for oxbow systems to provide a basis for TP, TN SD, and Chl-a criteria in oxbow systems.