Total Maximum Daily Load for Sediment/Siltation and Organic Enrichment/Low Dissolved Oxygen

Wolf Lake

Humphreys and Yazoo Counties, Mississippi

[FINAL Report – SEPTEMBER 2003]

Prepared for:

Mississippi Department of Environmental Quality
Office of Pollution Control
TMDL/WLA Section/Water Quality Assessment Branch

Prepared by:

Tetra Tech, Inc.
10306 Eaton Place
Fairfax, VA 22030

Foreword

This report has been prepared in accordance with the schedule contained in the federal consent decree dated December 22, 1998. The report contains four Total Maximum Daily Loads (TMDLs) for waterbody segments found on Mississippi's 1996 Section 303(d) List of Impaired Water Bodies. Because of the accelerated schedule required by the consent decree, many of these TMDLs have been prepared out of sequence with the state's rotating basin approach. The implementation of the TMDLs contained herein will be prioritized within Mississippi's rotating basin approach.

The amount and quality of the data on which this report is based are limited. As additional information becomes available, the TMDLs may be updated. Such additional information may include water quality and quantity data, changes in pollutant loads, or changes in land use within the watershed. In some cases, additional water quality data may indicate that no impairment exists.

Prefixes for fractions and multiples of SI units

Fraction	Prefix	Symbol	Multiple	Prefix	Symbol
10^{-1}	deci	D	10	deka	da
10^{-2}	centi	C	10^{2}	hecto	h
10^{-3}	milli	M	10^{3}	kilo	k
10^{-6}	micro	µ	10^{6}	mega	M
10^{-9}	nano	N	10^{9}	giga	G
10^{-12}	pico	P	10^{12}	tera	T
10^{-15}	femto	F	10^{15}	peta	P
10^{-18}	atto	A	10^{18}	exa	E

Conversion Factors

TO CONVERT FROM	**To**	**Multiply by**	TO CONVERT FROM	**To**	**Multiply by**
Acres	Sqare miles	0.0015625	Days	Seconds	86,400
Cubic feet	Cubic meters	0.028316847	Feet	Meters	0.3048
Cubic feet	Gallons	7.4805195	Gallons	Cubic feet	0.133680555
Cubic feet	Liters	28.316847	Hectares	Acres	2.4710538
Cubic Feet per Second	Gallon per minute	448.83117	Miles	Meters	1,609.344
Cubic Feet per Second	Million gallons per day	0.6463168	Milligrams per liter	Parts per million	1
Cubic meters	Gallons	264.17205	Micrograms per liter times cubic feet per day	Grams per day	2.45

Table of Contents

Tables

Figures

TMDL Summary

Total Maximum Daily Load (TMDL) for Sediment/Siltation, Organic Enrichment/Low Dissolved Oxygen (DO), and Nutrients in Wolf Lake (MS363WLM) and Wolf Lake Drainage Area (MS363E), Humphreys and Yazoo Counties, Mississippi

TMDL AT A GLANCE

State:	Mississippi
County:	Humphreys and Yazoo Counties
303(d) Listed Water Body:	Yes
Year Listed:	1996
303 (d) List Segment ID:	MS363WLM, MS363E
HUC:	08030206 – Lower Yazoo
Constituents Causing Impairment:	Sediment and organic enrichment/low DO
Source of Pollutants:	Agriculture, aquaculture, and natural background
Data Source:	Clean Lakes Project Phases I and II
Designated Uses:	*Lake:* Aquatic life support *Tributaries:* Aquatic life support
Applicable Water Quality Standard:	*Sediment*: Narrative water quality criteria *Organic Enrichment/Low DO:* General water quality criteria for dissolved oxygen: a daily average of 5.0 mg/L with an instantaneous minimum of not less than 4.0 mg/L.
Water Quality Target:	*Sedimentation/Siltation*: Average annual sedimentation rate of 0.12 cm or 0.08 cm *Organic Enrichment/Low DO:* Daily average DO of 5.0 mg/L
Technical Approach:	*Sedimentation/Siltation:* GWLF watershed model *Organic Enrichment/Low DO:* CE-QUAL-W2 receiving water model
TMDL:	*Sedimentation/Siltation:* 0.23 – 0.15 ton/acre/year *Organic Enrichment/Low DO:* 400.4 lb/day of TBODu
WLA:	*Sedimentation/Siltation:* 0.23 – 0.15 ton/acre/year *Organic Enrichment/Low DO:* 0 lb/day of TBODu
LA:	*Sedimentation/Siltation:* 0.23 – 0.15 ton/acre/year *Organic Enrichment/Low DO:* 400.4 lb/day of TBODu
Margin of Safety:	Implicit

Executive Summary

Wolf Lake, located in Humphreys and Yazoo Counties, Mississippi, is an oxbow lake formed by an abandoned meander of the Yazoo River. Mississippi Department of Environmental Quality (MDEQ) has identified Wolf Lake as not meeting its designated use of Aquatic Life Support. Water bodies that do not meet their designated use are listed as impaired as required by section 303(d) of the Clean Water Act and Environmental Protection Agency's (EPA) Water Quality Planning and Management Regulations (40 CFR part 130). The lake (water body MS363WLM) is on the Mississippi section 303(d) list as impaired by sediment/siltation and nutrients. The drainage area (water body MS363E) is on the list because of sediment/siltation, organic enrichment/low dissolve oxygen (DO), and nutrients. Mississippi currently does not have standards for allowable nutrient concentrations, so a total maximum daily load (TMDL) specifically for nutrients will not be developed. However, because elevated levels of nutrients may cause low levels of dissolved oxygen, the TMDL developed for organic enrichment/low DO also addresses the potential impact of elevated nutrients in the water body.

Section 303(d) requires the development of TMDLs for water bodies on the impaired waters list. A TMDL is the allowable amount of a single pollutant that a water body can receive from all contributing point and nonpoint sources and still meet water quality standards. The process is designed to restore and maintain the quality of impaired water bodies through the establishment of pollutant-specific allowable loads. The water quality standard for sedimentation/siltation is narrative. The water quality standard for dissolved oxygen is a daily average of 5.0 mg/L with an instantaneous minimum of not less than 4.0 mg/L.

To evaluate the relationship between the sources, their loading characteristics, and the resulting conditions in the lake, the study team used a combination of analytical tools. Assessments of the nonpoint source loading into the lake were developed for the Wolf Lake watershed using the Generalized Watershed Loading Function (GWLF) computer program. GWLF provided estimates of nutrients and sediments transported to the lake for individual land use categories. The lake was evaluated using the CE-QUAL-W2 water quality simulation computer model to estimate the concentrations of DO and oxygen-consuming constituents. The lake was segmented into two branches with a total of 22 segments to represent the system. The results of the watershed and lake models were compared with observed water quality data to evaluate the models' performance.

Model results were evaluated for the period from 1997 to 2000, which presented a range of climatic conditions. The year 1997, which was a predominantly wet year, was identified as the critical period for the TMDL, i.e., reflective of the poorest water quality conditions in the lake. Model segment 18 the outlet cell, was chosen as the location for evaluating the TMDL. This location exhibited the poorest water quality conditions in the lake based on model results.

For this TMDL, the loadings of oxygen-demanding material are given in terms of total ultimate biochemical oxygen demand (TBODu). TBODu represents the oxygen consumed by microorganisms while stabilizing or degrading carbonaceous or nitrogenous compounds under aerobic conditions. A 45 percent reduction of the oxygen-demanding source loadings or TBODu coming from the watershed is recommended to meet the prescribed DO criteria of a daily average of 5 mg/L. The target selected for sedimentation/siltation was selected as a range of values, from 0.08 cm/year to 0.12 cm/year. It should be noted, however, that the reductions specified in this TMDL report represent just one example of how pollutant loadings could be modified in order to improve water quality in Wolf Lake. Watershed management scenarios other than those included in this report are possible. There is little hydrological and water quality data available for Wolf Lake, and the management scenarios could be modified based on a reevaluation of the data and modeling if more data become available. For the present time, it is anticipated that some reductions of the current load can be achieved through a combination of land use and restoration practices such as erosion and sediment control practices, reduced tillage practices on croplands, forest management, and stream restoration.

The TMDLs for sedimentation/siltation have been expressed in terms of tons/acre/year. According to 40 CFR §130.2(i), TMDLs can be expressed in terms of mass per time, toxicity, or other appropriate measure. In this case, an "other appropriate measure" is used to express the TMDLs as the tons of sediment that can be discharged from an acre of a subwatershed per year (tons/acre/year) and still attain the applicable water quality standard. This results in a range of acceptable reference yields of 0.23 to 0.15 tons per acre per year. For these TMDLs, it is appropriate to apply the same target yield to permitted (WLA) and unpermitted (LA) watershed areas. For load TMDLs the WLA and LA are summed to calculate the TMDL. Because these sediment TMDLs are expressed as a yield, as long as all activities, permitted or unpermitted, meet the same yield, the TMDLs will be met, regardless of the relative load contribution.

Wet weather sources of sediment, which are discharged to a receiving waterbody as a result of storm events, are considered to be the primary concern for the sediment TMDLs. Wet weather sources can be broadly defined, for the purposes of this TMDL, into two categories: wet weather sources regulated by the NPDES program, and wet weather sources *not* regulated by NPDES. Wet weather sources regulated by the NPDES program include industrial activities (which include certain construction activities) and discharges from MS4s. The wet weather NPDES-regulated sources are provided a waste load allocation (WLA) in this TMDL, and all other wet weather sources of sediment (those not regulated by NPDES) are provided a load allocation (LA).

There are no municipal, industrial, or commercial facilities in the Wolf Lake watershed with National Pollutant Discharge Elimination System (NPDES) permits that are permitted for total suspended solids (TSS). It would not be appropriate to include these facilities since these sources provide negligible loads of sediment to the receiving waters compared with wet weather sources (e.g., NPDES-regulated construction activities, Municipal Separate Storm Sewer Systems [MS4s], and nonpoint sources). Also, the TSS component of a NPDES permitted facility is different from the pollutant addressed within this TMDL because the TSS component of the permitted discharges is generally composed more of organic material, and therefore, provides less direct impact on the biologic integrity of a stream (through settling and accumulation) than would stream sedimentation due to soil erosion during wet weather events. The pollutant of concern for the sedimentation TMDL is sediment from land use runoff.

Any future WLAs provided to NPDES municipal and industrial permitted dischargers will be implemented through the state's NPDES permit program and are not included in this TMDL. The wet weather WLAs provided to the NPDES-regulated construction activities and MS4s will be implemented through best management practices (BMPs) as specified in Mississippi's General Stormwater Permits for Small Construction, Construction, and Phase I & II MS4 permits, which can be found on the MDEQ web site (www.deq.state.ms.us). It is not technically feasible to incorporate numeric sediment limits into permits for these activities and facilities at this time. LAs for nonpoint sources will be achieved through the voluntary application of BMPs. Properly designed and well-maintained BMPs are expected to provide attainment of the wet weather WLAs and LAs.

The TMDLs are presented in Tables ES-1, ES-2, and ES-3. The margin of safety has been addressed through implicit assumptions.

Table ES-1. TMDL for TBODu for Wolf Lake

Pollutant	**WLA (lb/day)**	**LA (lb/day)**	**MOS* (lb/day)**	**TMDL (lb/day)**
CBODu	0	251.8	Implicit	251.8
NBODu	0	148.6	Implicit	148.6
TBODu	0	400.4	Implicit	400.4

* Margin of Safety

Table ES-2. TMDL for Sedimentation rate of 0.12 cm/year for Wolf Lake

Pollutant	**WLA (ton/acre/year)**	**LA (ton/acre/year)**	**MOS (ton/acre/year)**	**TMDL (ton/acre/year)**
Sediment	0.23	0.23	Implicit	0.23

Table ES-3. TMDL for Sedimentation rate of 0.08 cm/year for Wolf Lake

Pollutant	**WLA (ton/acre/year)**	**LA (ton/acre/year)**	**MOS (ton/acre/year)**	**TMDL (ton/acre/year)**
Sediment	0.15	0.15	Implicit	0.15

1.0 Problem Understanding

The identification of water bodies not meeting their designated use and the development of total maximum daily loads (TMDLs) for those water bodies are required by section 303(d) of the Clean Water Act and the Environmental Protection Agency's (EPA) Water Quality Planning and Management Regulations (40 CFR Part 130). A TMDL is the sum of the allowable amount of a single pollutant that a water body can receive from all contributing point and nonpoint sources and still meet water quality standards. The process is designed to restore and maintain the quality of impaired water bodies through the establishment of pollutant-specific allowable loads.

The Water Quality Assessment Branch of Mississippi Department of Environmental Quality (MDEQ) has identified Wolf Lake as being impaired as reported in the Mississippi 1998 Section 303(d) List of Water Bodies. The lake (water body MS363WLM) is listed as impaired by to sediment/siltation and nutrients. The drainage area (water body MS363E) is listed as impaired due to sediment/siltation, organic enrichment/low dissolved oxygen (DO), and nutrients.

This report presents the approach undertaken to develop TMDLs for Wolf Lake and its drainage area as well as a review of the potential causes of impairment and the required TMDL components.

1.1 Lake Description

A long erosional process within a meandering stream forms oxbow lakes. Meandering streams have a sinuous channel with broadly looping curves and exhibit an unequal distribution of flow velocity. As a consequence of the unequal velocities, the outer bank is eroded and sediment deposition occurs along the opposite side of the channel. The net effect is that the meander migrates laterally. Over time, the channel becomes so sinuous that the land separating the adjacent meanders becomes very narrow. During a flood, the stream will abandon its channel, cutting through the narrow strip of land, and flow the shorter distance (Monroe and Wincander, 1992). Sediment transported by the stream is deposited along the new stream bank at the site of the abandoned meander. Once the abandoned meander is completely isolated from the main channel it becomes an oxbow lake. Figure 1-1 below demonstrates this process. Over time, oxbow lakes naturally fill with sediment.

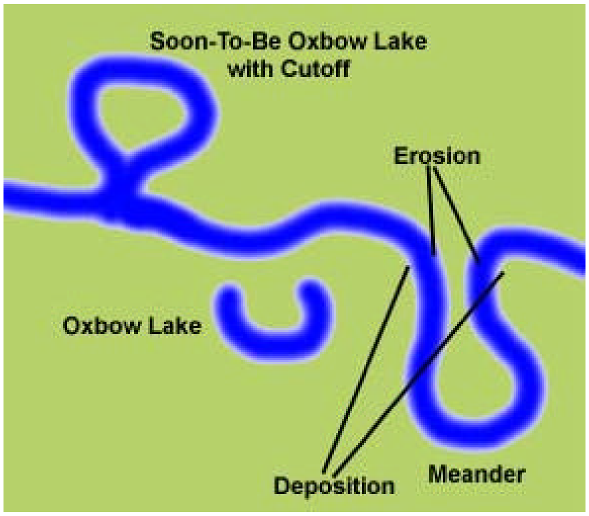

Figure 1-1. Oxbow Lake Creation Process

Wolf Lake is an elongated oxbow lake that was formed on an abandoned arm of the Yazoo River. It consists of both a northern arm and a southern arm (which is also known as Broad Lake). Inflow is through local runoff and through Broad Lake and Topeka Bayou; outflow is through the portion of the lake where Wolf Lake and Broad Lake meet (through a tributary that empties into a canal feeding Lake George and then ultimately into the Yazoo River). The lake behaves like a slow-moving river and has a short residence time of only 51 days. Morphometric and hydraulic data for Wolf Lake (including the Broad Lake arm) are shown in Table 1-1.

Table 1-1. Morphometric and Hydraulic Characteristics of Wolf Lake

Parameter	Measured
Volume	9.8 x 10^6 m^3
Surface area (acre)	1,117 (1.7 square miles)
Drainage area (acre)	27,113 (42.4 square miles) (110 km^2)
Depth	
Mean lake (m)	2.2 (7.2 ft)
Maximum lake (m)	6 (19.7)

Source: FTN Associates, 1991.
Note: Drainage area recalculated using topographic data.

1.2 303 (d) Listed Water Bodies

Wolf Lake and the Wolf Lake Drainage Area are listed on the state's 303(d) list of impaired water bodies (Table 1-2).

Table 1-2. 303(d) Listing

Water Body Name	Water Body ID	Location	Beneficial Use	Impairment
Wolf Lake	MS363WLM	Near Louise	Aquatic Life Support	Sediment/Siltation and Nutrients
Wolf Lake Drainage Area	MS363E	Near Carter	Aquatic Life Support	Sediment/Siltation, Organic Enrichment/Low DO, and Nutrients

Excessive sedimentation from anthropogenic sources is a common problem that can impact water bodies in a number of ways. In the Mississippi Valley, suspended sediment and turbid conditions caused by suspended sediment are among the primary water quality concerns (MDEQ, 1999). Suspended sediment can affect lake and stream biota in a number of ways. Deposited sediments reduce habitat complexity by filling in pools, riffle areas, and the interstitial spaces used by aquatic invertebrates. Elevated turbidity reduces the penetration of light necessary for photosynthesis in aquatic plants, reduces the feeding efficiency of visual predators and filter feeders, and lowers the respiratory capacity of aquatic invertebrates by clogging their gill surfaces. In addition, other contaminants such as nutrients and pesticides attached to sediment particles can be transported to lakes and streams during runoff events.

Dissolved oxygen has historically been used as the constituent that measures or indicates the overall quality of surface water. Dissolved oxygen analysis measures the amount of gaseous oxygen dissolved in an aqueous solution. Oxygen enters the water by diffusion from the surrounding air, by aeration (rapid movement), and as a waste product of photosynthesis. Adequate dissolved oxygen is necessary for good water quality and is a necessary element to all forms of life. Decreases in the dissolved oxygen concentrations can cause changes in the types and numbers of aquatic macroinvertebrates that live in a water ecosystem. As the dissolved oxygen levels decrease, pollution-intolerant organisms are replaced by pollution-tolerant worms and fly larvae, and there is a decrease in species that cannot tolerate decreases in dissolved oxygen (Ricklefs, 1990).

Plants and animals use oxygen for respiration. Aerobic bacteria consume oxygen during the process of decomposition. When organic matter and nutrients such as animal waste, fertilizer, or improperly treated wastewater enter a body of water, they are used by the bacteria within the streambed and the algae in the water column (Ricklefs, 1990; Wetzel, 1983). Algae and bacteria use the organic matter and nutrients for growth. The dissolved oxygen concentration decreases as the plant material dies off and decomposes through the action of the aerobic bacteria.

Nutrient transport is governed by several chemical, physical, and biological processes known as the nutrient cycle. The nitrogen cycle consists of four processes (nitrogen fixation, ammonification, nitrification, and denitrification) that convert nitrogen gas into usable nitrogen forms and back into nitrogen gas. Nitrogen fixation converts gaseous nitrogen into ammonia, while ammonification involves the breakdown of wastes and nonliving organic tissue into ammonia. The nitrification process oxidizes ammonia, resulting in nitrate and nitrite. Finally, the denitrification process converts nitrates back into gaseous nitrogen. Ammonia ions, nitrites, and nitrates are most important for water quality assessments because of their impact on water quality. The conversion of ammonia to nitrate consumes 4.57 pounds of oxygen for every pound of ammonia.

Instream dissolved oxygen concentrations fluctuate daily. The diurnal variations in dissolved oxygen concentrations are mainly due to photosynthesis and respiration of aquatic plants such as phytoplankton, aquatic weeds, or algae (Chapra, 1997; Wetzel, 1983). Photosynthesis is the process by which plants use solar energy to convert simple inorganic nutrients into more complex organic molecules. Because it requires solar energy, photosynthesis only occurs during daylight hours and is represented by the following simplified equation:

$6CO_2$ +	$6H_2O$	<--------->	$C_6H_{12}O_6$ +	$6O_2$
(Carbon Dioxide)	(Water)		(Sugar)	(Oxygen)

In this reaction, photosynthesis is the conversion of carbon dioxide and water into sugar and oxygen such that there is a net gain of dissolved oxygen in the water body (Ricklefs, 1990). Conversely, respiration and decomposition operate the process in reverse and convert sugar and oxygen into carbon dioxide and water, resulting in a net loss of dissolved oxygen to the water body. Respiration and decomposition occur at all times and are not dependent on solar energy. Water bodies exhibiting the typical diurnal variation of dissolved oxygen experience the daily maximum in mid-afternoon, during which photosynthesis is the dominant mechanism and the daily minimum in the predawn hours, during which respiration and decomposition have the greatest effect on dissolved oxygen and photosynthesis is not occurring (Wetzel, 1983).

1.3 Water Quality Standards and Beneficial Uses

The beneficial uses identified for Wolf Lake and the tributaries are designated as Aquatic Life Support (MDEQ, 2002). Although there are no specific applicable criteria for these beneficial uses, the criteria listed in Table 1-3 apply to all surface waters in Mississippi. The water quality objectives provide both a narrative and numeric basis for identifying appropriate TMDL endpoints for sedimentation/siltation and organic enrichment/low dissolved oxygen.

Table 1-3. Relevant Water Quality Objectives

Section	Water Quality Objective
Section II.3	Waters shall be free from materials attributed to municipal, industrial, agricultural, or other discharges producing color, odor, taste, total suspended or dissolved solids, sediment, turbidity, or other conditions in such degree as to create a nuisance, render the waters injurious to public health, recreation or to aquatic life and wildlife or adversely affect the palatability of fish, aesthetic quality, or impair the waters for any designated use.
Section II.7	Dissolved oxygen concentration shall be maintained at a daily average of not less than 5.0 mg/L with an instantaneous minimum of not less than 4.0 mg/L. When possible, samples should be taken from ambient sites according to the following guidelines: • For waters that are not thermally stratified, such as unstratified lakes, lakes during spring turnover, streams, and rivers. At mid depth if the total water column is 10 feet or less and at 5 feet from the water surface if the total water column is greater than ten feet. • For waters that are thermally stratified such as lakes, estuaries, and impounded streams. At mid depth if the epilimnion is 10 feet or less and at 5 feet from the water surface if the epilimnion depth is greater than 10 feet.

1.4 Watershed Description

The Wolf Lake watershed, which is part of United States Geological Survey (USGS) Hydrologic Unit Code (HUC) 08030206 encompasses approximately 42.4 square miles (27,113 acres). It is located in Humphreys and Yazoo Counties just northwest of Yazoo City, Mississippi (Figure 1-2). The watershed is located in a flat expanse of floodplain adjacent to the Yazoo River. It is composed of a complex series of natural levees, slack water areas, and shallow depressions that parallel the meander belt of the old river channel (FTN Associates, 1991).

The highest area of the watershed, with a peak of approximately 115 feet above mean sea level, is located in the northeast. The lowest point is Wolf Lake, at approximately 85 feet above mean sea level. Land use in the watershed is predominantly agricultural. The major crops within the watershed are corn, cotton, rice, sunflowers, sorghum, soybeans, other small grains, winter wheat, and snap beans; cotton is the major crop. The watershed is extremely flat and almost “swamp-like.” It includes a number of man-made aquaculture ponds that are used for raising catfish. Most of the aquaculture ponds are located in the northern portion of the watershed.

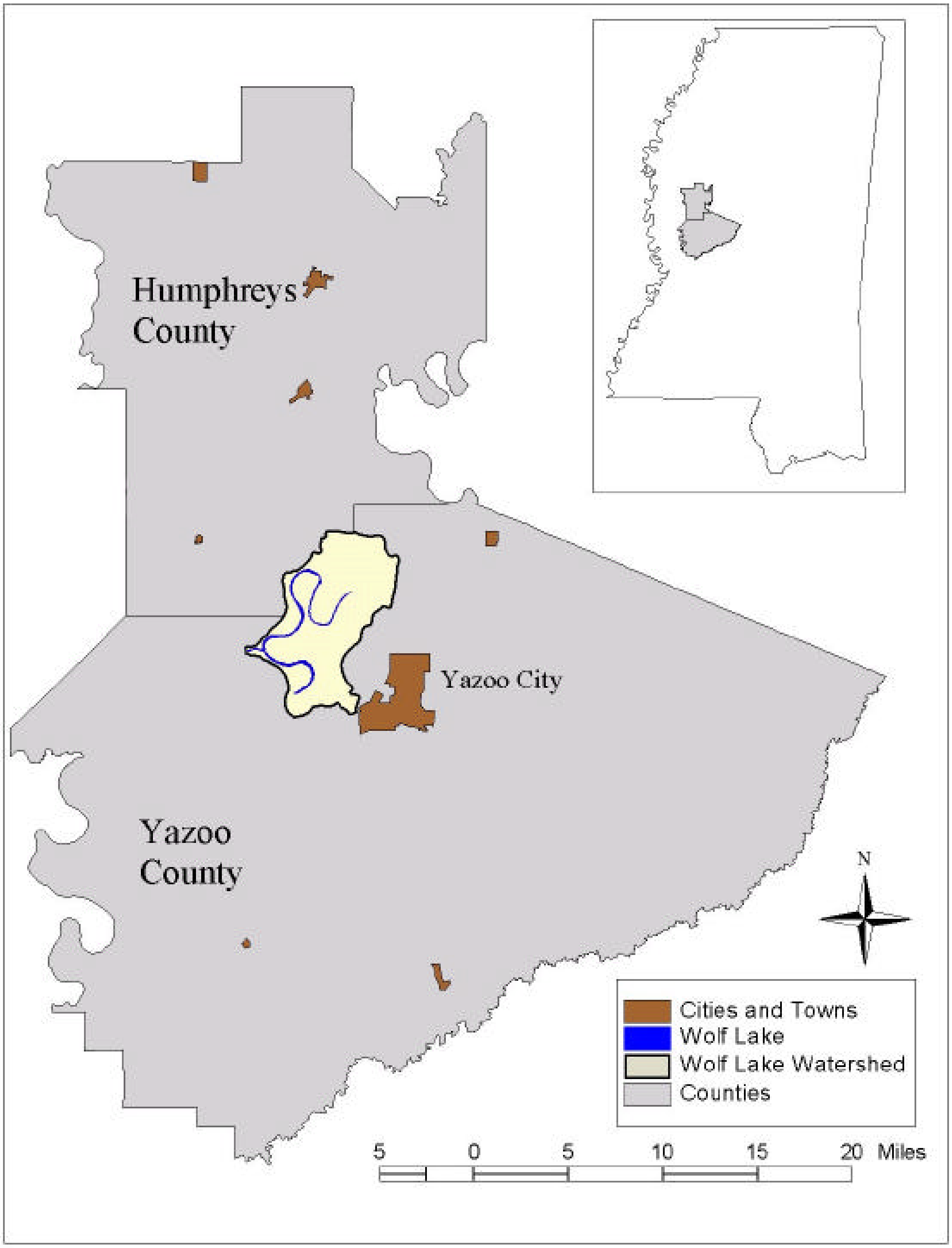

Figure 1-2. Watershed Location

1.4.1 Topography

The Wolf Lake watershed is generally flat, and varies by only about 30 feet in elevation from its lowest point to its highest point. The steepest slopes are located on the natural levees and along the banks of the lake; they range up to 5percent in gradient and are short in length (less than 30 meters). Slopes in the slack water areas are from 0 – 2 percent in gradient and are longer, sometimes exceeding 100 meters. Because of the flat topography, ditches are commonly used to drain cropland areas. The ditches drain to creeks that flow into the lake, or they are cut to drain directly into the lake itself. Figure 1-3 shows the digital elevation map for the Wolf Lake watershed.

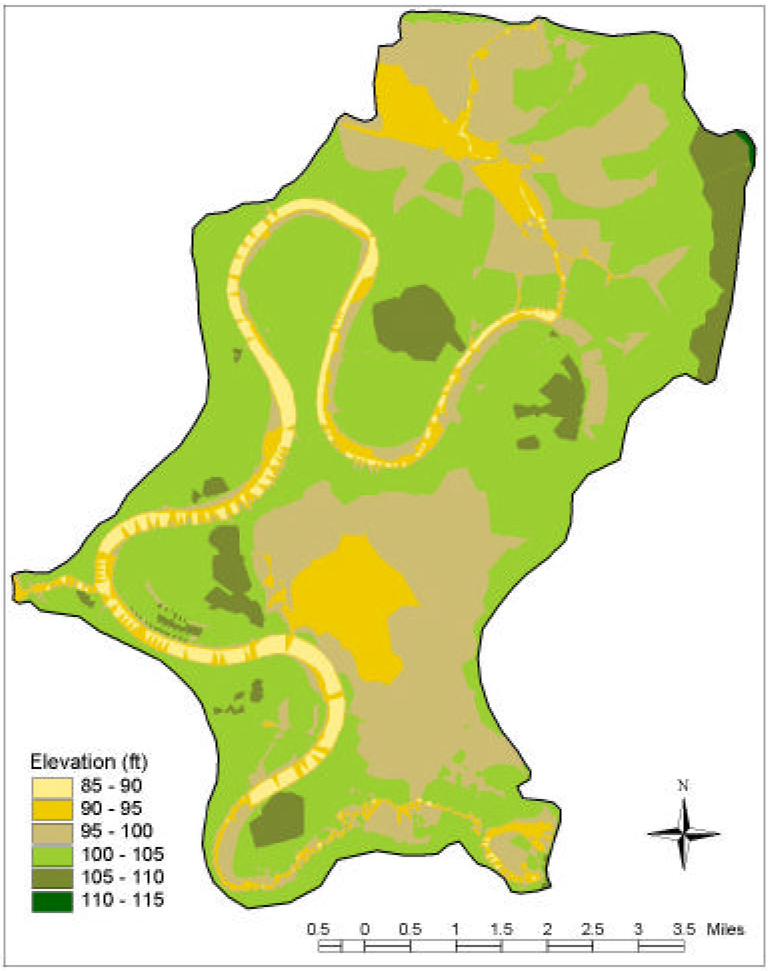

Figure 1-3. Digital Elevation Map

1.4.2 Soil Type

There are only two soils types in the Wolf Lake watershed. The Dundee-Dubbs-Sharkey soil group covers the majority of the watershed, and the Alligator-Sharkey-Forestdale soil group covers the remainder. Figure 1-4 and Table 1-4 present the soil group types. These types of soils have a moderately slow (0.5 to 1.5 cm/hr) to slow permeability (<0.2 cm/hr), and a soil erodibility factor (K) of 0.37 to 0.43.

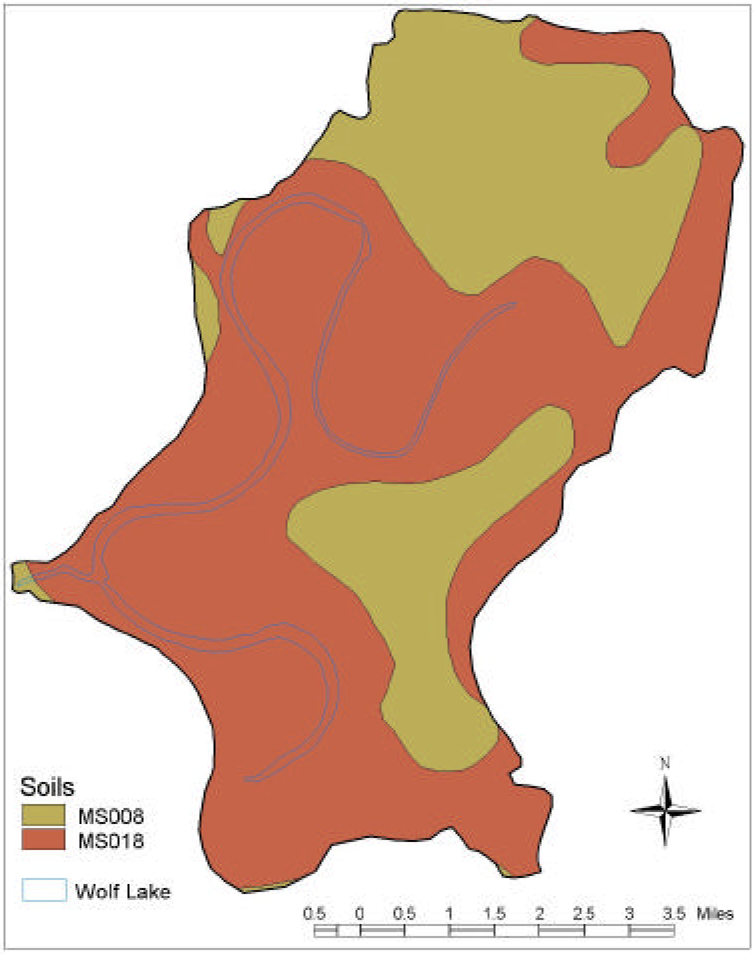

Figure 1-4. Soil Type

Table 1-4. Soil Types

Soil Type	Soil Name	Area (acres)
MS008	Alligator-Sharkey-Forestdale	9,132
MS018	Dundee-Dubbs-Sharkey	17,981
Total		**27,113**

1.4.3 Land Use

The majority of the watershed is rural; less than 1 percent is residential. The majority (44 percent) of the watershed is cropland (cultivated agriculture). About 23 percent is pasture/range/nonagriculture, and about 28 percent is bottomland hardwood forests/shrubs/woods/swamp (other). Aquaculture accounts for approximately 5 percent of the watershed. Figure 1-5 and Table 1-5 present the land use areas in the watershed.

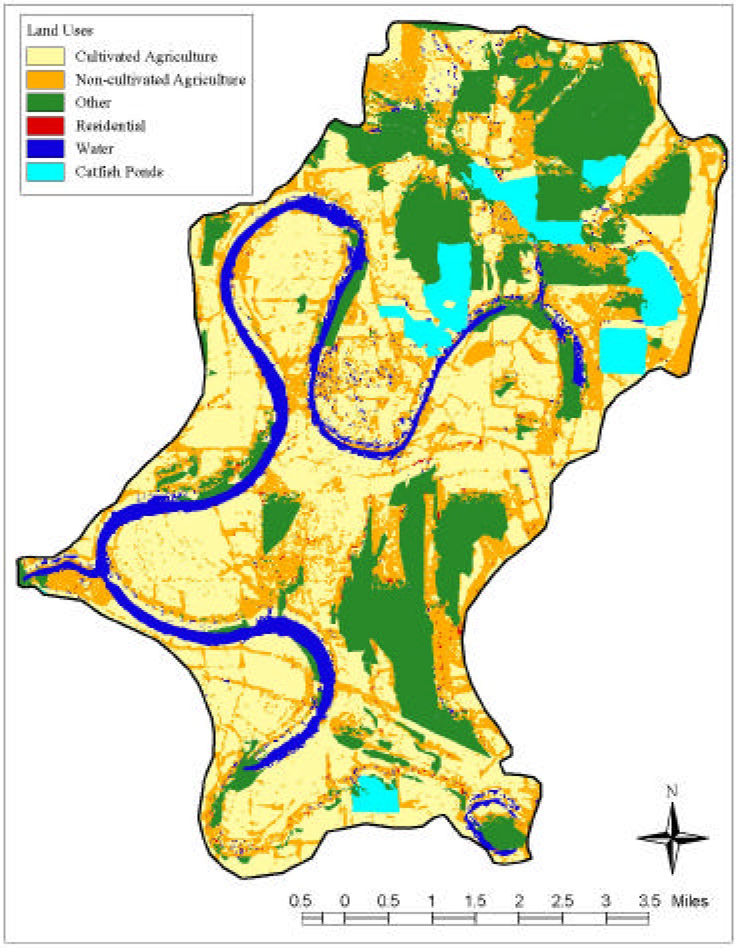

Figure 1-5. Mississippi Automated Resource Information System Land Use.

Table 1-5. Land Use

Land Use	Area (acres)	Area (%)
Cultivated Agriculture	11,879	44%
Noncultivated Agriculture	6,298	23%
Other	7,573	28%
Residential	108	<1%
Catfish Ponds	1,256	5%
Total	**27,113**	**100**

1.5 Climate Characteristics

Mississippi is located in the humid subtropical climate region, characterized by temperate winters and long, hot summers. Rainfall occurs more often in the winter and early spring. Late summer and fall are typically the driest times of the year. The state, however, is subject to periods of both drought and flood. Prevailing southerly winds provide moisture for high humidity from May through September. The potential for locally violent and destructive thunderstorms averages about 60 days each year. Eight hurricanes have struck Mississippi's coast since 1895, and tornadoes are a particular danger, especially during the spring season (Mississippi State Climatologist, 2003).

Normal mean annual temperatures for the Jackson weather station, which is the closest weather station monitoring daily temperature, is 18 degrees Celsius. Low temperatures have dropped to 4 ^{o}C, while the maximum temperatures have reached 29 ^{o}C. Mississippi, in general, has a climate characterized by the absence of severe cold in winter but by the presence of extreme heat in summer. The ground rarely freezes and outdoor activities are generally planned year-round. Cold spells are usually of short duration, and the growing season is long (Mississippi State Climatologist, 2003).

1.6 Socioeconomic Characteristics

The social and economic region in which Wolf Lake is located consists of Humphreys County and Yazoo County. The two county region is a sparsely populated area covering 1,337 square miles, with only 29 persons per square mile (US DOC, Census, 2002). Comparatively, Mississippi has 61 persons per square mile and the United States has 80 persons per square mile.

Farming in the region includes row crops such as cotton, corn, soybeans, rice, and sorghum. Yazoo County ranked 2nd in corn production in the state, 3rd in sorghum production, 5th in cotton production, and 10th in soybean production (ClarionLedger.com, 1999). Catfish farming is also a growing animal agricultural industry in the Mississippi Delta area. More catfish are produced in Humphreys County than in any other state in the country (Evans, no date).

1.7 Threatened or Endangered Species Within the Watershed

Mississippi Department of Wildlife, Fisheries, and Parks provided information on endangered species found within the Wolf Lake watershed. There is one species of concern, the Mississippi Map Turtle (*Graptemys pseudogeographica*), found in Wolf Lake (Mississippi Natural Heritage Program, 2000).

2.0 Data Summary

This section provides an inventory, description, and review of the data compiled to support TMDL development, as well as a brief description of data limitations.

2.1 Data Inventory

Tables 2-1 and 2-2 identify available data used to support the TMDL development effort. The two tables represent the major categories of data: geographic or location information, and monitoring data. Data include water quality observations, sediment source information, land use, and meteorological data.

Table 2-1. Available Geographic or Location Information

Type of Information	**Data Source(s)**[a]
Stream network	USEPA BASINS (Reach File, Versions 1 and 3); USGS NHD reach file; MARIS
Land use	MARIS
Cities/populated places	BASINS; MARIS; U.S. Census
Counties	BASINS; MARIS
Soils	BASINS (USDA-NRCS STATSGO); MARIS
Watershed boundaries	BASINS (8-digit hydrologic cataloging units); MARIS
Topographic and digital elevation models (DEMs)	BASINS (DEM); USGS digital raster graphs
Aerial photos	MARIS
Roads	BASINS; MARIS
Ecoregions	BASINS (USDA Level 3 ecoregions)
Water quality station locations	BASINS; MDEQ Clean Lakes Studies (FTN Associates, 1991)
Meteorological station locations	BASINS; NOAA-NCDC
Stream gage stations	BASINS; USGS
Surface geology	MARIS
Dam locations	MARIS
Impaired water bodies (303(d)-listed segments)	MDEQ

[a] USEPA = U.S. Environmental Protection Agency, BASINS = Better Assessment Science Integrating Point and Nonpoint Sources, USGS = U.S. Geological Survey, NHD = National Hydrography Dataset, MARIS = Mississippi Automated Resource Information System, MDEQ = Mississippi Department of Environmental Quality, USDA-NRCS = U.S. Department of Agriculture, Natural Resources Conservation Service, NOAA- NCDC = National Oceanic and Atmospheric Administration, National Climatic Data Center.

Table 2-2. Available Monitoring Data

Type of Information	**Data Source(s)**
Water Body Characteristics	
Physical data	BASINS (Reach File, Versions 1 and 3); USGS NHD reach data; MDEQ Clean Lakes Studies (FTN Associates, 1991)
Flow	
Historical flow record	USGS (gage sites located near but not in watersheds) MDEQ Clean Lakes Studies (FTN Assiciates, 1991)
Meteorological Data	
Rainfall	NOAA-NCDC, Earth Info
Temperature	NOAA-NCDC, Earth Info
Water Quality Data (surface water, groundwater)	
Water quality monitoring data	MDEQ Clean Lakes Studies (FTN Associates, 1991)

2.2 Monitoring Data Assessment of Wolf Lake

Tributary and inlake data were collected from February 1989 through February 1990 (FTN Associates, 1991). The lake was sampled twice a month from May through October and once a month for the remainder of the year. Figure 2-1 shows the routine water quality monitoring stations. A detailed description of all the sampled parameters along with a discussion on the spatial and temporal variability can be found in the Clean Lakes Study Report by FTN Associates (report dated May 1991). Results of the data collection are summarized in the following subsections.

2.2.1 Tributary Inflow

FTN Associates sampled tributary flow at one station near the inlet (WL-1) to Wolf Lake (Figure 2-1). Table 2-3 summarizes the inlet data for some of the parameters that have relevance to this study.

Table 2-3. Inlet (WL1) Water Quality Data (1989 - 1990)

Parameter	Count	Min.	Max.	Mean	Median
Temperature (°C)	18	6.5	28.0	20.2	22.3
Dissolved Oxygen (mg/L)	18	1.8	9.4	4.6	4.2
Total Suspended Solids (mg/L)	17	13.0	134.0	49.7	46.0
Total Kjeldahl Nitrogen (mg/L)	18	0.322	4.0	2.1	2.0
Ammonia -N (mg/L)	18	0.1	0.75	0.203	0.135
Nitrate + Nitrite-N (mg/L)	18	0.040	1.8	0.316	0.123
Total Phosphorus (mg/L)	18	0.04	0.68	0.226	0.175
Dissolved Orthophosphate (mg/L)	18	0.01	0.098	0.04	0.029

Source: FTN Associates, 1991.

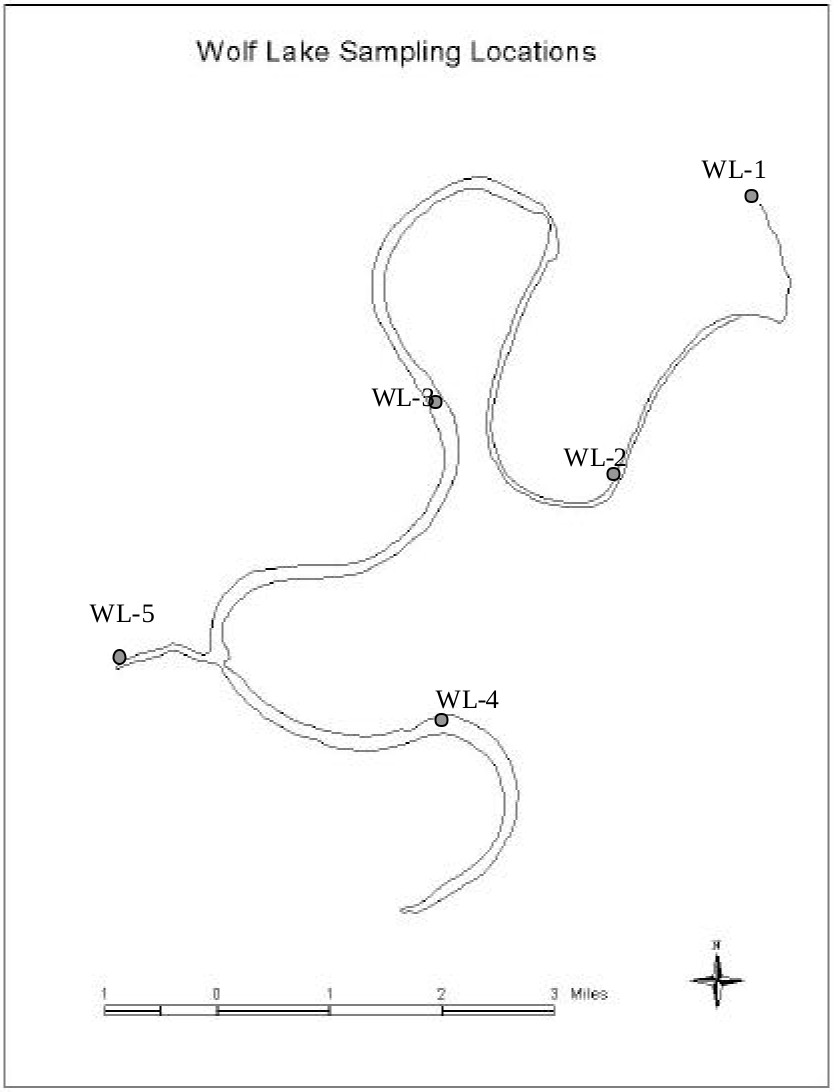

Figure 2-1. Sampling Locations for Wolf Lake

The temperatures generally followed a sinusoidal pattern in the lake, with the maximum temperatures occurring during August (28^{o}C) and minimum temperatures occurring in December (6.5^{o}C). The DO concentrations in the inlet were below the MDEQ instantaneous DO standard of 4mg/L for 7 out of the 18 observations from February 1989 to February 1990. However, the DO concentrations were observed to be almost as high as 9 mg/L during the colder months. The maximum TSS concentrations were observed in June while the minimum concentrations were observed in September. In general, the TSS concentrations were high during springtime and became low during the latter part of summer.

2.2.2 Stormwater Data

MDEQ collected stormwater quality data during a rainfall event of 2.7 centimeters (1.07 inches) on January 18, 1990 (FTN Associates, 1991). The location of the site was in close proximity to the inlet sampling station WL1. The report concludes that the most obvious difference between storm event sampling and the routine monitoring data are the increases in TSS, total dissolved solids (TDS), and total phosphorus. Thus a large part of the phosphorus is apparently attached to sediment particles and is transported into the lake during storm events. Dissolved orthophosphate concentrations were less than 0.05 mg/L, indicating that more than 40 percent of the total phosphorus was in particulate form (FTN Associates, 1991). Mean nitrate plus nitrogen were greater during the storm event, but the total Kjeldahl nitrogen (TKN) and ammonia-nitrogen concentrations remained similar to those measured during routine monitoring. Although DO measurements were high (7.5 mg/L), this does not provide an indication of critical periods of low DO.

2.2.3 Inlake Water Quality of Wolf Lake

Monthly inlake water quality was measured at three sites in Wolf Lake, stations WL-2, WL-3, and WL4, from February 1989 through February 1990 (FTN Associates, 1991). Figure 2-1 shows the locations of the three sampling stations in the lake. Sampling at station WL-3 included the surface, middle and bottom portions of the lake.

Results were summarized in the FTN Associates report with detailed analysis of temporal and spatial variability. Because of the amount of data collected only a summary of results of selected parameters is reported here. Several parameters were measured for the FTN Associates study, but the following are relevant to TMDL development for the present study. These parameters are consistent with those collected for tributary flow and provide guidance for TMDL development and model development. Table 2-4 provides descriptive statistics for some of the key parameters measured in the lake.

Table 2-4. Inlake (WL-2, WL-3 and WL-4) Water Quality Data (1989 - 1990)

Parameter	Count	Min	Max	Mean	Median
WL-2					
Temperature (°C)	17	11.20	31.20	23.30	23.40
Dissolved Oxygen (mg/L)	17	2.30	10.20	6.40	6.00
Chlorophyll (mg/L)	17	19.10	77.90	19.76	10.60
Total Suspended Solids (mg/L)	17	7.00	126.00	35.50	23.50
Total Kjeldahl Nitrogen (mg/L)	17	0.10	5.40	1.90	1.70
Ammonia -N (mg/L)	17	0.01	0.52	0.21	0.20
Nitrate+Nitrite-N (mg/L)	17	0.04	0.91	0.35	0.22
Total Phosphorus (mg/L)	17	0.01	1.60	0.26	0.14
Dissolved Orthophosphate (mg/L)	17	0.02	0.12	0.06	0.05
WL-3 (Surface)					
Temperature (°C)	17	11.00	32.00	23.00	22.10
Dissolved Oxygen (mg/L)	17	5.00	10.00	7.52	7.20
Chlorophyll (mg/L)	17	16.00	55.20	10.50	11.50
Total Suspended Solids (mg/L)	17	6.00	69.00	27.80	20.00
Total Kjeldahl Nitrogen (mg/L)	17	0.10	4.10	1.30	1.70
Ammonia -N (mg/L)	17	0.01.	0.35	0.14	0.10
Nitrate+Nitrite-N (mg/L)	17	0.04	1.08	0.39	0.24
Total Phosphorus (mg/L)	17	0.01	0.48	0.21	0.16
Dissolved Orthophosphate (mg/L)	17	0.02	0.11	0.06	0.06
WL-3 (mid-depth) Sample Depth = 2.0 ft					
Temperature (C)	17	10.90	29.50	22.00	21.90
Dissolved Oxygen (mg/L)	17	3.40	9.60	6.10	5.60
Chlorophyll (mg/L)	17	-	-	-	-
Total Suspended Solids (mg/L)	17	5.00	97.00	28.90	19.00
Total Kjeldahl Nitrogen (mg/L)	17	0.12	4.70	1.40	1.20
Ammonia -N (mg/L)	17	0.01	0.33	0.14	0.10
Nitrate+Nitrite-N (mg/L)	17	0.04	1.08	0.37	0.12
Total Phosphorus (mg/L)	17	0.05	0.51	0.22	0.14
Dissolved Orthophosphate (mg/L)	17	0.02	0.15	0.06	0.05
WL-3 (0.5 m off of bottom) Sample Depth = 3.5 ft					
Temperature (°C)	17	10.80	29.20	20.60	20.30
Dissolved Oxygen (mg/L)	17	0.20	9.40	3.80	2.40
Chlorophyll (mg/L)	17	-	-	-	-
Total Suspended Solids (mg/L)	17	8.00	79.00	30.60	26.50
Total Kjeldahl Nitrogen (mg/L)	17	0.10	10.30	1.70	1.10
Ammonia -N (mg/L)	17	0.10	0.35	0.17	0.15
Nitrate+Nitrite-N (mg/L)	17	0.04	1.05	0.36	0.11
Total Phosphorus (mg/L)	17	0.01	0.51	0.24	0.23
Dissolved Orthophosphate (mg/L)	17	0.02	0.14	0.07	0.06
WL-4 (Broad Lake arm of Wolf Lake)					
Temperature (°C)	18	9.30	33.00	22.50	24.00
Dissolved Oxygen (mg/L)	18	4.00	10.60	7.60	7.60
Chlorophyll (mg/L)	17	18.70	570.00	13.97	10.50
Total Suspended Solids (mg/L)	17	8.00	144.00	65.60	56.00
Total Kjeldahl Nitrogen (mg/L)	18	0.64	5.30	1.80	1.70
Ammonia -N (mg/L)	18	0.01	0.40	0.19	0.19
Nitrate+Nitrite-N (mg/L)	18	0.04	1.80	0.34	0.11
Total Phosphorus (mg/L)	18	0.05	1.10	0.30	0.24
Dissolved Orthophosphate (mg/L)	18	0.01	0.10	0.05	0.04

Source: FTN Associates, 1991.

The temperatures at sampling stations WL-2, WL-3, and WL-4 generally followed a sinusoidal pattern in the lake with the maximum temperatures occurring during July in Wolf Lake (32^{o}C) and in August for the Broad Lake arm of Wolf Lake (33^{o}C). Both DO and temperature data exhibit little spatial variability except where samples differed in depth. The depth-dependent variability indicates than the lake stratifies during the summer. The temperature, DO, and DO saturation plots indicate that Wolf Lake stratifies at station WL-3 in the summer months (FTN Associates, 1991). The DO concentrations at both the mid-depth level and the bottom were less than 5 mg/L over most of the spring and summer. Anoxic conditions near the bottom existed from April through July and in the latter part of August. Beginning in September mixing occurred and the lake remained mixed until the end of the study.

Two diurnal studies were also conducted on August 10, 1989, and on September 12, 1989. As expected, DO concentrations decreased with depth. At the surface the diurnal DO variation during the day in August was 3.4 mg/L at WL-3 and 6.6 mg/L at WL-4. At WL-3 the maximum DO was 8.4 mg/L and the minimum DO was 5.0 mg/L. At WL-4 the maximum DO was 10.1 mg/L and the minimum DO was 3.5 mg/L. In September the diurnal variation increased to 5.3 mg/L at WL-3 and 6.6 mg/L at WL-4. At WL-3 the maximum DO was 9.5 mg/L and the minimum DO was 4.2 mg/L. At WL-4 the maximum DO was 9.1 mg/L while the minimum DO was 2.5 mg/L (FTN Associates, 1991). This indicates a high level of algal photosynthetic activity. However, it may be noted that DO never went below the instantaneous standard of 4 mg/L in the epilimnion at any of the locations during the diurnal studies.

Surface TSS concentrations in Wolf Lake at WL2 and mid-lake station WL3 exhibited a seasonal pattern of low concentrations during the summer months from July through October, and high concentrations during the winter and spring, with WL4 showing consistently higher concentrations (FTN Associates, 1991). Chlorophyll-a concentrations tended to be higher when TSS concentrations were high. Chlorophyll-a concentrations in general were variable but tended to be higher in the summer than in spring or winter months (FTN Associates, 1991).

2.2.4 Outlet Water Quality of Wolf Lake

The water discharged from the lake was sampled at station WL-5 (Figure 2-1). Outlet temperatures also followed a sinusoidal pattern with a maximum of 32.5^{o}C and a minimum of 9.3^{o}C. The DO concentrations were variable but low during May (approximately 4 mg/L) and fell to a minimum of 3.4 mg/L in September (below the MDEQ instantaneous DO standard of 4 mg/L). At other times of the year the DO remained around 6 to 10 mg/L. The TSS concentrations were higher in the spring and winter, with maximum TSS concentrations measured during the latter part of October and minimum concentrations during the latter part of August (FTN Associates, 1991). Table 2-5 provides descriptive statistics for some of the key parameters measured at the lake outlet.

Table 2-5. Outlet (WL-5) Water Quality Data (1989 - 1990)

Parameter	Count	Min	Max	Mean	Median
Temperature (°C)	18	9.30	32.50	22.10	21.50
Dissolved Oxygen (mg/L)	18	3.40	9.90	6.80	6.60
Total Suspended Solids (mg/L)	17	6.00	49.00	25.90	25.50
Total Kjeldahl Nitrogen (mg/L)	18	0.87	5.80	1.80	1.30
Ammonia -N (mg/L)	18	0.01	0.52	0.14	0.10
Nitrate+Nitrite-N (mg/L)	18	0.04	1.00	0.34	0.17
Total Phosphorus (mg/L)	18	0.04	0.68	0.23	0.17
Dissolved Orthophosphate (mg/L)	18	0.01	0.09	0.04	0.03

Source: FTN Associates, 1991.

3.0 Source Assessment

This section describes the potential sources of pollutants in the Wolf Lake watershed. The source assessment, along with the available data for Wolf Lake described in the previous section, was used as the basis for developing the model and analyzing the TMDL allocation. The potential point and nonpoint sources are characterized by the best available information and literature values. This section documents all available information.

3.1 Point Sources

Pollutant sources under the Clean Water Act (CWA) are typically categorized as either point or nonpoint sources. Point sources, according to 40 CFR 122.2, are defined as any discernable, confined, and discrete conveyance, including but not limited to, any pipe, ditch, channel, tunnel, conduit, well, discrete fissure, container, rolling stock concentrated animal feeding operation, landfill, leachate collection system, vessel, or other floating craft from which pollutants are or may be discharged. The National Pollutant Discharge Elimination System (NPDES) Program, under CWA sections 318, 402, and 405, requires permits for the discharge of pollutants from point sources. There are several types of permits under the NPDES permit program: effluent from facilities, municipal wastewater treatment plants, storm water from construction sites, and municipal separate storm sewer systems.

As of March 2003, discharge of storm water from construction activities disturbing between 1 and 5 acres must also be authorized by an NPDES permit, as is required already of larger construction sites. The purpose of these NPDES permits is to eliminate or minimize the discharge of pollutants from construction activities. Since construction activities at a site are of a temporary, relatively short-term nature, the number of construction sites covered by the general permit at any moment in time varies. The target for these areas is the same range as the TMDL target of 0.23 to 0.15 tons per acre per year. The waste load allocations (WLAs) provided to the NPDES-regulated construction activities and MS4s will be implemented as best management practices (BMPs) as specified in Mississippi's General Stormwater Permits for Small Construction, Construction, and Phase I & II Municipal Separate Storm Sewer Systems (MS4) permits. It is not technically feasible to incorporate numeric sediment limits into construction storm water or MS4 permits at this time. WLAs should *not* be construed as numeric permit limits for construction or MS4 activities. Properly designed and well-maintained BMPs are expected to provide attainment of WLAs.

A review of Mississippi's automated resource information system discharge elimination file showed that no permitted point source discharges are located within the watershed. The towns within the Wolf Lake watershed are small and, according to the final Phase II Stormwater NPDES regulations, are not considered regulated small MS4s at the present time. However, the potential for sediment loadings from NPDES-regulated construction activities and Municipal Separate Storm Sewer Systems (MS4s) are considered point sources of sediment to surface waters. These discharges occur in response to storm events and are included in the WLA of this TMDL.

3.2 Nonpoint Source Data

Nonpoint sources in the watershed may also contribute pollutants to the lake and its tributaries. Nonpoint sources represent contributions from diffuse, non-permitted sources. Exceptions to this are some aquaculture facilities (which are discrete and non-permitted sources) and storm water collection systems that are in place regulating the runoff as a point source since the runoff is delivered to the receiving water body though a conduit. Nonpoint sources include both precipitation-driven and non-precipitation-driven events such as contributions from groundwater; septic systems; and direct deposition of pollutants from wildlife, livestock, or atmospheric fallout.

Nonpoint sources contribute sediment and oxygen-consuming loads into the waters of the Wolf Lake watershed. On land, oxygen-consuming constituents accumulate over time and wash off during rain events. As the runoff transports the sediment over the land surface, more oxygen-consuming constituents are collected and carried to the stream. The net loading into the stream is determined by the local watershed hydrology.

3.2.1 Agricultural Sources

The Mississippi Valley is one of the most intensively agricultural areas in the United States. The flat, fertile soils produce a variety of crops including cotton, corn, and soybeans. Cultivated and noncultivated agricultural lands cover 46 percent and 24 percent, respectively, of the Wolf Lake watershed area and have been identified as a major source of sediment and nutrients (FTN Associates, 1991). Cotton is the major crop in the Wolf Lake watershed representing 78 percent of the total cultivated agriculture land and 34 percent of the total watershed area. Corn and soybeans represent 6 percent and 5 percent, respectively, of the total cultivated agriculture land and 3 percent and 2 percent, respectively, of the total watershed area. Additional crops include sorghum, snap beans, other small grains, rice, winter wheat, and sunflowers.

3.2.2 Aquaculture

The production of catfish is the largest aquaculture crop in the United States. Catfish ponds located in the Mississippi Valley account for approximately 78 percent of the total land area devoted to catfish production (US EPA, 2002). The majority of the catfish ponds in the Mississippi Valley are groundwater fed, earthen levee ponds. The discharge of sediments rich in oxygen-consuming substances from catfish ponds occurs during drainage and overflow events. Drainage occurs occasionally, an average of once every 6 years for most ponds, when ponds are drained for harvesting or structural repairs. However, overflow from ponds occurs more often, when the pond level rises because of precipitation events. Therefore, in this analysis, the ponds are treated as non point sources. Common pond management practices that reduce the frequency of pollutant discharges include managing pond levels to maintain water storage potential and reducing the frequency of pond drainage for cleaning and repairs. These practices are currently used in most catfish ponds in Mississippi (Tucker et al., 1996). A complex of catfish ponds covering approximately 1,256 acres (approximately 5 percent of the watershed area) is present in the Wolf Lake watershed.

3.2.3 Septic Systems

Failing septic systems represent a source that may contribute oxygen-consuming constituents to receiving water bodies through surface or subsurface malfunctions. Quantifying loads from actual failing septic systems and potential illegal discharges is difficult.

Humphreys and Yazoo Counties have a total of only 14,153 housing units (Table 3-1). Approximately 2.5 percent of the housing units within the two counties lack complete plumbing facilities. Given this low percentage and the small number of dwellings within the lake's watershed septic systems were omitted from the analysis.

Table 3-1. Regional Housing Characteristics

	Humphreys County	**Yazoo County**	**Two-County Region (Total)**	**Two-County Region (%)**
Total housing units	4,138	10,015	14,153	100.0%
1-unit detached	3,154	6,724	9,878	69.8%
In building with 10 or more units	9	186	195	1.4%
Mobile homes	514	1,854	2,368	16.7%
Lacking complete plumbing facilities	137	210	347	2.5%
Occupied units	3,765	9,178	12,943	91.5%
Vacant units	373	837	1,210	8.5%
For seasonal, recreational, or occasional use	59	72	131	0.9%

Source: USDOC, Census, 2001.

3.2.4 Groundwater

The Mississippi River's alluvial aquifer underlies the alluvial plain, locally known as the Delta. The alluvial aquifer is the most heavily pumped aquifer in Mississippi (Arthur, 2001), 98 percent of it for agriculture. According to the USGS, "the aquifer receives water vertically from precipitation, internal streams and lakes, and locally from the Cockfield and Sparta aquifers where they directly underlie the alluvial aquifer. The alluvial aquifer also discharges water to the underlying aquifers, and during extended periods with no surface runoff, to the Mississippi River and to the internal streams and lakes"(Arthur, 2001).

The water quality of the alluvial aquifer is well suited for agriculture but less suited for municipal and some industrial use. It is commonly a hard, bicarbonate type. It contains appreciable amounts of manganese and dissolved iron concentrations usually greater than 3.0 mg/L. According to the USGS, nutrient concentrations are generally low. All nitrate concentrations have been below the USEPA drinking water standard of 10 mg/L (Kleiss et al., 1999).

3.2.5 Background Sources

TMDL load allocation must take into account the natural background loading of a pollutant. For these TMDLs, the contributions of sediment and organic material from forested areas were considered to be the background load. Forested land, including bottomland hardwood forest, upland scrub, and riverine swamp, covers 28 percent of the Wolf Lake watershed. Sediment contributions are generated by forested areas and other nonanthropogenic areas. While present, they are generally lower than those from disturbed land uses. Forested areas that are subject to silviculture and other forestry activities may exhibit elevated sediment contributions. The monitoring data for the Wolf Lake watershed were insufficient to separate natural forest loadings from other forest sources.

The yield of oxygen-consuming substances from forested land is generally low compared with that of other land uses because the dense vegetative cover stabilizes soil, reduces rainfall impact, and in many cases encourages the uptake of nutrients.

4.0 Technical Approach

The objective of this section is to present key issues considered for TMDL development, and technical approaches that fulfill the TMDL requirements.

4.1 Technical Approach Selection

The technical approach selected for TMDL development was based on evaluation of the following criteria (US EPA, 1991):

- Technical criteria
- Regulatory criteria

Technical criteria refer to the model's simulation of the physical system in question, including watershed and lake characteristics and processes and constituents of interest. Regulatory criteria make up the constraints imposed by regulations, such as water quality standards or procedural protocol.

Key technical factors that were considered in identifying the appropriate analytical approach for the sediment/siltation impairments include the following:

- Sediment loads are contributed only by nonpoint sources.
- Erosion and sediment transport generally occur as a result of rainfall events.
- Sedimentation problems in the lake and its tributaries cause cumulative contributions.
- Insufficient monitoring data are available in the watershed to evaluate the magnitude of stream channel and bank erosion.

Key technical factors that were considered in identifying the appropriate analytical approach for the nutrient and organic enrichment/low DO impairments include the following :

- Oxygen-demanding substances (including nutrients) are contributed only by nonpoint sources.
- Oxygen-demanding substances are contributed both from the land surface (as a results of rainfall events) and from the subsurface (due to groundwater contributions).
- The annual load of oxygen-demanding substances is responsible for the accumulated benthic blanket of the water body, which in turn, is expressed as sediment oxygen demand (SOD).

A properly designed and applied technical approach provides the source-response linkage component of the TMDL and makes it possible to accurately assess the assimilative capacity allocation proposition. A water body's assimilative capacity is determined through adherence to predefined water quality criteria (i.e., regulatory considerations). Mississippi's applicable water quality standards were presented earlier in this report and provide the basis for establishing appropriate TMDL targets. For sediment/siltation, the standard is narrative; however, for low DO, the standard is numeric. The instream DO target for this TMDL is a daily average of not less than 5.0 mg/L. The instantaneous minimum portion of the DO standard was considered when establishing the instream target for this TMDL. However, it was determined that using the daily average standard with the conservative modeling assumptions would be sufficiently protective of the instantaneous minimum standard.

Based on the considerations identified above, the technical approach to address sediment/siltation and organic enrichment/low DO impairments in Wolf Lake includes a combination of watershed and lake water quality models:

- A simplified watershed model to predict runoff and loadings of sediment, nutrients, and organic material to the tributaries and lake to address both sediment/siltation and organic enrichment/low DO impairments.
- Receiving water model of the organic enrichment/low DO in Wolf Lake for prediction of instream DO concentrations for comparison to selected endpoints.
- Siltation rate analysis for the lake.

The technical approach to TMDL development must take into account the dominant watershed and inlake processes. Pollutant loading in Wolf Lake watershed is primarily from non-point or diffuse sources, which are typically rainfall-driven and relate to surface runoff and subsurface discharge to a stream. Apart from aquaculture within the watershed, which is treated as a point source, no point sources exist in the watershed. The inlake processes include advective and diffusive transport and nutrient cycling. The approach will provide a hydrologic, sediment, and nutrient loading budget for the watershed that can be linked to an inlake and instream water quality model to assess the inlake water quality.

4.2 Modeling

Both watershed and receiving water models were used to identify the TMDLs for sediment and organic enrichment. For ease of discussion, the models are discussed by impairment in the following subsections.

4.2.1 Sedimentation

The Generalized Watershed Loading Function (GWLF) model (Haith and Shoemaker, 1987) was selected to simulate the loading of sediment and oxygen-consuming substances from the Wolf Lake watershed. The GWLF model has been widely used to estimate sediment and nutrient loads from agricultural watersheds. The GWLF model uses the Soil Conservation Service Curve Number (SCS-CN) approach to model surface runoff and the Universal Soil Loss Equation (USLE) algorithm to model erosion and sediment yield. The SCS-CN and USLE methods are a component of other watershed models, including the Agricultural Non Point Source Loading (AGNPS) model and the Soil and Water Assessment Tool (SWAT).

GWLF is an aggregate distributed/lumped parameter watershed model. For surface loading, it is distributed in the sense that it allows multiple land use and cover scenarios.

Each category area is assumed to be homogeneous with respect to various attributes considered by the model. In addition, the model does not spatially distribute the source areas, but aggregates the loads from each area into a watershed total. In other words, there is no spatial routing. For subsurface loading, the model acts as a lumped parameter model using a water balance approach. No distinctly separate areas are considered for subsurface flow contributions. Daily water balances are computed for an unsaturated zone as well as for a saturated subsurface zone, where infiltration is computed as the difference between precipitation and snowmelt minus surface runoff plus evapotranspiration. Monthly calculations are made for sediment and nutrient loads, based on daily water balance totals that are summed to give monthly values.

The sediment accumulation in Wolf Lake can be assessed using trap efficiency calculations. The Brune method (USACE, 1989) is a widely used trap efficiency estimation method for lakes and reservoirs, using a graphical relationship between trap efficiency and the ratio of water body volume to annual volumetric inflow. Using the volume of the lake and estimated annual inflows from the GWLF model, the trap efficiency (%) of the lake can be estimated. Based on the trap efficiency, the siltation rate can be estimated. More detailed modeling information may be found in Appendix A.

4.2.2 Organic Enrichment/Low DO and Nutrients

The Wolf Lake system is fairly long and hydrologically active with a hydraulic residence time of approximately 51 days. Inlake conditions vary along the length of the system and vertical stratification occasionally occurs. The existing calibrated CE-QUAL-W2 (Cole and Buchak, 1995) hydrodynamic model for this system was used to simulate eutrophication processes. The model is vertically and horizontally two-dimensional and simultaneously simulates hydrodynamics and the transport and transformation of water quality variables. The model was configured with 22 longitudinal segments, 1500 meters long, and a maximum of six 1-meter-thick vertical layers. The total number of active model cells was 82. Longitudinally and vertically varying cell widths ranged from 200 meters at the surface to 10 meters at the bottom. The model was calibrated for the period between 1989 and 1990, corresponding to the interval of available inlake water quality monitoring data (FTN Associates, 1991). In general the simulated DO followed the observed data fairly well, capturing the seasonal trends and capturing the critical warmer months during the calibration period. More detailed information about model calibration (plots and discussion), model set up, assumptions, and limitations may be found in Appendix B.

Once the model setup and calibration were complete, the model was run for the selected critical period from 1997 to 2000 under baseline conditions. The baseline model run reflects the existing conditions for these years without any reduction in the oxygen-consuming loadings from the watershed. The model was then run using a trial-and-error process to determine the maximum TBODu loads from the watershed that would not exceed the water quality standards for DO in the epilimnion. These constituted the load reduction scenarios. The model simulation results were analyzed in the epilimnion with the daily average DO criteria. The epilimnion for Wolf Lake was determined to be at a depth of 1 meter, based on the observed diurnal profile data presented in the Clean Lakes Study (FTN Associates, 1991). The model outlet cell was chosen as the location for evaluating the TMDLs because it exhibited the poorest water quality conditions in the lake based on model results.

The load reduction scenarios showed that 1997 was the most critical year. Model results showed that when a 45 percent reduction was included, the water quality standard was met in the epilimnion. Figures 4-1 and 4-2 show the baseline and the 45 percent load reduction case in the epilimnion for the daily average and instantaneous minimum DO at the outlet cell.

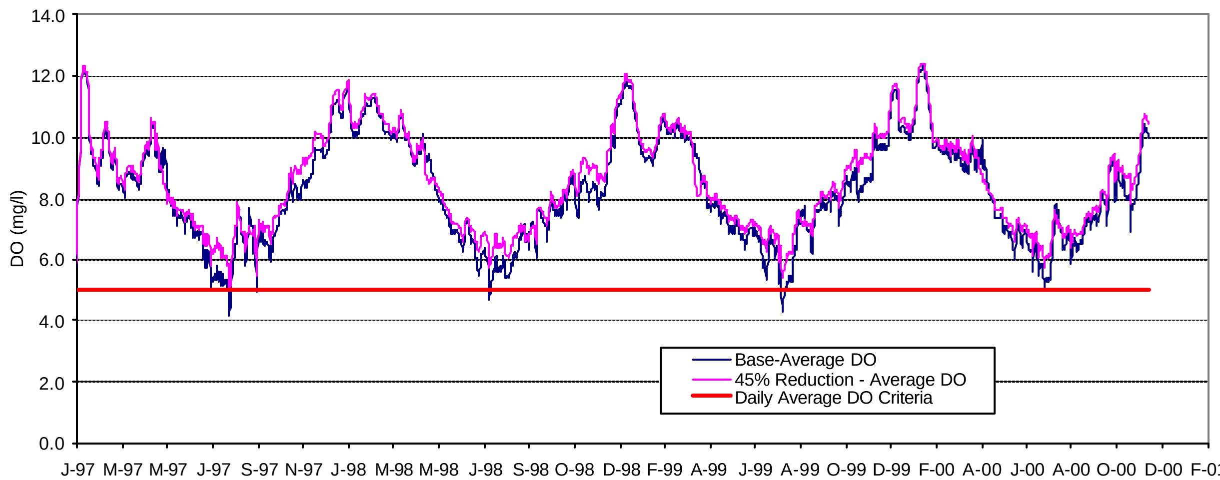

Figure 4-1. Daily Average DO in the Epilimnion.

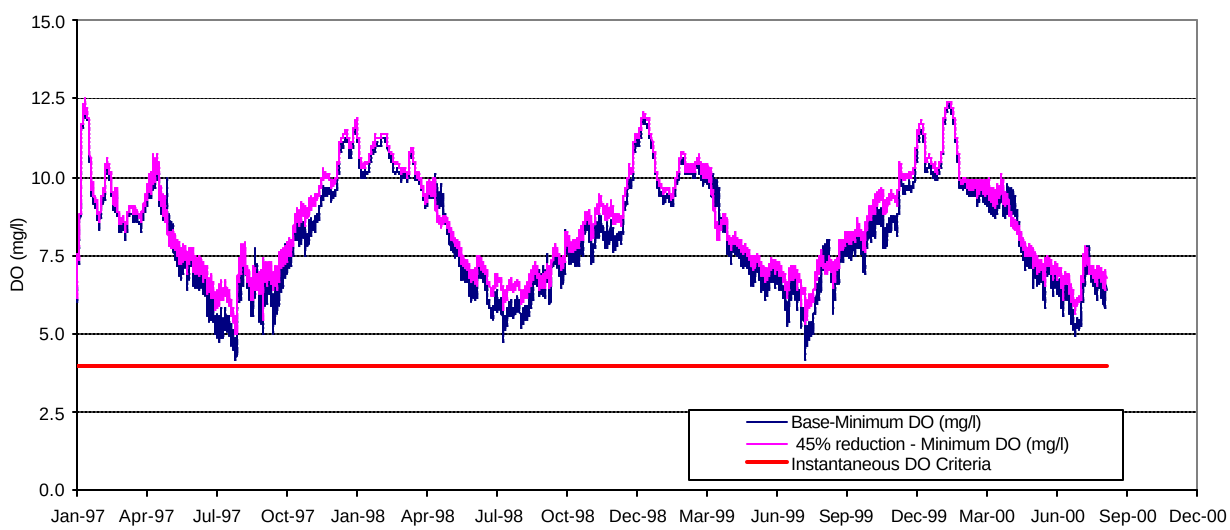

Figure 4-2. Instantaneous Minimum DO in the Epilimnion.

4.2.3 Modeling Assumptions

The major underlying assumptions for this analysis include the following:

General

- Meteorological data from Jackson, Mississippi were assumed to be representative of the entire watershed contributing to the lake, although the station is located outside the watershed. The Jackson, Mississippi station was used because it is the station nearest to Wolf Lake that has complete meteorological records.
- The watersheds delineated were based on topographic data and available stream and channel coverages. Data regarding flow diversions to or from other watersheds were not available and were therefore not considered in the analysis.

Sedimentation Analysis

- The lake's life span was estimated by predicting the amount of sediment contributed to the lake over time and determining the reservoir volume reduced by the sediment. Sediment reaching the lake was assumed to be deposited homogeneously over the entire lake bottom. In reality, however, sediment deposition varies depending on many factors, such as bathymetry. The life of the lake was assumed to be exhausted when the lake surface area was reduced by approximately 50 percent.
- The lake's sediment trapping efficiency was based on Brune's method (USACE, 1989).
- The sediment distribution was assumed to be an equal mix of sand, silt, and clay particles.
- Sedimentation at the land use level was predicted using USLE, and only a portion of this load was delivered to the lake. The percentage of eroded sediment delivered to the lake was determined on a sediment delivery ratio.
- Available data indicated that no timber harvesting was occurring within the watershed. Therefore, forested land was assumed to be consistent throughout the watershed, with respect to sediment load contributions.
- The sedimentation prediction assumed that unpaved roads do not play a major role in sediment contribution to the lake.
- Land management practices including reduced tillage, cover crops, and detention ponds are widely used in the Mississippi Delta area (Yuan and Bingner, 2002). Therefore, agricultural land in the watershed was assumed to be managed under moderate tillage.

Organic Enrichment/Low DO and Nutrients

- Monthly loads are assumed to sufficiently represent loading variability in the lake model.

- Since a complete hourly data set for the meteorological parameters was not available, the model uses representative rather than actual wind data in determining hydrodynamic transport and surface reaeration.
- The watershed model gives an estimate of the total phosphorus and total nitrogen. These loadings were split based on the nutrient ratios determined from inlake monitoring data to provide the required loadings (as per W2 model requirements) of dissolved and particulate organic material, ammonia, nitrate-nitrite, and ortho-phosphorus that feed into the W2 model.
- Long-term contributions of nutrients and other oxygen-demanding substances to the lakes ultimately result in high sediment oxygen demand (SOD) levels. Due to this relationship, during the allocation process SOD levels were reduced when incoming nutrient and oxygen-demanding substance reductions were made. Past studies using predictive sediment diagenesis models have suggested that the SOD is reduced by approximately half the percentage reduction of incoming nutrients and oxygen-demanding substances (USEPA, 2002).
- The watershed model did not simulate dissolved oxygen and water temperature, therefore a number of assumptions were made regarding boundary conditions (inputs from the watershed) for the lake model. A dissolved oxygen concentration time series equal to 90 percent saturation was assumed for all inputs. Water temperatures feeding into the lake were taken from the inlet station WL-1 and were used for both branches.
- Although backflow into Wolf Lake from the unnamed tributary of the Yazoo River at the lake outlet is common, there are insufficient data to fully reflect these processes in the modeling effort. The backwater effects were not considered in the analysis.

4.2.4 Limitations

A number of limitations were inherent in the analytical process because of the approach selected. These limitations are identified below. Despite these limitations, the approach successfully resulted in TMDL identification. If additional data are collected for Wolf Lake, many of these limitations can be addressed.

Sedimentation Analysis

- The analysis did not explicitly consider stream-bank erosion. Only surface erosion and delivery were considered.
- Sediment deposition varies depending on many factors, such as bathymetry. Sediment deposition was assumed to occur evenly over the entire lake area. The life of the lake was assumed to be exhausted when the water volume in the lake surface area was reduced by approximately 50 percent.
- Forested land was assumed to be consistent throughout the watershed, with respect to sediment load contributions.

Organic Enrichment/Low DO and Nutrients

- Sediment nutrient and oxygen flux data were not available for the lake. Collection of these data are important to further understanding the overall sediment fluxes in the lake and their implications for dissolved oxygen levels. If additional sediment flux data are collected, the existing reservoir model could be extended to consider predictive sediment diagenesis processes, which dynamically link sediment response to nutrient inputs; this would provide a better long-term prediction of SOD. At present, the CE-QUAL-W2 model does not include a sediment modeling system that directly interacts with the water column, i.e., there is no separate sediment compartment.
- Based on the nitrogen:phosphorus ratio calculated using the limited available water quality monitoring data and past studies, the lake was assumed to be nitrogen-limited. This analysis does not consider the possibility that once the nitrogen load is reduced, it is possible that phosphorus will become the limiting nutrient. Without additional monitoring data to support model calibration (i.e., data that quantitatively demonstrate this phenomenon), this shift in nutrient limitation cannot be explicitly modeled.
- The impact of sediment reduction on light extinction in the lake was not considered during the allocation process. It is possible that as sediment loads are reduced, more light will be available to algae in the lake. Increased light may result in increased algae growth and possibly greater variability in dissolved oxygen concentration.

4.2.5 Recommendations

Although data collection activities are not planned at the present time, this report suggests types of data that could be used to refine the assumptions and address the limitations of the modeling effort. Additional data collection would allow for a more detailed and refined analysis of sedimentation and dissolved oxygen/organic enrichment dynamics in the lake. These data would ultimately lead to more refined TMDL values and load allocations.

General

- Quantitative information regarding backflow into the lake from downstream tributaries is important to fully understanding the lake's water balance and nutrient/oxygen-demanding substance balance.
- No flow gages are currently located within the watershed. Flow monitoring would provide valuable insight into the watershed's hydrology and support further evaluation of meteorological and land-based impacts on the lake.

Sedimentation Analysis

- Insufficient sediment monitoring data were available to perform a detailed evaluation of sedimentation and resuspension in the lake. Further evaluation of sedimentation spatially and temporally throughout the lake would provide a more precise estimate of the life span.

- Further analysis of stream channel morphology and evolution is recommended to identify the significance of stream-bank erosion no the lake's sedimentation rate. In the event that stream-bank erosion is found to play a major role in sediment contributions to the lake, simulation of stream channel evolution may be a useful analytical tool.
- Additional ground-truthing of unpaved road locations and their impact on sedimentation in the watershed is recommended.

Organic Enrichment/Low DO and Nutrients

- Additional water quality monitoring data within the lake are necessary to support model calibration and to understand the lake's dynamics in greater detail. These data should be collected at multiple locations throughout the lake during different seasons, and they should include depth-variable temperature, dissolved oxygen, and nutrient samples; diurnal dissolved oxygen data; and algal bioassays.
- Water quality monitoring data for the lake's tributaries are important in evaluating locational and source-specific pollutant contributions, as well as identifying seasonal and critical period trends. It is recommended that water quality samples be collected at multiple locations throughout the watershed for baseflow and storm flow conditions.
- The relationship between sediment reduction, light extinction, and algae growth needs to be further explored. Sediment reduction levels, without an associated reduction in nutrients, may result in increased light availability and thus increased algae growth and diurnal dissolved oxygen variations. It is important to collect data that provide more insight into these dynamics.

5.0 TMDL Development

A total maximum daily load (TMDL) for a given pollutant and water body is the sum of individual waste load allocations (WLAs) for point sources, and load allocations (LAs) for both nonpoint sources and natural background levels. In addition, the TMDL must include a margin of safety (MOS), either implicitly or explicitly, to account for the uncertainty in the relationship between pollutant loads and the quality of the receiving water body. Conceptually, this definition is represented by the equation

TMDL = ? WLAs + ? LAs + MOS

The TMDL is the total amount of pollutant that can be assimilated by the receiving water body while still achieving water quality standards. In TMDL development, allowable loads from all pollutant sources that cumulatively amount to no more than the TMDL must be established and thereby provide the basis for establishing water quality-based controls.

5.1 TMDL Water Quality Endpoints

One of the major components of a TMDL is the establishment of instream numeric endpoints, which are used to evaluate the attainment of acceptable water quality. Instream numeric endpoints represent the water quality goals that are to be achieved by meeting the load allocations specified in the TMDL. The endpoints allow for a comparison between observed instream conditions and conditions that are expected to restore designated uses. Specifications of numeric water quality endpoints or targets are discussed by pollutant below.

5.1.1 Sediment/Siltation

No numeric endpoints are defined in Mississippi's Water Quality Standards; therefore an appropriate target was defined for TMDL development. Oxbow lakes are naturally dynamic systems and have limited life spans, typically filling with sediment over time (Monroe and Wincander, 1992). As a result, a reasonable goal for TMDL development is not necessarily to prevent sediment accumulation entirely, but to return the lake to its natural rate of sediment accumulation. Therefore, a target sedimentation rate was defined based on an assessment of current watershed sediment loading rates and sediment loading rates under various land management conditions. The land management scenarios used to develop the target sedimentation rates include only a few examples of how the current land uses could be modified to reduce the sediment loading. Other options, beyond those presented in this report, are possible.

5.1.2 Organic Enrichment/Low DO and Nutrients

The endpoint used to develop an organic enrichment/low DO and nutrient TMDL for Wolf Lake is based upon the daily average of not less than 5.0 mg/L in the epilimnion.

Generally, an organic enrichment/low DO impairment suggests critical conditions in the water body that result from processes that link sources of nutrients and organic material to biological processes and DO levels.

For this TMDL, organic enrichment has been expressed in terms of total biochemical oxygen demand (TBODu). TBODu represents the oxygen consumed by microorganisms while stabilizing or degrading carbonaceous and nitrogenous compounds under aerobic conditions over an extended time period. The carbonaceous compounds are referred to as $CBOD_u$ and the nitrogenous compounds are referred to as NBODu TBODu is equal to the sum of CBODu and TBODu.

$$TBODu = CBODu + NBODu \qquad [1]$$

The watershed model gives an estimate of oxygen-consuming substances from which an estimate of the TBODu has been made. The CBODu load can be estimated from the stoichiometric relationship between the total organic carbon (TOC) and oxygen, which is 2.67 pounds of oxygen per pound of carbon consumed (Thomann and Mueller, 1987). Since the watershed model does not directly simulate TOC, an indirect estimate of TOC can be made based on the stoichiometric equivalent between organic matter (OM) and carbon. OM can be converted to TOC using a stoichiometric relationship, which is 0.45 times the OM (Cole and Buchak, 1995). Thus, the $CBOD_u$ can then be determined from the OM by multiplying it by (0.45 x 2.67) or a factor of 1.2.

In order to convert the ammonia nitrogen (NH_3-N) loads to an oxygen demand, a factor of 4.57 pounds of oxygen per pound of ammonia nitrogen (NH_3-N) oxidized to nitrate nitrogen (NO_3-N) was used (USEPA, 1993). Using this factor is a conservative modeling assumption because it assumes that all of the ammonia is converted to nitrate through nitrification, which is not necessarily accurate. The oxygen demand caused by nitrification of ammonia is equal to the NBODu load. Thus TBODu can be estimated using the revised equation given below:

$$TBODu = 1.2\ OM + 4.57\ NH_3\text{-}N \qquad [2]$$

5.2 Critical Conditions and Seasonality

40 CFR Section 130 requires that TMDLs take into account critical environmental conditions and seasonal environmental variations. The requirements are designed to simultaneously ensure that water quality is protected during times when it is most vulnerable and take into account changes in streamflow and loading characteristics that result from hydrological or climatological variations. These conditions are important because they describe the factors that combine to cause exceedances of water quality standards and because they can help identify necessary remedial actions.

5.2.1 Sediment/Siltation

The sediment analysis considered seasonality by simulating monthly watershed loadings based on historic precipitation records. Sediment impacts on the lake were evaluated for the average annual conditions representing the response to long-term, cumulative siltation. The TMDL and load allocation are presented as an annual average loading consistent with the type of impairment (siltation) and water body type (oxbow lake). Reduction of the average annual load is needed in order to meet water quality standards.

The critical conditions for the sediment TMDLs were selected to evaluate the type of impairment (siltation) and the type of water body (oxbow lake). Protection of the lake condition requires the control of long-term loadings and accumulation of sediment. The lake condition was evaluated based on mean siltation rates in response to long-term annual loading and trapping of sediments in the lake.

5.2.2 Organic Enrichment/ Low DO and Nutrients

The organic enrichment/low DO and nutrients analysis considered seasonality by simulating monthly watershed loadings based on historic precipitation records. Long-term simulation of the lake model under varying precipitation and meteorological conditions takes the seasonality into account.

The analysis used historic precipitation values for a period of 15 years from 1985 to 2000 (Figure 5-1) at the Yazoo City precipitation station (see Figure B-3 in Appendix B for the location of the Yazoo City station). The years from 1997 to 2000 were chosen as the TMDL simulation period because they were not extreme and were close to the annual average precipitation. This period had a wet year, 1997, and a dry year, 2000 (Figure 5-1). Extreme years (very dry or very wet) were not considered for the TMDL. Also the period from 1997 through 2000 corresponded to the years for which the most complete set of hourly meteorological data was available from the Jackson, Mississippi, surface airways station (Figure B-3).

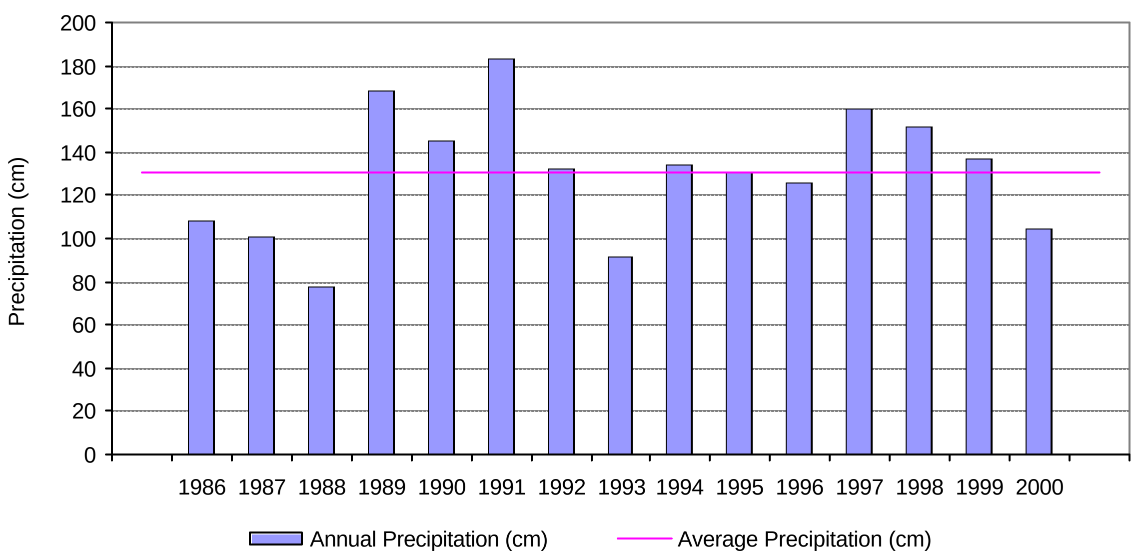

Figure 5-1. Historic Precipitation 1985–2000 (Yazoo City).

Simulation results from the inlake model for this period showed that 1997 was the critical period and the MDEQ DO criteria during this period would be used to determine the TMDL. As shown in Figure 5-2, the simulation period exhibited a wide range of hydrologic conditions with a wet spring and a dry summer. Lakes are typically conducive to eutrophication under these conditions. It may be noted that this year had some relatively dry summer months as well.

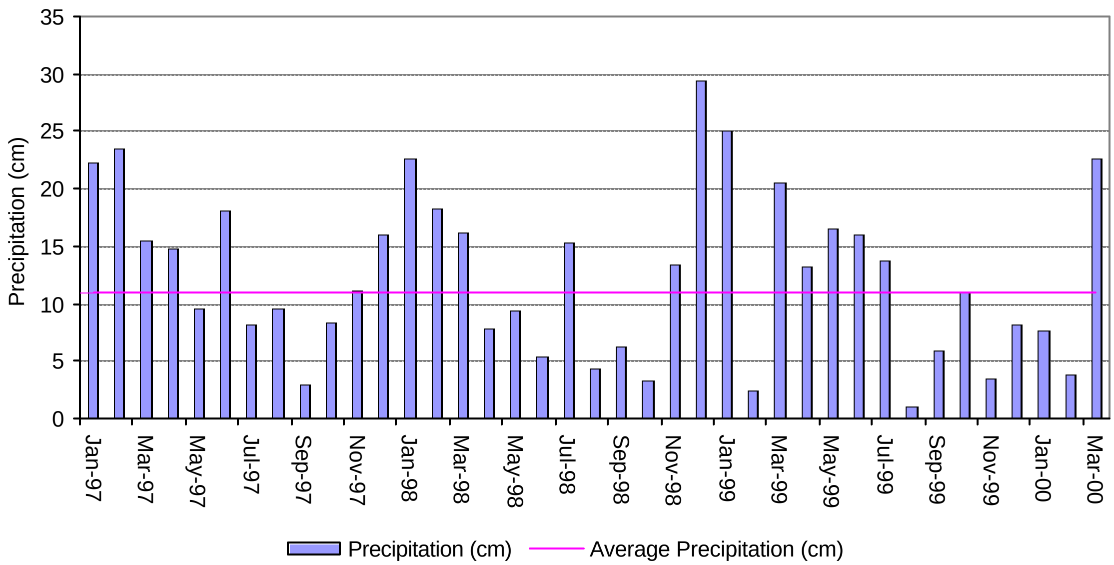

Figure 5-2. Monthly Precipitation 1997–2000 (Yazoo City)

5.3 Sediment Loading Analysis

The sediment loading analysis was based on the long-term average sedimentation rate. Table A-6 in Appendix A provides the computed mean sedimentation rate of the lake for six possible land management scenarios: (1) existing condition (moderate tillage), (2) conventional tillage, (3) 50 percent wooded and moderate tillage, (4) no tillage, (5) 50 percent wooded and no tillage, (6) 100 percent wooded. The life span of the lake under these six conditions is presented in Figure 5-3.

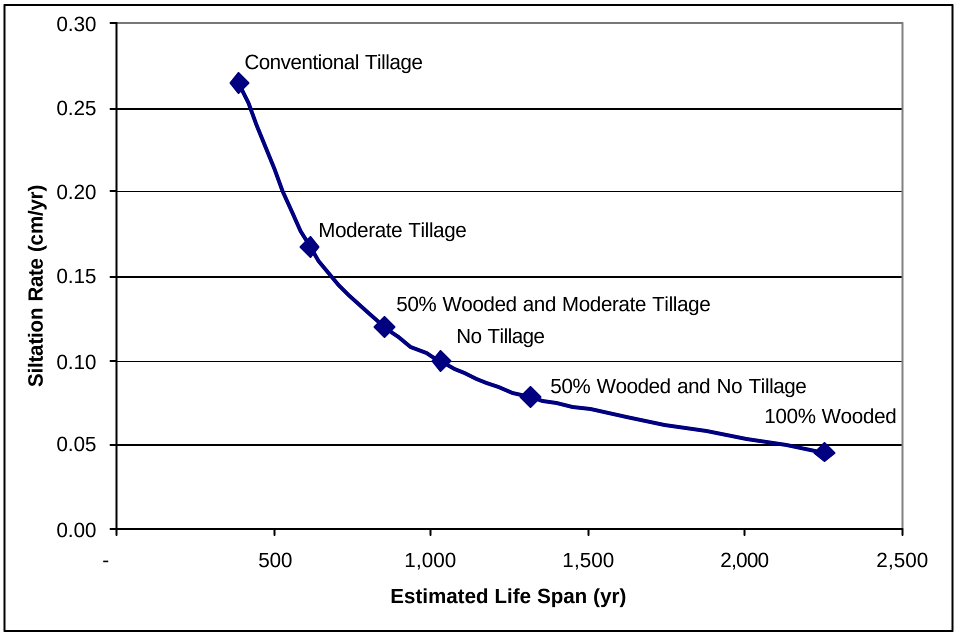

Figure 5-3. Estimated Life Span for Scenarios

These scenarios are based on example land management practices that would result in varying life spans for the lake. The target range was selected in order to achieve a reasonable improvement in sedimentation rates. A range of rates from 0.12 cm/year to 0.08 cm/year was identified as a long-term average sedimentation endpoint. While this range corresponds to the scenarios of 50 percent wooded and moderate tillage to 50 percent wooded and no tillage, these TMDLs are not requiring that these particular BMPs be implemented in the watershed. The reductions can be achieved through various combinations of BMPs that could reasonably be put in place in the Wolf Lake watershed. These TMDLs encourage the use of land management practices, including planting additional forested area and riparian strips and using conservative tillage practices in agricultural areas. As shown in Figure 5-3, the use of these land management practices will significantly extend the life span of Wolf Lake.

5.4 TMDL Allocations of Sediment

According to the model, a sedimentation rate of 0.12 cm/year occurred when the sediment load from the watershed was reduced by 29 percent. A sediment load reduction of 54 percent gave an estimated sedimentation rate of 0.08 cm/year. This range of sedimentation rates is estimated to extend the life span of the lake from approximately 500 years under existing conditions to between 800 and 1,300 years

This reduction was distributed among the different land use categories in the watershed, based on load reduction feasibility (Table 5-1). No reduction was applied to the “other” land use category, which was considered a background (non-anthropogenic) land use. The “other” land use category consists of bottomland hardwood forests, shrubs, woods, and swamp. No reduction was applied to the “residential” land use category since residential land use in the Wolf Lake watershed was negligible and accounted for less than 1 percent of the total land use in the watershed. Although the sediment load from the "Aquaculture" category is small, it was reduced, because its contribution was significant in terms of oxygen-demanding substances.

Table 5-1. Load Reduction Scenario Sedimentation Rate of 0.12 cm/year

LAND USE	BASELINE (t/yr)	REDUCTION (t/yr)	REDUCTION (%)
Agriculture Cultivated	6,841	2,091	31
Agriculture Noncultivated	970	296	31
Aquaculture	32	10	31
Residential	15	0	0
Other	509	0	0
Total	**8,367**	**2,397**	29%

Table 5-2. Load Reduction Scenario Sedimentation Rate of 0.08 cm/year

LAND USE	BASELINE (t/yr)	REDUCTION (t/yr)	REDUCTION (%)
Agriculture Cultivated	6,841	3,925	57
Agriculture Noncultivated	970	557	57
Aquaculture	32	18	56
Residential	15	0	0
Other	509	0	0
Total	**8,367**	**4,500**	54%

The TMDLs for the selected range of sedimentation rates are presented in Tables 5-3 and 5-4. Based on the model, the sediment load that would produce a sedimentation rate of 0.12 cm/year is 0.23 tons/acre/year, and the sediment load that would produce a sedimentation rate of 0.08 cm/year is approximately 0.15 tons/acre/year. It should be stressed that these numbers are only approximations, based on an interpretation of the limited data available for Wolf Lake. There were many assumptions and limitations used in calculating these loads. Collection of additional data or the consideration of other land use management scenarios may result in refinement or modifications of the TMDLs.

Sediment loadings from NPDES-regulated construction activities and Municipal Separate Storm Sewer Systems (MS4s) are considered point sources of sediment to surface waters. These discharges occur in response to storm events and are included in the WLA of this TMDL as the same target yield as the TMDL of 0.23 to 0.15 tons per acre per year.

Table 5-3. TMDL for Sedimentation Rate of 0.12 cm/year for Wolf Lake

Pollutant	WLA (ton/acre/year)	LA (ton/acre/year)	MOS (ton/acre/year)	TMDL (ton/acre/year)
Sediment	0.23	0.23	Implicit	0.23

Table 5-4. TMDL for Sedimentation Rate of 0.08 cm/year for Wolf Lake

Pollutant	WLA (ton/acre/year)	LA (ton/acre/year)	MOS (ton/acre/year)	TMDL (ton/acre/year)
Sediment	0.15	0.15	Implicit	0.15

5.5 TMDL Allocations of TBODu

A 45 percent reduction in the annual watershed loading is recommended to achieve the inlake DO criteria. This reduction could be distributed among the different land use categories in the watershed, based on load reduction feasibility (Table 5-5). No reduction was applied to the "other" land use category, which was considered a background (non-anthropogenic) land use. The "other" land use category consists of bottomland hardwood forests, shrubs, woods, and swamp. No reductions were applied to the "residential" land use category since residential land use in the Wolf Lake watershed was negligible and accounted for less than 1 percent of the total land use in the watershed. Thus, accordingly the reductions were adjusted among the remaining three land uses. The load reduction scenarios given in Table 5-5 are just one example of how land management could be modified in order to reduce pollutant loads in Wolf Lake. Other management scenarios that have not been described in this report are possible.

Table 5-5. Load Reduction Scenarios

	BASELINE		REDUCTION		
LAND USE	**NBODu (lb/day)**	**CBODu (lb/day)**	**NBODu (lb/day)**	**CBODu (lb/day)**	**Reduction (%)**
Agriculture Cultivated	168.2	293.1	80.7	140.7	48
Agriculture Noncultivated	53.6	85.9	25.7	41.2	48
Aquaculture	29.3	44.6	14.1	21.4	48
Other	16.9	29.5	0.0	0.0	0
Residential	1.2	2.0	0.0	0.0	0
Total	**269.1**	**455.1**	**120.5**	**203.3**	**45**

Based on these reductions the TBODu was computed using equation [2] described in Section 5.1.2. The TMDL is presented in Table 5-6. The TMDL for TBODu was computed to be approximately 400.4 lb/day.

Table 5-6. TMDL for TBODu for Wolf Lake

Pollutant	WLA (lb/day)	LA (lb/day)	MOS (lb/day)	TMDL (lb/day)
CBODu	0	251.8	Implicit	251.8
NBODu	0	148.6	Implicit	148.6
TBODu	0	400.4	Implicit	400.4

5.6 Margin of Safety

The margin of safety (MOS) one of the required elements of a TMDL. There are two basic methods for incorporating the MOS (USEPA, 1991):

- Implicitly incorporating the MOS using conservative model assumptions to develop allocations.
- Explicitly specifying a portion of the total TMDL as the MOS; and using the remainder for allocations.

The margin of safety for this TMDL was expressed implicitly through implicit conservative assumptions that provide a margin of safety. Specific conservative assumptions include the following:

- The loadings calculated by the nonpoint source model (GWLF) were derived using conservative assumptions in the selection of nutrient potency and sediment loading factors.
- The use of conservative assumptions in developing the loading model results in relatively high loads and slightly larger required load reductions.

5.7 Reasonable Assurance

The reasonable assurance component of TMDL development does not apply because there are no point sources requesting a reduction based on LA components and reductions.

5.8 Public Participation

This TMDL will be published for a 30-day public notice period. During this time, the public will be notified by publication in the statewide newspaper. The public will be given an opportunity to review the TMDLs and submit comments. MDEQ also distributes all TMDLs at the beginning of the public notice period to those members of the public who have requested to be included on a TMDL mailing list. TMDL mailing list members may request to receive the TMDL reports through either e-mail or the postal service. Anyone wishing to become a member of the TMDL mailing list should contact Greg Jackson at (601) 961-5098 or Greg_Jackson@deq.state.ms.us.

All comments received during the public notice period and at any public hearings become a part of the record of the TMDLs for Wolf Lake. All comments will be considered in the submission of this TMDL to EPA Region 4 for final approval.

5.9 Future Monitoring

MDEQ has adopted the Basin Approach to Water Quality Management, a plan that divides Mississippi's major drainage basins into five groups. During each yearlong cycle, MDEQ's resources for water quality monitoring will be focused on one of the basin groups. During the next monitoring phase in the Yazoo Basin, Wolf Lake may receive additional monitoring to identify any change in water quality. The additional monitoring may allow refinements of the assumptions used to calculate these TMDLs.

5.10 Conclusion

To evaluate the relationship between the sources, their loading characteristics, and the resulting conditions in the lake, a combination of analytical tools was used. This involved source response linkage between the GWLF watershed model for the Wolf Lake watershed and a two-dimensional inlake water quality model, CE-Qual-W2, for Wolf Lake. The sediment load estimates from the GWLF model were used in the analysis of the lake's sedimentation rate. The sedimentation rate analysis was based on a long-term average sedimentation rate that assessed a range of land management practices. A range of 0.12 cm/year to 0.08 cm/year was identified as a long-term average sedimentation endpoint based on the example land management scenarios included in the sediment TMDLs.

A 45 percent reduction of the oxygen-demanding source loadings coming from the watershed was recommended to meet the prescribed DO criteria of a daily average of 5 mg/L. A 29 to 54 percent reduction of sediment load was also recommended to address the siltation loading. The sediment TMDL was computed to be approximately 0.23 tons/acre/year to 0.15 tons/acre/year of sediment for the range of selected endpoints. The organic enrichment/low DO TMDL for TBODu was computed to be approximately 400.4 pounds/day.

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Definitions

Ammonia: Inorganic form of nitrogen (NH_3); product of hydrolysis of organic nitrogen and denitrification. Ammonia is preferentially used by phytoplankton over nitrate for uptake of inorganic n itrogen.

Ammonia Nitrogen: The measured ammonia concentration reported in terms of equivalent ammonia concentration; also called total ammonia as nitrogen (NH_3-N)

Ammonia Toxicity: Under specific conditions of temperature and pH, the un-ionized component of ammonia can be toxic to aquatic life. The un-ionized component of ammonia increases with pH and temperature.

Ambient Stations: A network of fixed monitoring stations established for systematic water quality sampling at regular intervals, and for uniform parametric coverage over a long-term period.

Assimilative Capacity: The capacity of a body of water or soil-plant system to receive wastewater effluents or sludge without violating the provisions of the State of Mississippi Water Quality Criteria for Intrastate, Interstate, and Coastal Waters and Water Quality regulations.

Background: The condition of waters in the absence of man-induced alterations based on the best scientific information available to MDEQ. The establishment of natural background for an altered water body may be based upon a similar, unaltered or least impaired, water body or on historical pre-alteration data.

Biological Impairment: Condition in which at least one biological assemblage (e.g., fish, macroinvertabrates, or algae) indicates less than full support with moderate to severe modification of biological community noted.

Carbonaceous Biochemical Oxygen Demand: Also called CBODu, the amount of oxygen consumed by microorganisms while stabilizing or degrading carbonaceous compounds under aerobic conditions over an extended time period.

Calibrated Model: A model in which reaction rates and inputs are significantly based on actual measurements using data from surveys on the receiving water body.

Critical Condition: Hydrologic and atmospheric conditions in which the pollutants causing impairment of a water body have their greatest potential for adverse effects.

Daily Discharge: The "discharge of a pollutant" measured during a calendar day or any 24-hour period that reasonably represents the calendar day for the purposes of sampling. For pollutants with limitations expressed in units of mass, the daily discharge is calculated as the total mass of the pollutant discharged over the day. For pollutants with limitations expressed in other units of measurement, the daily average is calculated as the average.

Designated Use: Use specified in water quality standards for each water body or segment regardless of actual attainment.

Discharge Monitoring Report: Report of effluent characteristics submitted by an NPDES-permitted facility.

Dissolved Oxygen: The amount of oxygen dissolved in water. It also refers to a measure of the amount of oxygen that is available for biochemical activity in a water body. The maximum concentration of dissolved oxygen in a water body depends on temperature, atmospheric pressure, and dissolved solids.

Dissolved Oxygen Deficit: The saturation dissolved oxygen concentration minus the actual dissolved oxygen concentration.

DO Sag: Longitudinal variation of dissolved oxygen representing the oxygen depletion and recovery following a waste load discharge into a receiving water.

Effluent Standards and Limitations: All state or federal effluent standards and limitations on quantities, rates, and concentrations of chemical, physical, biological, and other constituents to which a waste or wastewater discharge may be subject under the federal act or the state law. This includes, but is not limited to, effluent limitations, standards of performance, toxic effluent standards and prohibitions, pretreatment standards, and schedules of compliance.

Effluent: Treated wastewater flowing out of the treatment facilities.

First Order Kinetics: Describes a reaction in which the rate of transformation of a pollutant is proportional to the amount of that pollutant in the environmental system.

5-Day Biochemical Oxygen Demand: Also called BOD5, the amount of oxygen consumed by microorganisms while stabilizing or degrading carbonaceous or nitrogenous compounds under aerobic conditions over a period of 5 days.

Groundwater: Subsurface water in the zone of saturation. Groundwater infiltration describes the rate and amount of movement of water from a saturated formation.

Impaired Water Body: Any water body that does not attain water quality standards due to an individual pollutant, multiple pollutants, pollution, or an unknown cause of impairment.

Land Surface Runoff: Water that flows into the receiving stream after application by rainfall or irrigation. It is a transport method for nonpoint source pollution from the land surface to the receiving stream.

Load Allocation (LA): The portion of a receiving water's loading capacity attributed to or assigned to nonpoint sources (NPS) or background sources of a pollutant

Loading: The total amount of pollutants entering a stream from one or multiple sources.

Mass Balance: An equation that accounts for the flux of mass going into a defined area and the flux of mass leaving a defined area; the flux in must equal the flux out.

Nonpoint Source: Pollution contained in runoff from the land. Rainfall, snowmelt, and other water that does not evaporate become surface runoff and either drain into surface waters or soak into the soil and finds their way into groundwater. This surface water may contain pollutants that come from land use activities such as agriculture, construction, silviculture, surface mining, disposal of wastewater, hydrologic modifications, and urban development.

Nitrification: The oxidation of ammonium salts to nitrites via Nitrosomonas bacteria and the further oxidation of nitrite to nitrate via Nitrobacter bacteria.

Nitrogenous Biochemical Oxygen Demand: Also called NBODu, the amount of oxygen consumed by microorganisms while stabilizing or degrading nitrogenous compounds under aerobic conditions over an extended time period.

NPDES Permit: An individual or general permit issued by the Mississippi Environmental Quality Permit Board pursuant to regulations adopted by the Mississippi Commission on Environmental Quality under Mississippi Code Annotated (as amended) §§ 49-17-17 and 49-17- 29 for discharges into state waters.

Photosynthesis: The biochemical synthesis of carbohydrate-based organic compounds from water and carbon dioxide using light energy in the presence of chlorophyll.

Point Source: Pollution loads discharged at a specific location from pipes, outfalls, and conveyance channels from either wastewater treatment plants or industrial waste treatment facilities. Point sources can also include pollutant loads contributed by tributaries to the main receiving stream.

Pollution: Contamination, or other alteration of the physical, chemical, or biological properties, of any waters of the state, including change in temperature, taste, color, turbidity, or odor of the waters, or such discharge of any liquid, gaseous, solid, radioactive, or other substance, or leaks into any waters of the state, unless in compliance with a valid permit issued by the Permit Board.

Publicly Owned Treatment Works (POTW): A waste treatment facility owned and/or operated by a public body or a privately owned treatment works, which accepts discharges, which would otherwise be subject to Federal Pretreatment Requirements.

Reaeration: The net flux of oxygen occurring from the atmosphere to a body of water across the water surface.

Regression Coefficient: An expression of the functional relationship between two correlated variables that is often empirically determined from data, and is used to predict values of one variable when given values of the other variable.

Respiration: The biochemical process by means of which cellular fuels are oxidized with the aid of oxygen to permit the release of energy required to sustain life. During respiration, oxygen is consumed and carbon dioxide is released.

Sediment Oxygen Demand: The solids discharged to a receiving water are partly organics, which upon settling to the bottom decompose aerobically, removing oxygen from the surrounding water column.

Storm Runoff: Rainfall that does not evaporate or infiltrate the ground because of impervious land surfaces or a soil infiltration rate slower than rainfall intensity, but instead flows into adjacent land or water bodies or is routed into a drain or sewer system.

Streeter-Phelps DO Sag Equation: An equation, which uses a mass balance approach to determine the DO concentration in a water body downstream of a point source discharge. The equation assumes that the stream flow is constant and that CBODu exertion is the only source of DO deficit while reaeration is the only sink of DO deficit.

Total Ultimate Biochemical Oxygen Demand: Also called TBODu, the amount of oxygen consumed by microorganisms while stabilizing or degrading carbonaceous or nitrogenous compounds under aerobic conditions over an extended time period.

Total Kjeldahl Nitrogen: Also called TKN, organic nitrogen plus ammonia nitrogen.

Total Maximum Daily Load or TMDL: The calculated maximum permissible pollutant loading to a water body at which water quality standards can be maintained.

Waste: Sewage, industrial wastes, oil field wastes, and all other liquid, gaseous, solid, radioactive, or other substances that may pollute or tend to pollute any waters of the State.

Waste load Allocation (WLA): The portion of a receiving waters loading capacity attributed to or assigned to point sources of a pollutant.

Water Quality Standards: The criteria and requirements set forth in State of Mississippi Water Quality Criteria for Intrastate, Interstate, and Coastal Waters. Water quality standards are standards composed of designated present and future most beneficial uses (classification of waters), the numerical and narrative criteria applied to the specific water uses or classification, and the Mississippi antidegradation policy.

Water Quality Criteria: Elements of state water quality standards, expressed as constituent concentrations, levels, or narrative statements, representing a quality of water that supports the present and future most beneficial uses.

Waters of the State: All waters within the jurisdiction of this state, including all streams, lakes, ponds, wetlands, 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 U.S.C.1251 et seq.).

Watershed: The area of land draining into a stream at a given location.

Abbreviations

BASINS.....................Better Assessment Science Integrating Point and Nonpoint Sources
BMP .... Best Management Practice
$CBOD_5$ .... 5-Day Carbonaceous Biochemical Oxygen Demand
$CBOD_U$.. Carbonaceous Ultimate Biochemical Oxygen Demand
CWA .... Clean Water Act
DMR...Discharge Monitoring Report
US EPA ....U.S. Environmental Protection Agency
GIS ....Geographic Information System
HUC .... Hydrologic Unit Code
LA...Load Allocation
MARIS .... Mississippi Automated Resource Information System
MDEQ.. Mississippi Department of Environmental Quality
MGD.. Million Gallons per Day
MOS..Margin of Safety
$NBOD_U$.. Nitrogenous Ultimate Biochemical Oxygen Demand
NH_3...Total Ammonia
NH_3-N... Total Ammonia as Nitrogen
NO_2+ NO_3 ....Nitrite Plus Nitrate
NPDES ....National Pollutant Discharge Elimination System
RBA.. Rapid Biological Assessment
7Q10..............7-Day Average Low Stream Flow with a 10-Year Occurrence Period
$TBOD_5$.. 5-Day Total Biochemical Oxygen Demand
$TBOD_u$ .... Total Ultimate Biochemical Oxygen Demand
TKN...Total Kjeldahl Nitrogen
TN..Total Nitrogen
TOC... Total Organic Carbon
TP .... Total Phosphorus
USGS.. United States Geological Survey
WLA...Waste Load Allocation

APPENDIX A

Watershed Model and Siltation Analysis for Wolf Lake Watershed

1.0 Model Selection

The Generalized Watershed Loading Function (GWLF) model was selected to estimate sediment and oxygen-demanding substance loadings to Wolf Lake. Key characteristics of the GWLF model include:

- Limited data requirements
- Sediment simulation using the standard USLE method
- Hydrology simulation using Curve Number method
- Ability to represent heterogeneous land uses

The sediment loads from all land uses except aquaculture (catfish ponds) were generated using the GWLF model for the Wolf Lake watershed. The catfish pond sediment load was simulated outside of the GWLF model to account for pond management practices and seasonal variation in sediment concentrations. The GWLF model loads and catfish pond sediment loads were applied to a siltation and life span analysis to assess siltation/sediment impairments.

The nutrient load from all land uses except catfish ponds were generated using the GWLF model for the Wolf Lake watershed. The catfish pond nutrient load was simulated outside of the GWLF model to account for pond management practices and seasonal variation in nutrient concentrations. The GWLF model loads and catfish pond nutrient loads were applied to CEQUAL, a separate receiving water model, to assess the organic enrichment/low DO and nutrient impairments.

2.0 Model Framework

The GWLF model, which was originally developed by Cornell University (Haith and Shoemaker, 1987; Haith et al., 1992), makes it possible to simulate runoff, sediment, and nutrient loadings from watersheds given variable-size source areas (e.g., agricultural, forested, and developed land). It also has algorithms for calculating septic system loads and allows for the inclusion of point source discharge data. GWLF is a continuous simulation model that uses daily time steps for weather data and water balance calculations. Monthly calculations are made for sediment and nutrient loads, based on daily water balance totals that are summed to give monthly values.

GWLF is an aggregate distributed/lumped parameter watershed model. For surface loading, it is distributed in the sense that it allows multiple land use and cover scenarios. Each area is assumed to be homogeneous with respect to various attributes considered by the model. In addition, the model does not spatially distribute the source areas, but aggregates the loads from each area into a watershed total. In other words, there is no spatial routing. For subsurface loading, the model acts as a lumped parameter model using a water balance approach. No distinctly separate areas are considered for subsurface flow contributions. Daily water balances are computed for an unsaturated zone as well as for a saturated subsurface zone, where infiltration is computed as the difference between precipitation and snowmelt minus surface runoff and evapotranspiration.

GWLF models surface runoff using the Soil Conservation Service Curve Number (SCS-CN) approach with local daily weather (temperature and precipitation) inputs. Erosion and sediment yield are estimated using monthly erosion calculations based on the Universal Soil Loss Equation (USLE) algorithm (with monthly rainfall-runoff coefficients) and a monthly composite of KLSCP values for each source area (e.g., land cover and soil type combination). The KLSCP factors are variables used in the calculations to depict changes in soil loss/erosion (K), the length/slope factor (LS), the vegetation cover factor (C), and the conservation practices factor (P). The USLE approach is commonly used to predict erosion, particularly in agricultural areas, and it is a component of other watershed models such as the Agricultural Non Point Source Loading model (AGNPS) and the Soil and Water Assessment Tool (SWAT). A sediment delivery ratio (SDR), based on watershed size, and a transport capacity, based on average daily runoff, are applied to the calculated erosion to determine sediment yield for each source area.

Surface nutrient losses are determined by applying dissolved nitrogen and phosphorus coefficients to surface runoff and a sediment coefficient to the yield portion for each agricultural source area. Point source discharges, which are not of concern in this study area, can also contribute to dissolved loads to the stream and are specified in terms of kilograms per month. Manured areas, as well as septic systems, also can be considered. Urban nutrient inputs are all assumed to be solid-phase, and the model uses an exponential accumulation and washoff function for these loadings. Subsurface losses are calculated using dissolved nitrogen and phosphorus coefficients for shallow groundwater contributions to stream nutrient loads, and the subsurface submodel considers only a single, lumped-parameter contributing area.

Evapotranspiration is determined using daily weather data and a cover factor dependent on land use and cover type. A water balance is performed daily using supplied or computed precipitation, snowmelt, initial unsaturated zone storage, maximum available zone storage, and evapotranspiration values. All of the equations used by the model can be found in the original GWLF paper (Haith and Shoemaker, 1987) and GWLF User's Manual (Haith et al., 1992).

3.0 Model Configuration

Watershed data needed to run the GWLF model with the BasinSim 1.0 interface were generated using GIS spatial coverages, local weather data, literature values, and other information. For execution, the model requires three separate input files containing transport parameters, nutrient parameters, and weather-related data.

More detailed information about these parameters and other secondary parameters can be obtained from the GWLF User's Manual (Haith et al., 1992). Pages 15 through 41 of the manual provide specific details that describe equations and typical parameter values used in the model.

3.1 Transport Parameters

The transport file (TRANSPRT.DAT) defines parameters that are a function of hydrology, erosion, and sedimentation. These parameters include global transport parameters, seasonal transport parameters, and source area transport parameters.

3.1.1 Source Area Transport Parameters

Model inputs for the source area transport parameters are shown in Figure A-1. These parameters account for spatial variation in hydrology, erosion, and sedimentation. They include land use area, curve number, and the Universal Soil Loss Equation (USLE) parameters K, LS, C, and P.

Land Use Type	Area (ha)	CN	K*LS*C*P
Corn	286	80	0.0132
Cotton	3,742	88	0.0229
Other Small Grains	87	82	0.0084
Rice	87	85	0.0083
Snap Beans	80	83	0.0232
Sorghum	97	82	0.0194
Soybeans	239	84	0.0228
Sunflowers	55	83	0.0193
Winter Wheat	133	83	0.0082
Pasture/Range/Non-Agriculture	2,549	78	0.0057
Catfish Ponds	508	100	0.0000
Bottomland Hardwood Forest	1,915	72	0.0031
Freshwater	158	100	0.0000
Freshwater Scrub/Shrub	81	72	0.0031
Riverine Swamp	36	75	0.0030
Upland Scrub/Shrub	232	73	0.0031
Woods	190	75	0.0031
Urban Pervious	39	82	0.0057
Urban Impervious	4	98	0.0000

Figure A-1. Land Use Parameters

The watershed boundary was delineated using a 10-meter Digital Elevation Map (DEM), USGS 7.5-minute digital topographic maps (24K DRG – Digital Raster Graphics), and delineations provided in the Final Report for Wolf Lake – Phase I Diagnostic/Feasibility Study (FTN Associates, 1991).

The land use and land cover percentages were derived from a data layer developed as part of the Mississippi Land Cover Project (MDEQ, 1997) and the 2001 cropland data layer developed by the National Agricultural Statistics Service (USDA, 2001). The 19 land uses used for model simulation were grouped into five categories for model result presentation (Table A-1).

Table A-1. Land Use Categories

Category	Land Use/Land Cover	Area (ha)	Area (% of Total)
Cultivated Agriculture	Cotton, Corn, Soybeans, Sorghum, Snap Beans, Other Small Grains, Rice, Winter Wheat, Sunflower	4,807	46
Noncultivated Agriculture	Pasture, Range, Fallow	2,549	24
Catfish Ponds	Catfish Ponds	508	5
Residential	Pervious Residential, Impervious Residential	44	1
Other	Bottomland Hardwood Forest, Riverine Swamp, Upland Scrub, Woods, Freshwater Scrub, Open Water	2,613	25

The curve number parameter determines the amount of precipitation that infiltrates into the ground or enters surface water as runoff. It is based on specified combinations of land use and cover and hydrologic soil type and is calculated directly using digital land use and soils covers.

Soils data were obtained from Mississippi county soil surveys and the State Soil Geographic (STATSGO) database for Mississippi, as developed by the Natural Resources Conservation Services (NRCS).

The Universal soil loss equation determines soil erodibility based on the K factor, LS factor, C factor, and P factor. Unless otherwise specified, these parameters are derived from the NRCS Natural Resources Inventory (NRI) database (1992). The individual parameters are described below.

- *K factor:* This factor relates to inherent soil erodibility, and it affects the amount of soil erosion taking place on a given unit of land. K-factor values were derived from STATSGO for the each soil type and assigned to land use areas based on the distribution of soils within that land use area.

- *LS factor:* This factor is a function of the length and grade of the slope from a source area to the waterbody. An average grade of 0.5 percent was used for the entire watershed based on the 10-meter DEM coverage. The slope length was derived from regional crop-specific reference values from the NRCS Natural Resources Inventory (NRI) database (1992).

- *C factor:* This factor is related to the amount of vegetative cover in an area and is largely controlled by the crops grown and the cultivation practices used. Values range from 0 to 1.0, with larger values indicating a lower potential for erosion. The C factor was derived from crop-specific reference values from the NRCS Natural Resources Inventory (NRI) database (1992) based on moderate tillage practices.

- *P factor:* This factor is directly related to the conservation practices used in agricultural areas. Values range from 0 to 1.0, with larger values indicating a lower potential for erosion.

3.1.2 Seasonal Transport Parameters

Model inputs for the seasonal transport parameters are shown in Figure A-2. These parameters account for seasonal variability in hydrology, erosion, and sedimentation. The monthly evapotranspiration cover coefficient, day length, and erosivity coefficient are based on regional literature values. (Haith et al., 1992).

Month	ET Cover Coef.	Day Length (hr)	Growing Season	Erosivity Coef.
Apr	0.999	12.8	1	0.2
May	0.999	13.7	1	0.2
Jun	0.999	14.2	1	0.2
Jul	0.999	14	1	0.2
Aug	0.999	13.2	1	0.2
Sep	0.999	12.2	1	0.2
Oct	0.999	11.2	1	0.2
Nov	0.700	10.2	0	0.11
Dec	0.700	9.8	0	0.11
Jan	0.700	10	0	0.11
Feb	0.700	10.8	0	0.11
Mar	0.700	11.8	0	0.11

Figure A-2. Seasonal Transport Parameters

3.1.3 Global Transport Parameters

Model inputs for the global parameters are shown in Figure A-3. Critical global parameters include the unsaturated water capacity, seepage coefficient, recession coefficient, and SDR. The unsaturated water capacity is a function of the maximum watershed rooting depth and the soil available water storage capacity. The seepage coefficient is a function of the loss of water to the deep aquifer. The recession coefficient is a function of the basin's hydrologic response to precipitation events. SDR specifies the percentage of eroded sediment delivered to surface water and is empirically based on watershed size. These parameters were set within reasonable ranges to match basin characteristics.

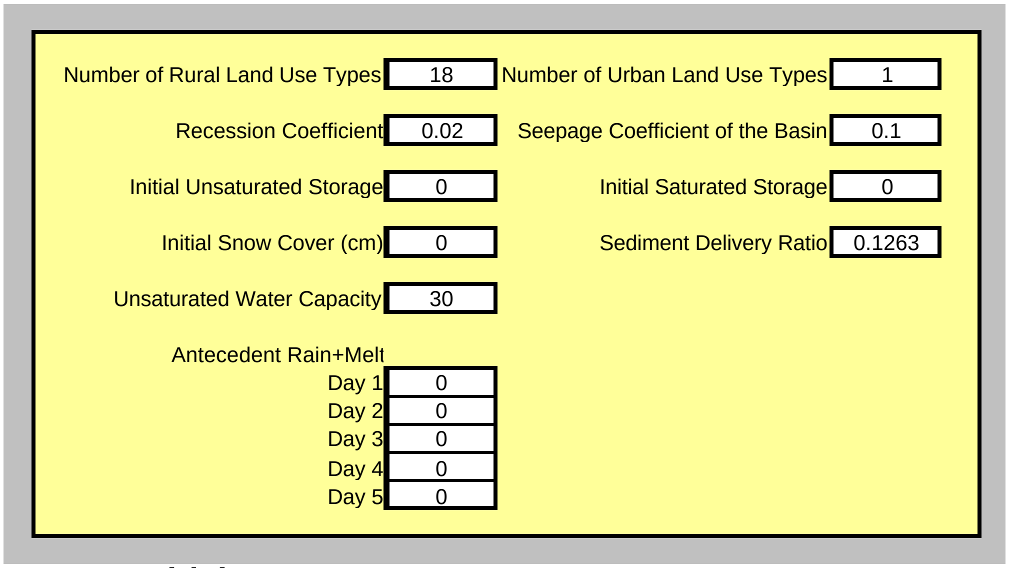

Figure A-3. Global Transport Parameters

3.2 Nutrient Parameters

The nutrient file (NUTRIENT.DAT) specifies the loading parameters for the different sources. The dissolved concentrations for each land use are derived from the literature values for fallow, corn, and small grains and are shown in Figure A-4 (Haith et al., 1992). Soil nitrogen and phosphorus concentrations of 1,000 mg/kg and 880 mg/kg, respectively, and groundwater nitrogen and phosphorus concentrations of 1.08 mg/L and 0.029 mg/L, respectively, were also determined using regional literature values (Haith et al., 1992).

No. of Rural Land Uses: 18

Land Use	N mg/L	P mg/L
Corn	2.90	0.26
Cotton	2.90	0.26
Other Small Grains	1.80	0.30
Rice	1.80	0.30
Snap Beans	1.80	0.30
Sorghum	2.90	0.26
Soybeans	1.80	0.30
Sunflowers	2.90	0.26
Winter Wheat	1.80	0.30
Pasture/Range/Non-Agriculture	2.60	0.10
Aquaculture	2.00	0.30
Bottomland Hardwood Forest	1.00	0.13
Freshwater	0.00	0.00
Freshwater Scrub/Shrub	1.00	0.13
Riverine Swamp	1.00	0.13
Upland Scrub/Shrub	1.00	0.13
Woods	1.00	0.13
Urban Pervious	3.00	0.25
Urban Impervious		

Figure A-4. Dissolved Nitrogen and Phosphorus Concentrations

3.3 Weather Data

The weather file (WEATHER.DAT) contains daily average temperature and total precipitation values for each year simulated. Daily precipitation and temperature data were obtained from local National Climatic Data Center (NCDC) weather stations and are shown in Table A-2 and Figure A-5. The period of record selected for model runs April 1, 1990 through March 31, 2000 was based on the availability of daily precipitation and temperature data.

Table A-2. Weather Stations

Weather Station	**Station Code**	**Data Type**	**Data Period**
Yazoo City 5 NNE	MS9860	Daily Precipitation	1960 – 2000
Jackson International Airport	WBAN 03940	Daily Max/Min Temp	1963-2000

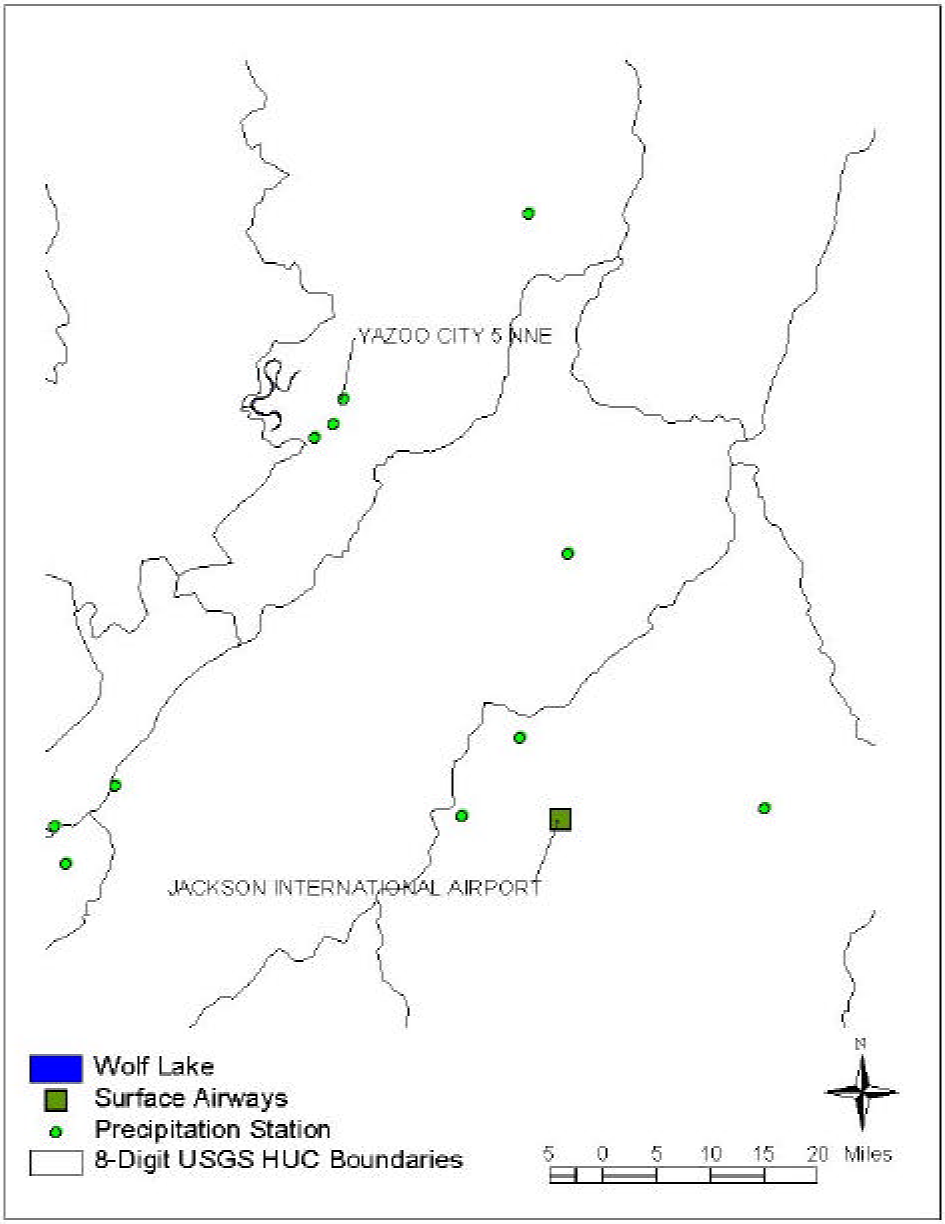

Figure A-5. Precipitation and Temperature Gage Locations

4.0 Watershed Model Calibration

The GWLF model was not calibrated to actual observations, since insufficient data were available. However, local land use, soil, and meteorological data were used to define model parameters and ensure that the parameters were appropriate for load estimation. Land management practices including reduced tillage, cover crops, and detention ponds are widely used in the Mississippi Delta (Yuan and Bingner, 2002). Therefore, cover factors used in the USLE method were based on moderate tillage.

5.0 Catfish Pond Analysis

Catfish ponds, representing 508 hectares or 5 percent of the total watershed area, were simulated outside of GWLF to account for pond management practices and seasonal variations in sediment and nutrient concentrations. Sediment, total nitrogen, and total phosphorus loads were simulated using a spreadsheet tool based on the method described in Tucker et al. (1996). The following critical assumptions regarding pond management practices in the Yazoo River Basin were incorporated into this analysis:

- Pond surface level is maintained between 7.5 and 15 centimeters below top of drain.
- Food fish ponds represent 90 percent of the total catfish pond area,
- One sixth of the food fish ponds are drained annually spread throughout the year.
- Fingerling ponds represent 10 percent of the total catfish pond area, and all of the fingerling ponds are drained annually between December and April.
- Broodfish ponds represent a negligible percentage of the total catfish pond area.

Catfish pond overflows were predicted from January 1997 to December 2000 on a daily time step based on assumed pond level management practices and daily precipitation, evaporation, and infiltration. The overflow was calculated using the following equation from Tucker et al. (1996), and is shown in Figure A-6.

$$\mathbf{O_d = L_{d-1} - L_d - P_d - 0.8 * E_d - I + GW_d}$$

Where:

O_d = Overflow (cm) on day d
L_{d-1} = Pond Water Level (cm) at end of day d-1
L_d = Pond Water Level (cm) at end of day d
P_d = Precipitation (cm) on day d
E_d = Pan Evaporation on day d
I = Daily infiltration loss (0.04 cm)
GW_d = Groundwater pumped into pond (cm) on day d

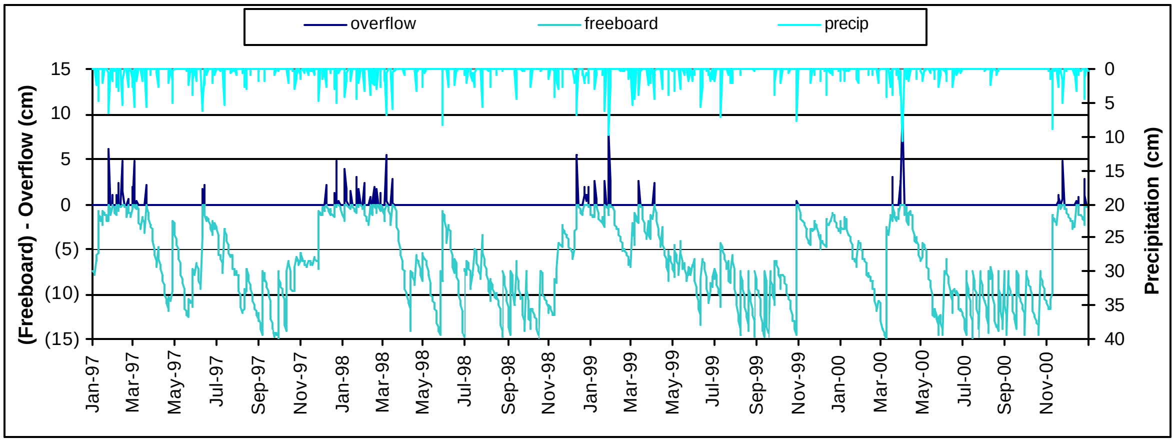

Figure A-6. Predicted Daily Catfish Pond Overflows Jan. 1997–Dec. 2000

Pond sediment and nutrient loads are predicted on a monthly time step based on average seasonal concentrations, daily overflow water balance totals summed to monthly values, and pond drainage volume assumptions. The predicted seasonal nonvolatile suspended sediment (NVSS) and particulate and soluble phosphorus and nitrogen are shown in Table A-3. NVSS was estimated to be 70 percent of the total suspended solids (C. Tucker, 2003).

Table A-3. Seasonal NVSS, Total Phosphorus, and Total Nitrogen Concentrations

Season	**NVSS (mg/L)**	**TP (particulate) (mg/L)**	**TP(soluble) (mg/L)**	**TN(particulate) (mg/L)**	**TN(soluble) (mg/L)**
Spring	92	0.33	0.02	3.00	1.84
Summer	87	0.47	0.06	5.95	1.17
Autumn	61	0.29	0.02	3.31	3.23
Winter	72	0.33	0.01	3.55	1.76
Mean	78	0.35	0.03	3.95	2.00

Source: Tucker et al., 1996

The predicted monthly sediment and nutrient loads from January 1997 to December 2000 are shown in Figures A-7 to A-10. The predicted average annual loads from catfish ponds are 32.4 tons of sediment, 8.6 tons of nitrogen, and 0.2 tons of phosphorus. Sediment, nitrogen, and phosphorus loads were highest in the winter months, between November and March, when the highest precipitation occurred and the fingerling ponds were drained. Overflow discharges only rarely occurred outside of the winter months.

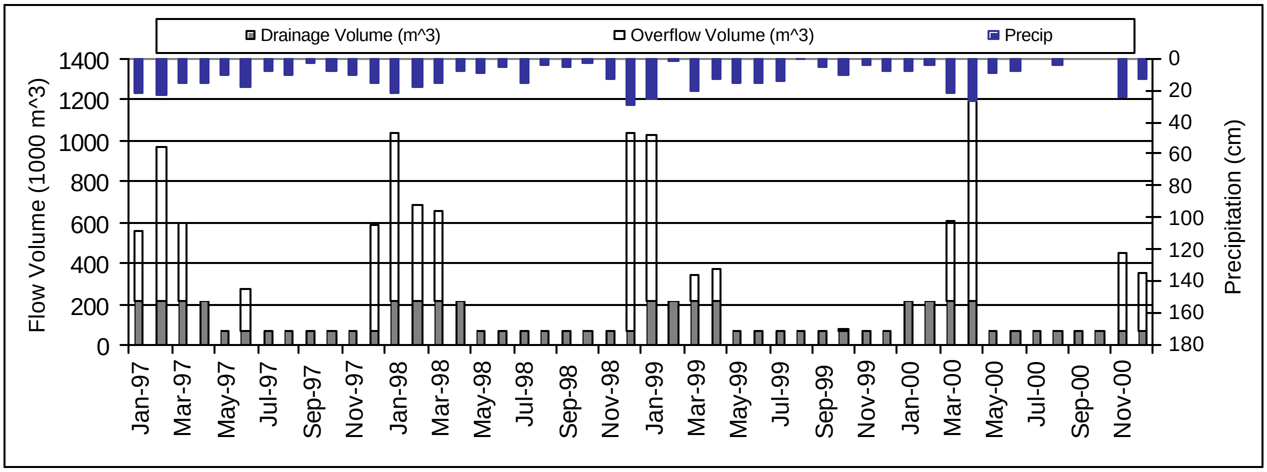

Figure A-7. Monthly Precipitation and Catfish Pond Overflow and Drainage

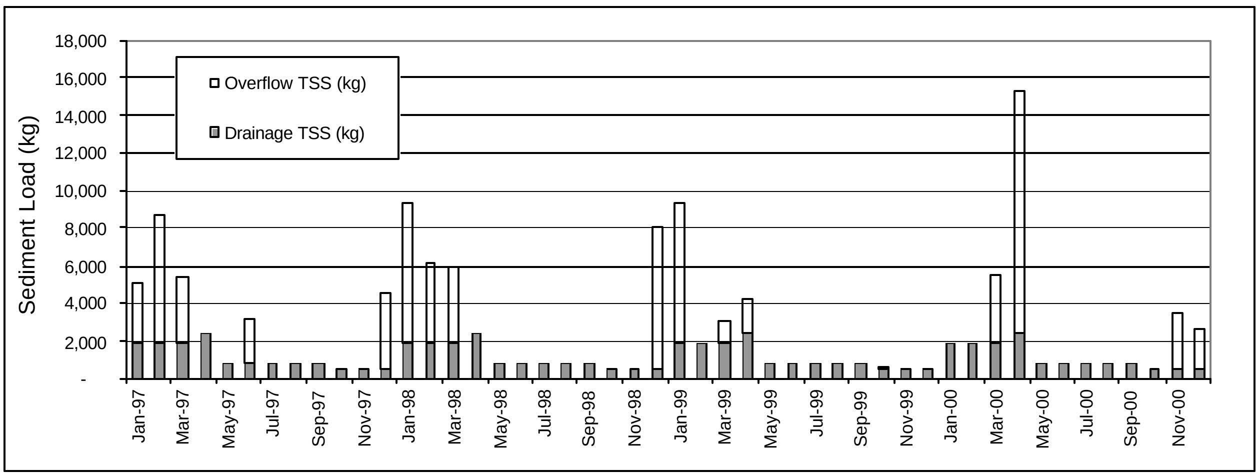

Figure A-8. Monthly Catfish Pond Overflow and Drainage Sediment Load

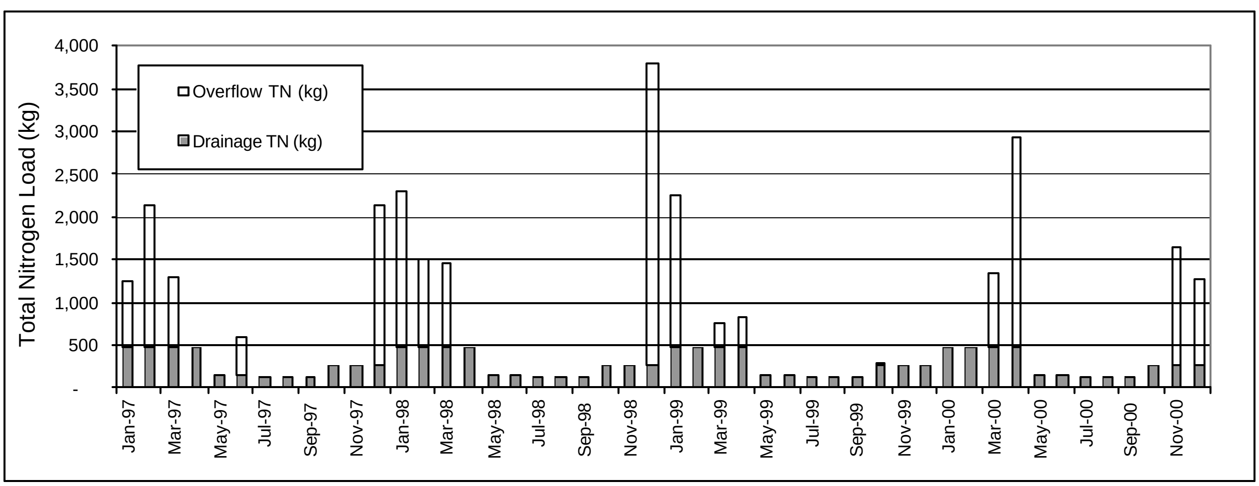

Figure A-9. Monthly Catfish Pond Overflow and Drainage Nitrogen Load

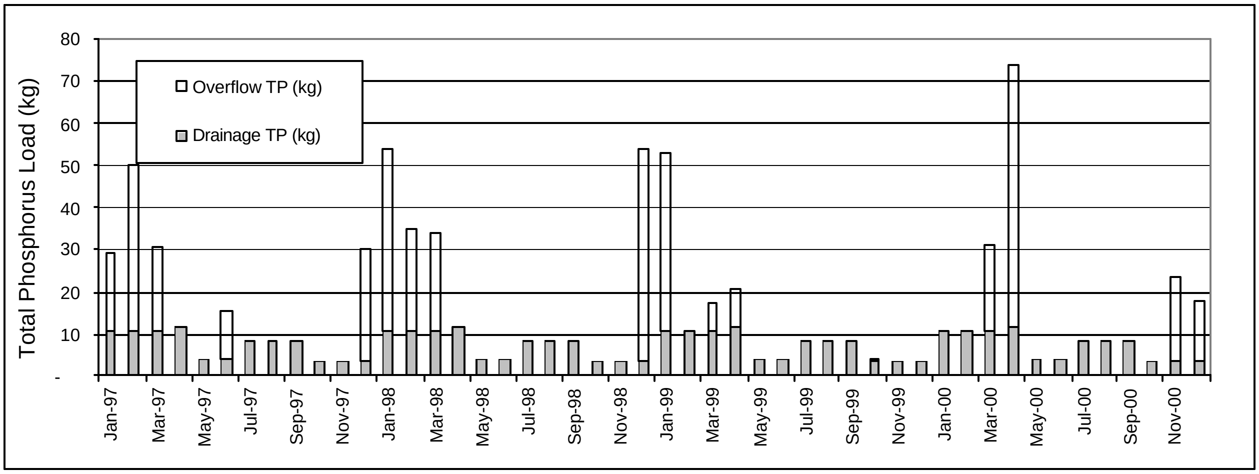

Figure A-10. Monthly Catfish Pond Overflow and Drainage Phosphorus Load

6.0 GWLF Model Results

The GWLF model was run for a 10-year period from April 1, 1990, to March 31, 1999. The first year of the model run was excluded because the GWLF model takes approximately 1 year to stabilize.

The predicted annual sediment, nitrogen, and phosphorus loads for April 1991 to March 1999 are shown in Figures A-11 to A-13. The peak load generally follows the annual precipitation pattern with the highest sediment load occurring in 1993 and the highest nitrogen and phosphorus loads occurring in 1998.

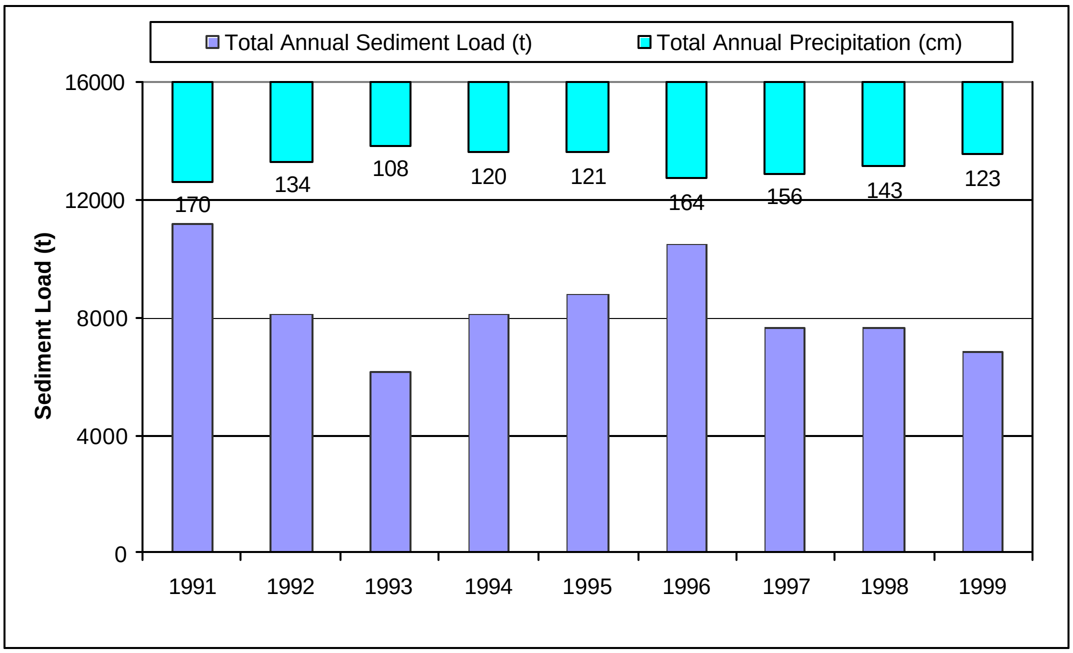

Figure A-11. Predicted Annual Sediment Load and Precipitation

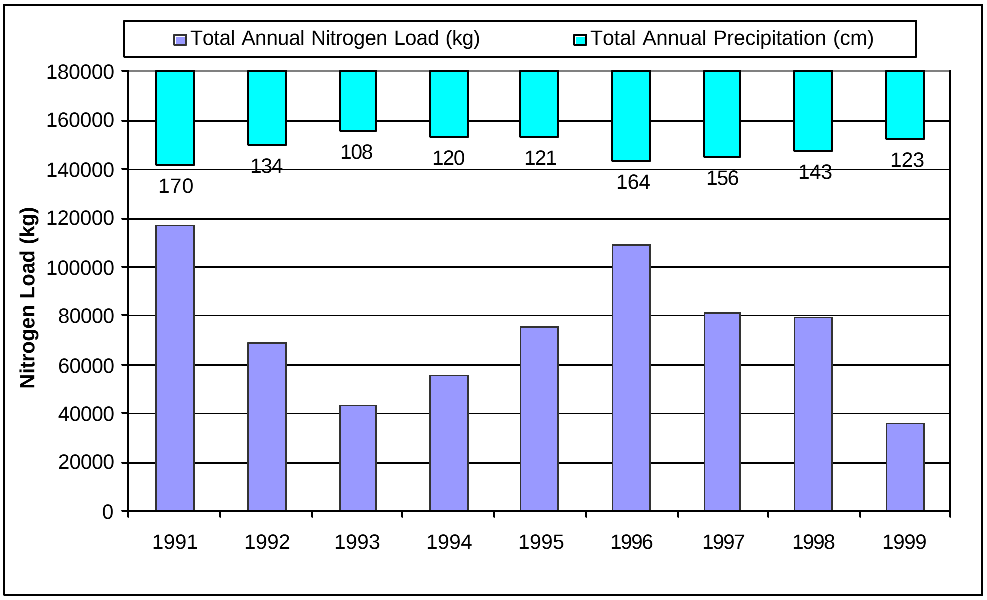

Figure A-12. Predicted Annual Nitrogen Load and Precipitation

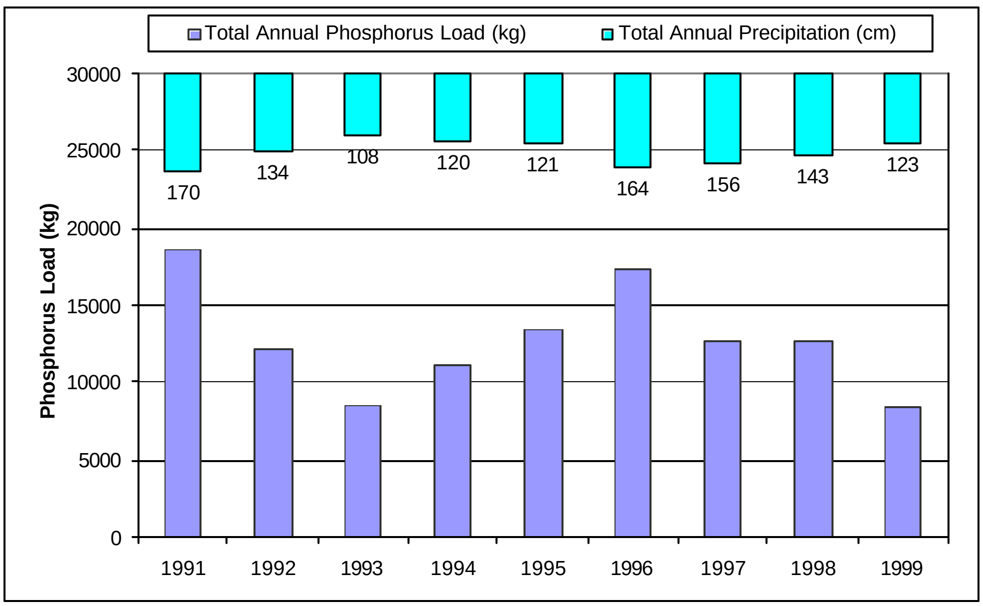

Figure A-13. Predicted Annual Phosphorus Load and Precipitation

The predicted average monthly sediment, nitrogen, and phosphorus loads are shown in Figures A-14 to A-16. These are the loads that actually reach the lake, and take into account the delivery ratio. The predicted load generally follows the monthly inflow pattern with the highest sediment, nitrogen, and phosphorus loads occurring in winter and early spring.

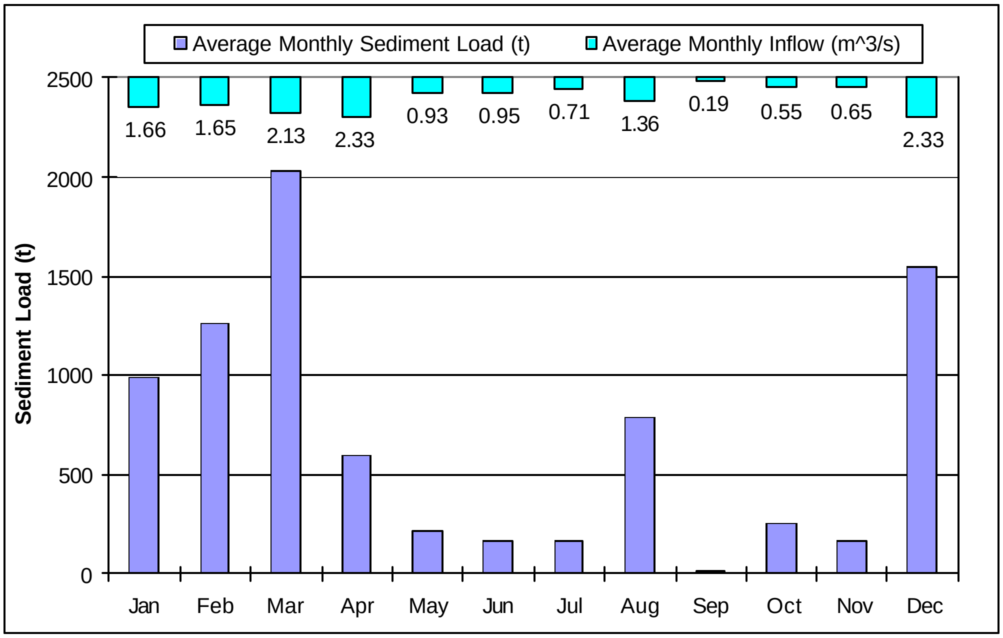

Figure A-14. Predicted Average Monthly Sediment Load and Inflow

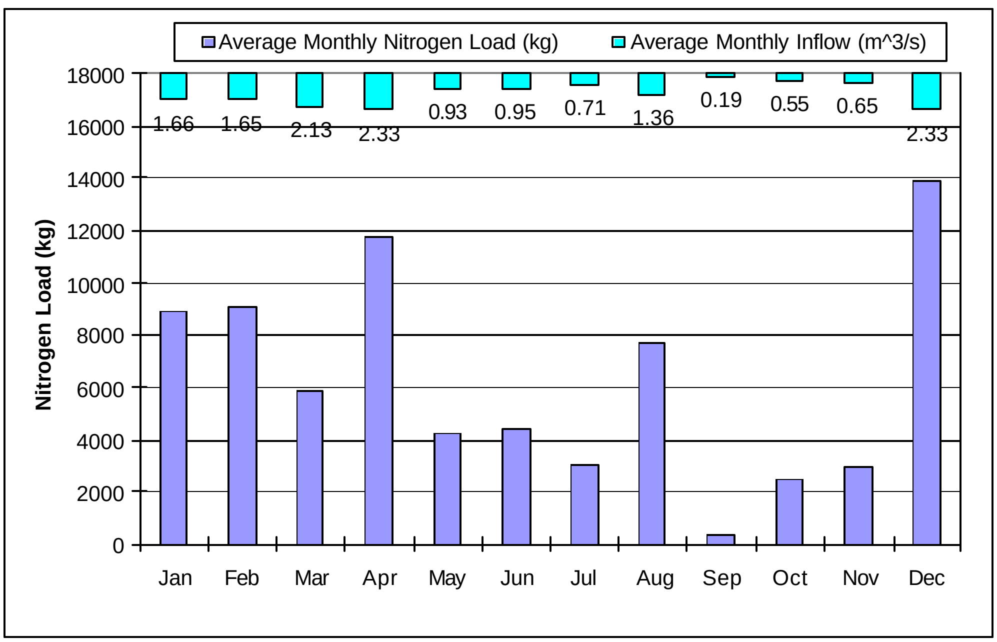

Figure A-15. Predicted Average Monthly Nitrogen Load and Inflow

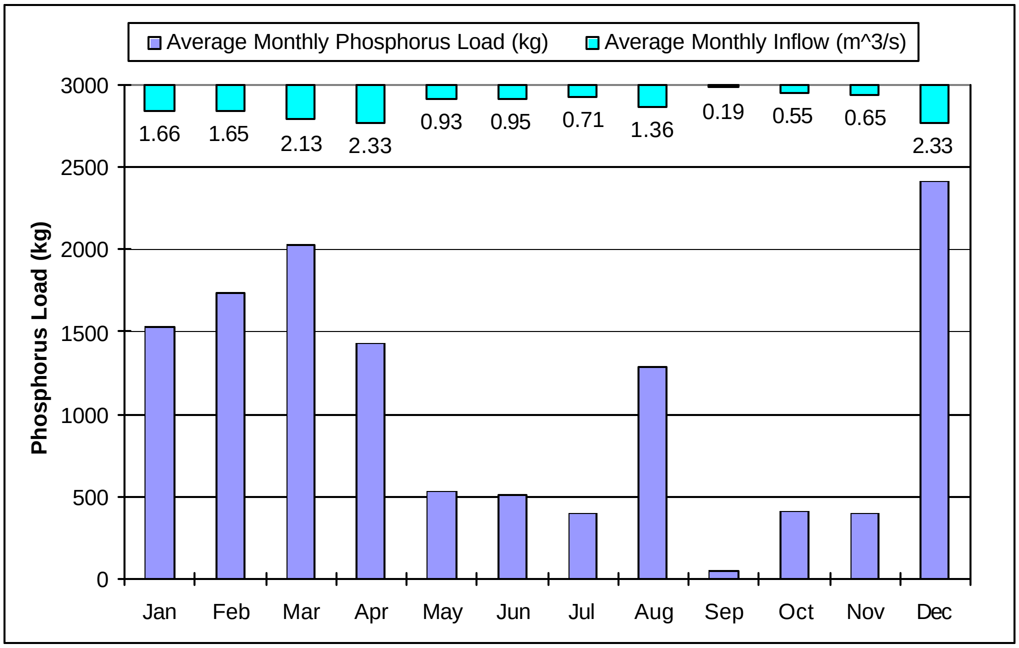

Figure A-16. Predicted Average Monthly Phosphorus Load and Inflow

6.0 Watershed Model Results

Sediment, total nitrogen, and total phosphorus loads by land use category are shown in Table A-4.

Table A-4. Predicted Average Annual Sediment, Nitrogen, and Phosphorus Loads

Land Use Category	Sediment Load (t/year)	Total Nitrogen Load (t/year)	Total Phosphorus Load (t/year)
Cultivated Agriculture	6841	51.13	10.25
Noncultivated Agriculture	970	15.00	1.39
Catfish Ponds	32.4	8.60	0.20
Residential	15	0.34	0.04
Other	509	4.74	1.00
Total	8367	79.82	12.88

6.1 Siltation Rate/Estimated Life Span

The siltation rate in Wolf Lake was assessed using the mean annual sediment load and the estimated trap efficiency. In addition, this analysis relies on two fundamental assumptions:

- Sediment accumulation occurs homogeneously over the entire lake area.
- The lake's life span extends to until approximately 50 percent of the lake surface area or 30 percent of the lake volume is reached. At this point the lake in considered "non-functioning."

Trap efficiency refers to the ability of lakes and reservoirs to retain a portion of the sediment loading. This efficiency is expressed as the percentage of sediment retained compared with the total incoming sediment. The Brune method (USACE, 1989) is a widely used trap efficiency estimation method based on the ratio of waterbody volume to the annual inflow volume.

$$E = 100 * 97^{0.19^{\log(C/I)}}$$

where:
E = Trap Efficiency
C = Lake Capacity (Volume)
I = Inflow Volume

Based on this equation, the mean annual trap efficiency for Wolf Lake is 92%. The predicted average sedimentation rate for the years 1991 to 1999 is 0.17 centimeters per year. The estimated life span, based on the predicted sedimentation rate, is 600 years.

Model Scenarios

The GWLF model was run for five additional scenarios to evaluate the effects of different land practices as well as the incorporation of wooded buffers. The goal of this analysis was to identify reasonable and achievable sedimentation rate targets while considering realistic land management and land use conversion options as well as long-term effects on the lake. However, the analysis does not make the attempt to include all of the possible changes in land use and land management. There are many other options available that have not been included in this report. The selected scenarios are described in Table A-5. Table A-6 presents the mean annual sediment load and the mean annual siltation rate for existing conditions and the additional scenarios.

Table A-5. Existing Conditions and Model Scenarios

	Scenario	Description
Existing	Moderate Tillage	The C factor in the USLE was adjusted to reflect moderate tillage practices on cultivated agricultural land.
Scenarios	Conventional Tillage	The C factor in the USLE was adjusted to reflect conventional tillage practices on cultivated agricultural land.
	50% Wooded and Moderate Tillage	The C factor in the USLE was adjusted to reflect moderate tillage practices on cultivated agricultural land. The wooded area was increased from 21% to 50% and agricultural land was reduced from 66% to 43% of the watershed area.
	No Tillage	The C factor in the USLE was adjusted to reflect no tillage practices on cultivated agricultural land.
	50% Wooded and No Tillage	The C factor in the USLE was adjusted to reflect no tillage practices on cultivated agricultural land. The wooded area was increased from 21% to 50% and agricultural land was reduced from 66% to 43% of the watershed area.
	100% Wooded	The wooded area was increased from 21% to 100% of the watershed area.

Table A-6. 1991-1999 Mean Annual Sediment Load

Scenario	Sediment Load (kt)	Siltation Rate (cm/yr)
Conventional Tillage	13.23	0.26
Moderate Tillage (Baseline)	**8.37**	**0.17**
50% Wooded and Moderate Tillage	5.97	0.12
No Tillage	4.97	0.10
50% Wooded and No Tillage	3.87	0.08
100% Wooded	2.21	0.05

The siltation rates and estimated life spans for the existing conditions and additional scenarios are shown in Figures A-17 and A-18, respectively. The siltation rates and estimated life spans in this analysis are based on the conservative assumption that no compaction occurs in the deposited sediment and the specific weight of the sediment remains constant at 1 g/cm^3 (62 lbs/ft^3). It is expected that the actual siltation rates will be lower and estimated life span will be longer due to the compaction of the silt and clay factions of deposited sediment. Compaction occurs when sediment particles are slowly pressed together over time, reducing the pore space between them. Over extended periods compaction of silt and clay factions of sediment can increase the specific weight of the sediment and decrease the volume occupied by the sediment (Vanoni, 1975).

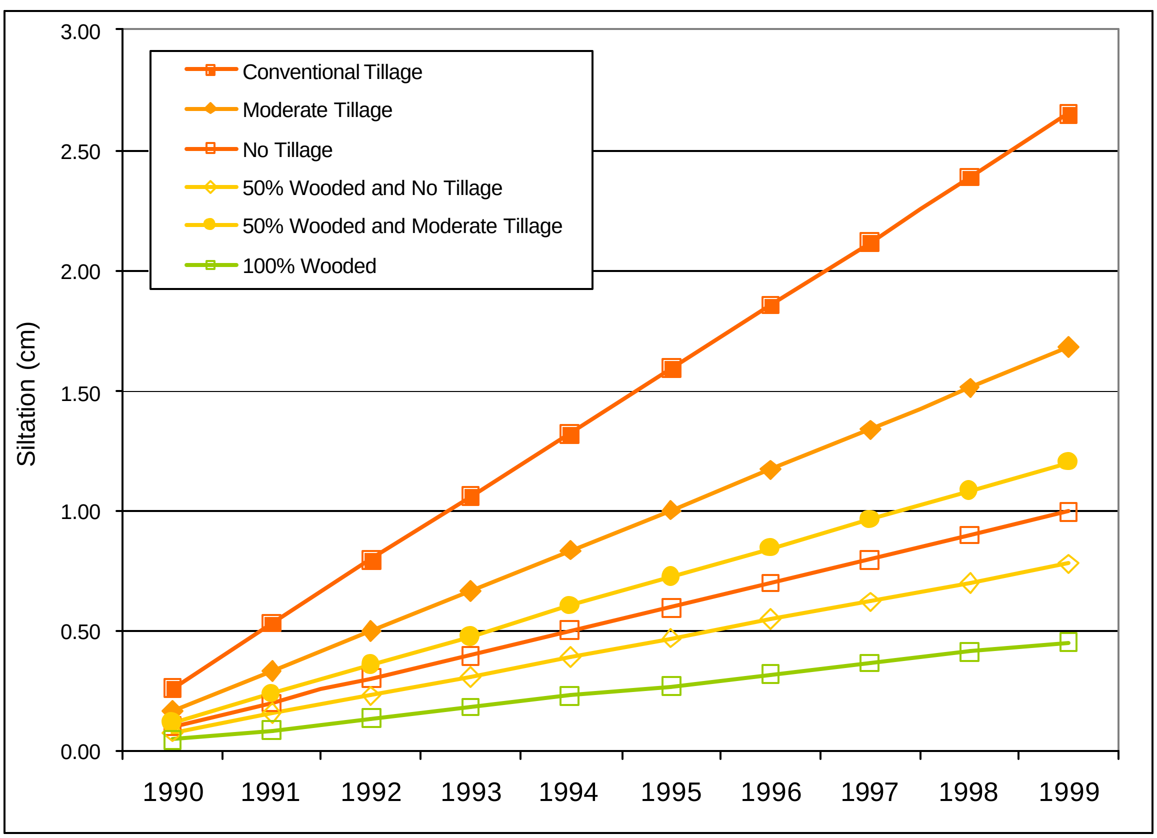

Figure A-17. Inlake Siltation: Existing Conditions and Modeling Scenarios

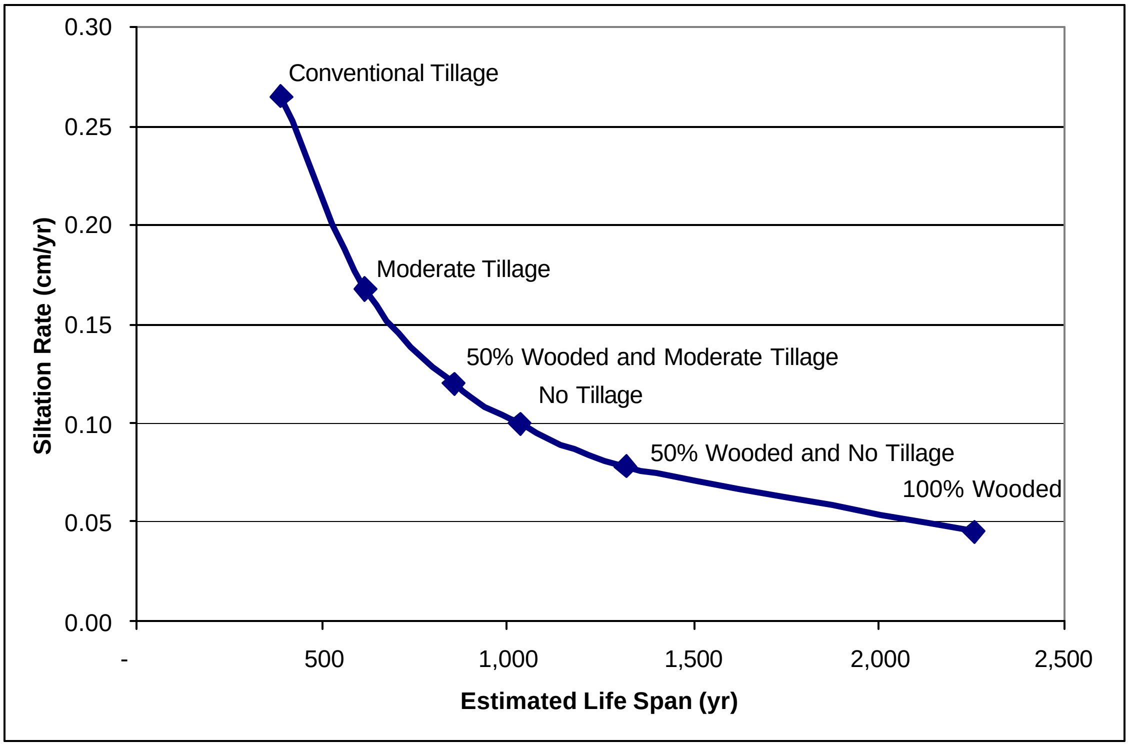

Figure A-18. Estimated Life Span for Modeling Scenarios

After reviewing the results of each of these scenarios, MDEQ determined that the TMDL should be based on a range of siltation rates, reflecting the land management practices that could reasonably be put in place in the Wolf Lake watershed. The upper limit of the siltation rate was set to reflect the land management scenario in which some of the agricultural land is returned to wooded areas, so that 50 percent of the total watershed is wooded. The remaining agricultural areas would continue to be cultivated using the moderate tillage practices that are currently in place. Thus, the upper limit of the siltation rate in Wolf Lake is 0.12 cm/year. The lower limit of the siltation rate was set based on the most conservative land use management practices that would be practicable for the Wolf Lake watershed. The most conservative practices were determined to be the scenario in which some of the agricultural land is returned to wooded areas, so that 50 percent of the total watershed is wooded. The remaining agricultural areas would be cultivated so that no tillage was done in the watershed. Thus, the lower limit of the siltation rate in Wolf Lake is 0.08 cm/year.

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APPENDIX B

Wolf Lake Water Quality Model

1.0 Development of the Water Quality Model for the Wolf Lake

Wolf Lake is fairly long, narrow, and hydrologically active lake with a hydraulic residence time of approximately 51 days. Inlake conditions vary along the length of the system and vertical stratification occurs. The current MDEQ water quality standard requires meeting a daily average and daily minimum dissolved oxygen (DO) criteria, as no nutrient criteria currently exists. Because of these technical and regulatory considerations, the CE-QUAL-W2 hydrodynamic and water quality model (Cole and Buchak, 1995) was used to simulate eutrophication processes within the lake.

2.0 Model Framework

The U.S. Army Corps of Engineers CE-QUAL-W2 model was selected as the receiving water model for simulating the eutrophication processes in Wolf Lake. CE-QUAL-W2 (W2) is a two-dimensional, longitudinal/vertical (laterally averaged), hydrodynamic and water quality model. The model can be applied to multiple branches of geometrically complex waterbodies (dendritic/branching lakes and reservoirs) with variable grid spacing, time-variable boundary conditions, and multiple inflows and outflows from point and nonpoint sources and precipitation.

The two major components of the W2 model include hydrodynamics and water quality kinetics. Both of these components are coupled, i.e., the hydrodynamic output is used to drive the water quality at every time step. The hydrodynamic portion of the model predicts water surface elevations, velocities, and temperature. The water quality portion can simulate 21 constituents including dissolved oxygen (DO), nutrients, and phytoplankton interactions. Any combination of constituents can be simulated. See Cole and Buchak's document *CE-QUAL-W2: A Two-Dimensional Laterally Averaged, Hydrodynamic and Water Quality Model, Version 2.0 – Users Manual (EL-95)* for a more detailed discussion of simulated processes and model parameters.

3.0 Model Configuration

Model configuration involved setting up the model computational grid (bathymetry) from the contour map (FTN Associates, 1991) and setting initial conditions, boundary conditions, and hydraulic and kinetic parameters for the hydrodynamic and water quality simulations. This section describes the configuration and key components of the model.

3.1 Segmentation/Computational Grid Setup

The computational grid setup defines the process of representing Wolf Lake in the finite difference scheme. Wolf Lake consists of a main branch, and a branch feeding into it (Figure B-1). The model requires the user to set up the bathymetry file for each branch defining the upstream and downstream segments. The contour map provided in FTN Associates, 1991 report was used to generate the bathymetry (Figure B-2). The model was configured with 22 longitudinal segments, each 1,500 meters long, and contains up to a maximum of six 1-meter thick vertical layers. Branch 1 consists of 17 segments and Branch 2 consists of 5 segments.

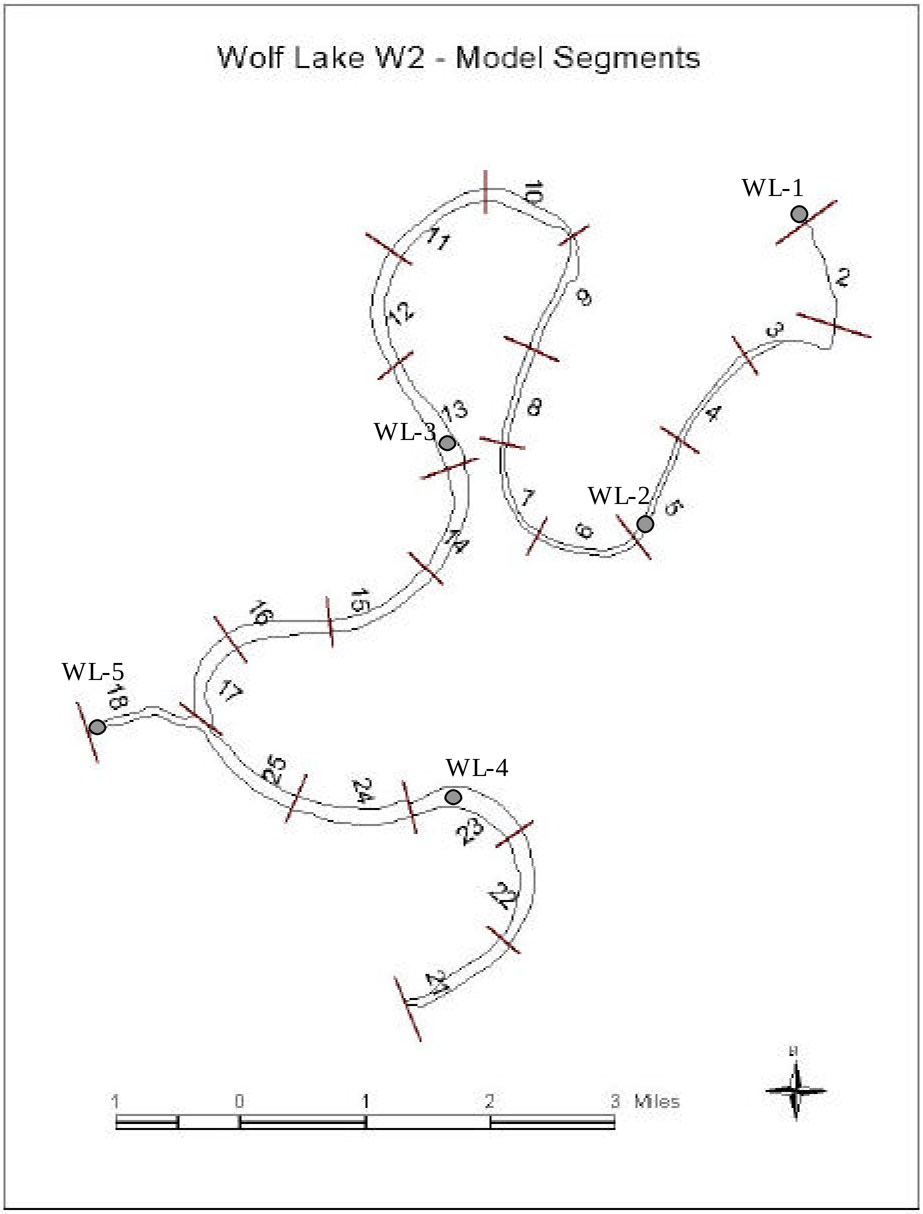

Figure B-1. Wolf Lake Segmentation

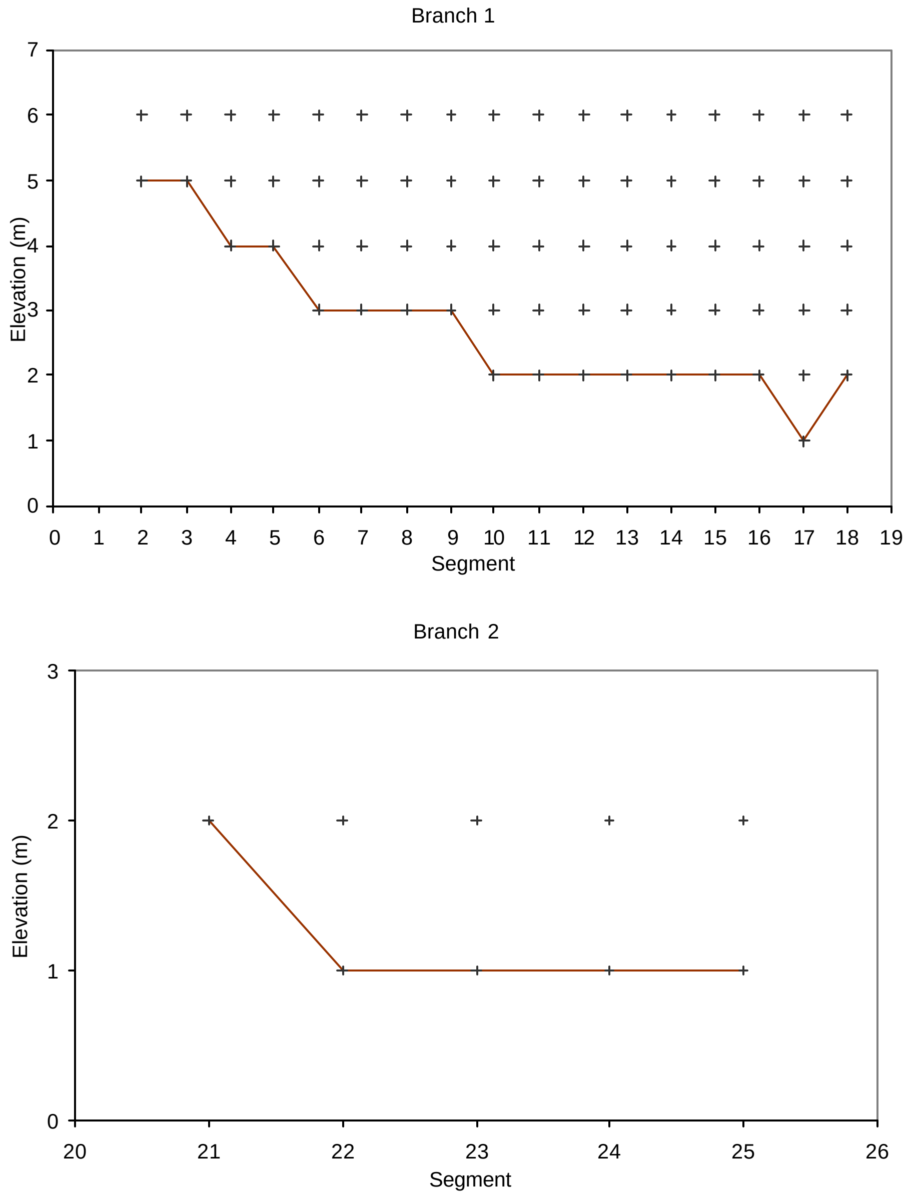

Figure B-2. Longitudinal Profiles of Wolf Lake

3.2 Initial Conditions

The W2 model requires specifying initial conditions in the control and bathymetry input files. The control file specifies the initial temperature and constituents (ammonia, nitrate-nitrite, organic nitrogen, ortho-phosphorus, and organic phosphorus). A constant initial temperature of 16 °C was specified for the lake along its entire length and depth. Default constant constituents were also specified for the lake along its entire length and depth. All the initial conditions values were based on observed inlake monitoring data at the start of the calibration period. The number and location of inflows and outflows are also provided in the control file as part of initial conditions. For Wolf Lake, inflows were specified at segments 2 and 21 and outflow at segment 18. In addition to the geometric data in the bathymetry file, an initial water surface elevation was specified for the bathymetry of the lake (equal to the deepest point in the lake).

3.3 Boundary Conditions and Linkages

Boundary conditions are a set of input files required to drive the W2 model. They represent external contributions to the lake. For each of the inflows at Branch 1 and Branch 2 a flow, concentration, and temperature input file was set up.

The hydrodynamic component of the W2 model, including temperature predictions, was forced by monthly averaged inflows from the GWLF model and hourly surface airways meteorological data. The lake level was assumed to remain constant with the monthly average outflows set equal to inflows. The monthly average inflow rates used in the model for the calibration period are shown in Table B-1. Temperature time series data corresponding to each inflow for both branches of the lake were provided using the observed temperature at the inlet station WL-1 (FTN Associates, 1991).

Table B-1. Monthly Average Inflows and Total Nutrient Loads Estimated from the GWLF Model

Month	Monthly Average Inflow (m^3/sec)	Total Nitrogen (tons)	Total Phosphorus (tons)
April 1989	0.54	2.64	0.24
May 1989	6.46	41.89	5.59
June 1989	2.17	13.99	1.77
July 1989	0.51	3.29	0.41
August 1989	0.06	0.31	0.04
September 1989	0.46	2.89	0.38
October 1989	0.04	0.20	0.03
November 1989	2.20	15.74	2.97
December 1989	0.42	2.71	0.38
January 1990	2.49	16.27	2.64
February 1990	1.87	10.92	1.93
March 1990	1.37	5.43	1.43

The water quality component of the W2 model requires data concerning the loadings of dissolved and particulate organic material, ammonia, nitrate-nitrite, ortho-phosphorus and dissolved oxygen. These loadings were estimated from the total load estimates from the GWLF model (Table B-1). Nutrient ratios were determined from inlake monitoring data (FTN Associates, 1991). These ratios were used to partition total nitrogen and total phosphorus into ammonia, nitrate-nitrite, organic nitrogen, ortho-phosphorus, and organic phosphorus. Table B-2 shows the time-averaged ratios at the seven monitoring stations as well as the average of the seven stations. Dissolved organic material (DOM) loads were estimated based on one-half the organic nitrogen load. Particulate organic material (POM) loads were estimated from the remaining half of the organic nitrogen and the total organic phosphorus (Tetra Tech, 1997). The DOM and POM form the source of carbon for the model.

Table B-2. Time-Averaged Nutrient Ratios (estimated from inlake data)

Station	Segment	NH_3/TN	NOx/TN	Organic N/TN	Ortho-P/TP	Organic P/TP
WL-1	2	0.1092	0.1311	0.7598	0.2907	0.7093
WL-2	6	0.1520	0.1745	0.6735	0.4921	0.5079
WL-3 (surface)	13	0.1390	0.2066	0.6544	0.4324	0.5676
WL-3 (middle)	13	0.1270	0.2026	0.6704	0.4142	0.5858
WL-3 (bottom)	13	0.1295	0.2040	0.6665	0.4719	0.5281
WL-4	23	0.1128	0.1462	0.7410	0.2625	0.7375
WL-5	18	0.0929	0.1684	0.7387	0.3130	0.6870
Average		**0.1232**	**0.1762**	**0.7006**	**0.3824**	**0.6176**

The average of the seven stations shown in Table B-2 was used to partition the total nitrogen and total phosphorus. The DO was assumed to be entering Wolf Lake at 90 percent of saturation. The saturation value was derived from the *Rates, Kinetics and Constants Handbook* (USEPA, 1985). A value of 6.67 mg/L of DO was ultimately used.

3.4 Meteorological Data

Meteorological data are an important component of the W2 model. The surface boundary conditions are determined by the meteorological conditions. The meteorological data required by the W2 model are air temperature, dew point temperature, wind speed, wind direction, and cloud cover. In general, hourly data are recommended (expressed in Julian Day) (Cole and Buchak, 1995). The data used here are hourly meteorological data from the Jackson Airport, Mississippi, which was the nearest available hourly monitoring station and had the most complete data set (Figure B-3).

Unfortunately, data gaps exist in the meteorological data for the calibration period, which was 1989-1990. Wind stress forcing data values were generated by sequencing typical monthly records corresponding to National Oceanic and Atmospheric Administration/National Weather Service (NOAA/NWS) data for Jackson, Mississippi. Surface heat transfer for the model's temperature prediction component was determined using daily maximum and minimum air temperatures, daily mean dew point temperatures, and a fractional cloud cover for Jackson, Mississippi. Short-wave solar radiation was directly calculated in the model. Evaporation is calculated by the model from air temperature, dew point temperature, and wind speed.

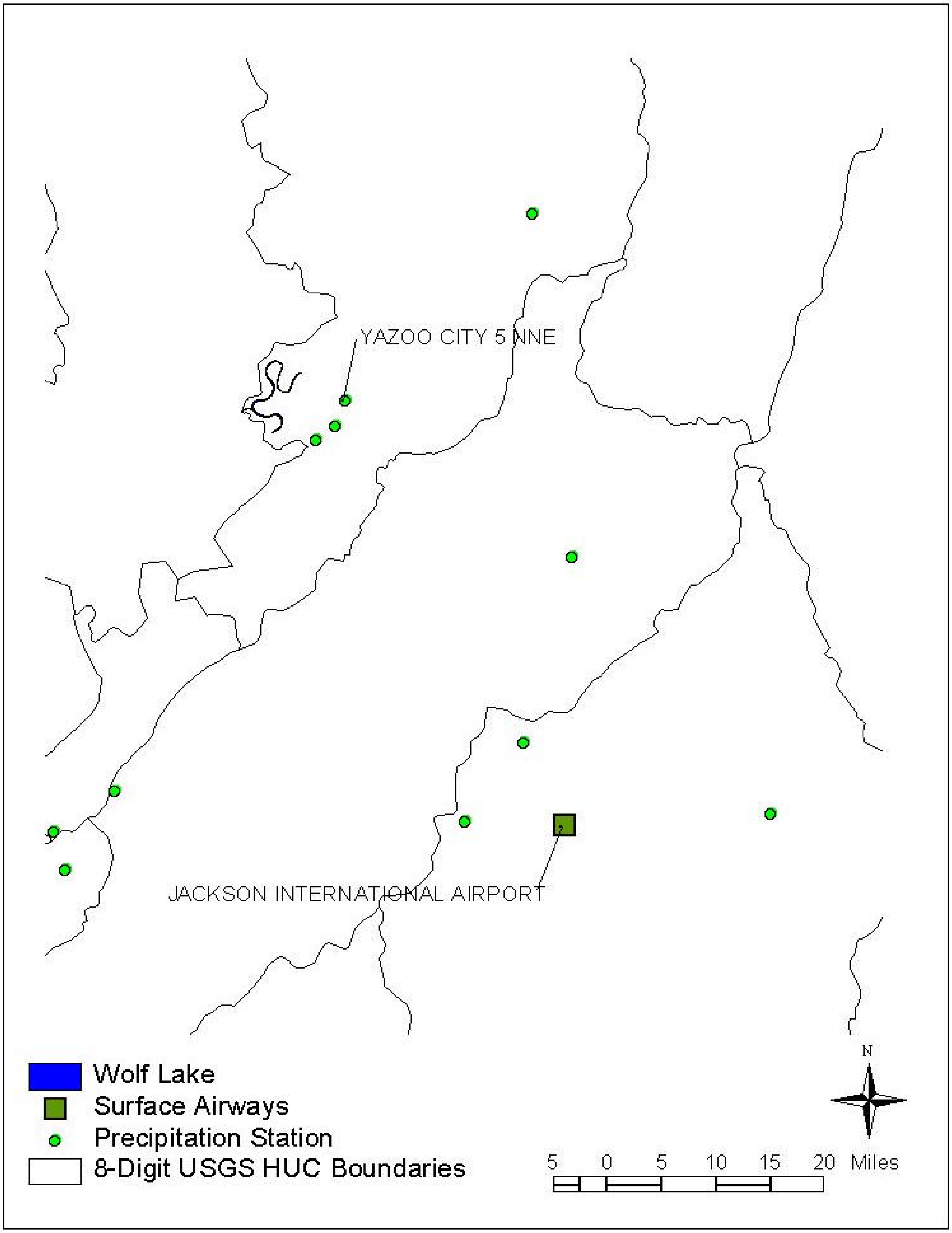

Figure B-3. Weather Station Locations

Recent precipitation data from Yazoo City (Figure B-3) were also available, but for the lake model, evaporation was assumed to cancel out precipitation. Sensitivity on the model runs did not show any major influence of the precipitation falling directly on the lake. However, it maybe noted that the effects of precipitation were indirectly considered via the loads coming from the watershed model for which precipitation was the major driver. The GWLF model used the Yazoo City rain gage, which had the most complete and recent precipitation data (Figure B-3).

For the critical condition period that was chosen (1997-2000) hourly climatological data (unedited) exists on the NOAA National Data Center Web site (from July 1996 onward) for the Jackson Airport meteorological station. Hourly surface airways data were downloaded for each month and a composite file was generated for this period.

3.5 Time Period

The time period chosen for the calibration was from April 1989 to March 1990. This corresponded to the interval of available inlake water quality monitoring data (FTN Associates, 1991). Insufficient monitoring data were available to support model validation. As shown in Figure B-4, 1989 exhibited a wide range of hydrologic conditions with a wet spring and a dry summer. Lakes are typically conducive to eutrophication under these conditions. It may be noted that this year has some relatively dry summer months as well.

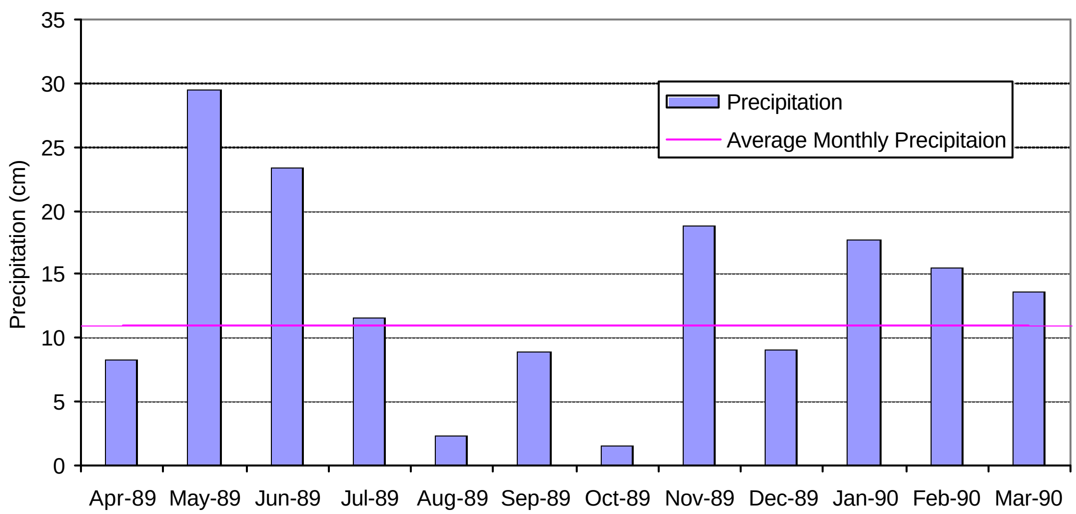

Figure B-4. Monthly Precipitation (Yazoo City)

4.0 Modeling Parameters

Coefficients are needed to describe the water quality reaction rates in the lake. Initial estimates were obtained from CE-QUAL-W2 default values, general literature values (USEPA, 1985), and from the W2 user's manual (Cole and Buchak, 1995). These coefficients were then refined as necessary through iterative model simulations so that the model captured the major processes influencing the lake by trying to match the observed data. The water quality calibration coefficients as well as the phytoplankton calibration coefficient data for the lake are presented below in Table B-3.

Table B-3. Kinetic Coefficients Used in the Calibration of the Wolf Lake Model

Parameter	Description	Units	Value
PO4R	Sediment release rate of phosphorus	fraction of SOD	0.015
PARTP	Phosphorus partitioning coefficient for suspended solids	-	0.6
NO3DK	Nitrate decay rate	1/day	0.102
NO3T1	Lower temperature for nitrate decay	°C	0
NO3T2	Upper temperature for nitrate decay	°C	20
NO3K1	Lower temperature rate multiplier for nitrate decay	-	0.2
NO3K2	Upper temperature rate multiplier for nitrate decay	-	0.99
NH4DK	Ammonium decay rate	1/day	0.30
NH4R	Sediment release rate of ammonium	fraction of SOD	0.05
NH4T1	Lower temperature for ammonium decay	°C	0
NH4T2	Upper temperature for ammonium decay	°C	20
NH4K1	Lower temperature rate multiplier for ammonium decay	-	0.2
NH4K2	Upper temperature rate multiplier for ammonium decay	-	0.99
SOD	Sediment oxygen demand	gCm2/day	0.5
AG	Growth rate	1/day	2.5
AR	Dark respiration rate	1/day	0.08
AE	Excretion rate	1/day	0.04
AM	Mortality rate	1/day	0.05
AS	Settling rate	1/day	0.1
AHSP	Phosphorus half-saturation coefficient	g/m^3	0.003
AHSN	Nitrogen half-saturation coefficient	g/m^3	0.014
ASAT	Light saturation	W/m^3	100
AT1	Lower temperature for minimum algal rates	°C	5
AT2	Lower temperature for maximum algal rates	°C	25
AT3	Upper temperature for minimum algal rates	°C	30
AT4	Upper temperature for maximum algal rates	°C	33
AK1	Lower temperature rate multiplier for minimum algal rates	-	0.1
AK2	Lower temperature rate multiplier for maximum algal rates	-	0.85
AK3	Upper temperature rate multiplier for minimum algal rates	-	0.85
AK4	Upper temperature rate multiplier for maximum algal rates	-	0.1

Some of the parameters required a change from the previous preliminary modeling study of Wolf Lake (Tetra Tech, 1997). The lake is nitrogen-limited and the model was found to be sensitive to the ammonia decay rate [NH4DK] (ammonia oxidation to nitrate-nitrite). The NH4DK rate had to be reduced from its value in the previous study to achieve DO calibration. This brought the NH4DK within the range of literature values. The model was also sensitive to the SOD values. A value of 0.5 $g/cm^2 day^{-1}$ was found to achieve the most reasonable DO calibration. No SOD measurements were made for Wolf Lake. This value was within the range of that reported in the literature (Cole and Buchak, 1995). Minor adjustments were made to the temperature bounds for the algal rates to better mimic the observed sinusoidal temperatures in the lake.

5.0 Assumptions and Limitations

- Monthly loads are assumed to sufficiently represent loading variability in the lake model.
- Since a complete hourly data set for the meteorological was not available, the model uses representative rather than actual wind data in determining hydrodynamic transport and surface reaeration.
- The model does not explicitly predict sediment diagenesis processes and long-term effects of reduced nutrient loads. In order to evaluate the effects of reduced pollutant load input on dissolved oxygen, SOD rates were reduced accordingly. The SOD rate was reduced by half the percentage reduction applied to the nutrients; for example a 30 percent nutrient load reduction corresponds to a 15 percent SOD rate reduction. This approximate estimate was derived from a lake study that used a predictive sediment diagenesis component (USEPA, 2002)
- The watershed model gives an estimate of the total phosphorus and total nitrogen. These loadings were split based on the nutrient ratios determined from inlake monitoring data to provide the loadings required by the W2 model of dissolved and particulate organic material, ammonia, nitrate-nitrite, and ortho-phosphorus that feed into the W2 model.
- The model does not consider the backflows coming from the unnamed tributary of the Yazoo River at the lake outlet. The timing and estimates of these contributions are currently unknown.

6.0 Model Calibration

The hydrodynamic calibration involved calibrating the lake temperatures to observed data to reproduce the thermal structure within the lake profile. Figure B-5 shows the temperature calibration at station WL-3. In general the model follows the sinusoidal nature of the observed data and follows the seasonal trend fairly well. The model consistently over-predicts from April to August. There is a sharp drop during winter, the cause of which is unknown. It is possible that this may be an artifact of the surface boundary condition (meteorological file). This is explanation is plausible because, during the simulation from 1997 to 2000 this sharp drop is not seen. The period from 1997 to 2000 is the period in which a complete data set could be obtained to characterize the meteorological conditions. Because of the lack of data, the water surface elevation and velocity predicted by the model could not be calibrated.

Calibration of the water quality model involved minor adjustments to the default recommended rate coefficients in the W2 model. Figures B-6 and B-7 show the comparison of the observed versus predicted dissolved oxygen and ammonium at monitoring station WL-3. Ammonium calibration plots are included since the system is nitrogen limited and was found to be most responsive to ammonium. Station WL-3 was the only station where observations were taken across multiple depths (i.e., surface, middle, and bottom).

There is reasonable agreement: the model clearly represents the annual trend in the lake's response and captures the critical summer period where the DO problem is evident from the observed data. It can be seen from the WL-3 bottom plot (Figure B-6) that the model predicts anoxic conditions fairly well in the hypolimnion. The level of agreement is further qualified by noting that the model used representative rather than actual wind data in determining hydrodynamic transport and surface reaeration, and that monthly rather than daily loads were used. Currently the model handles the monthly load estimates provided by the GWLF model by using the interpolation routine in the W2 model. The data is linearly interpolated between the data points for each month. The over-prediction in the early and latter parts of the year can be attributed to one or a combination of factors explained above. One of the possible reasons could be high nutrient loadings entering the lake during the early part of the year, for example during May (Table B-1).

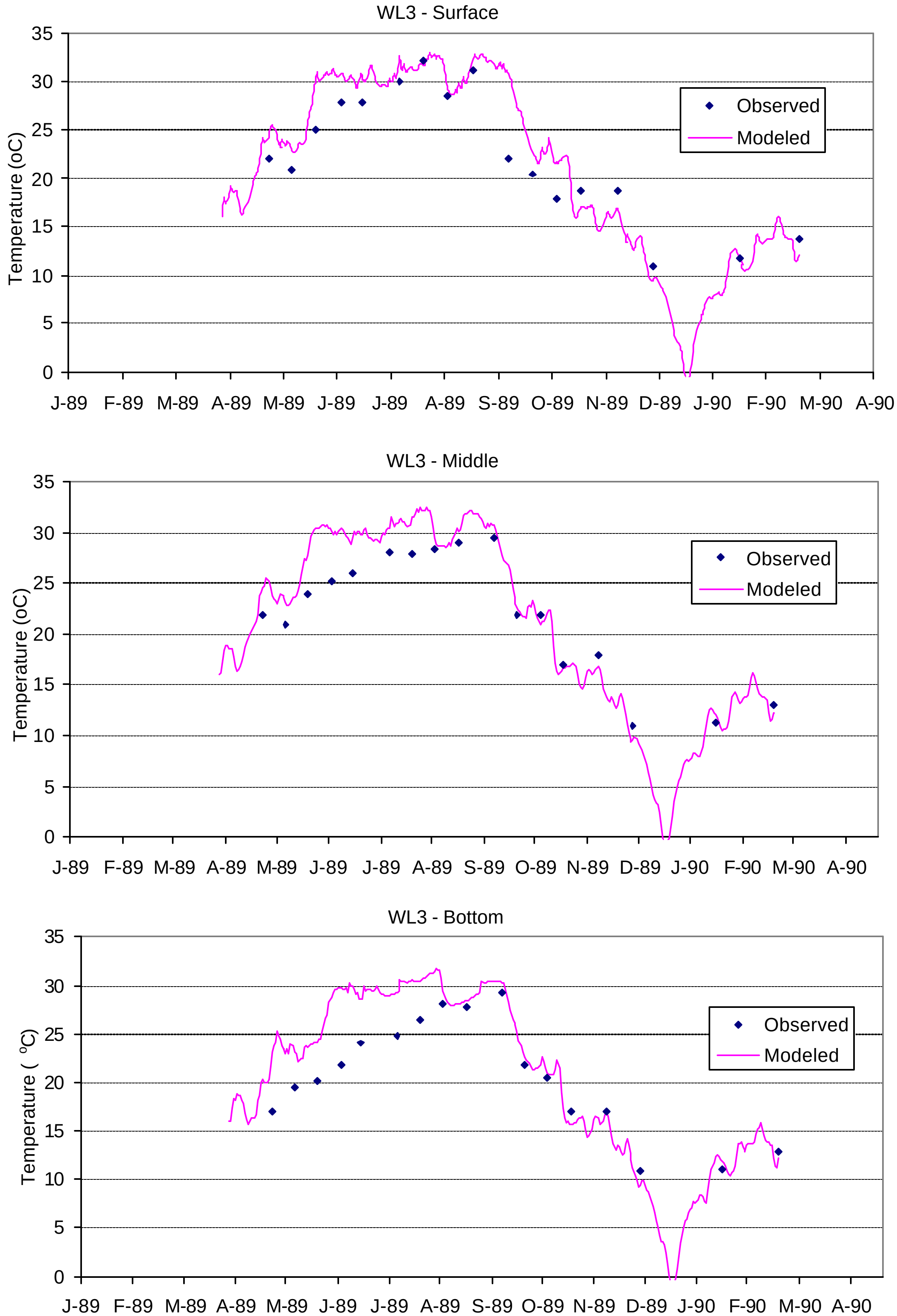

Figure B-5. Temperature (°C) Calibration for 1989-1990 at Segment 13

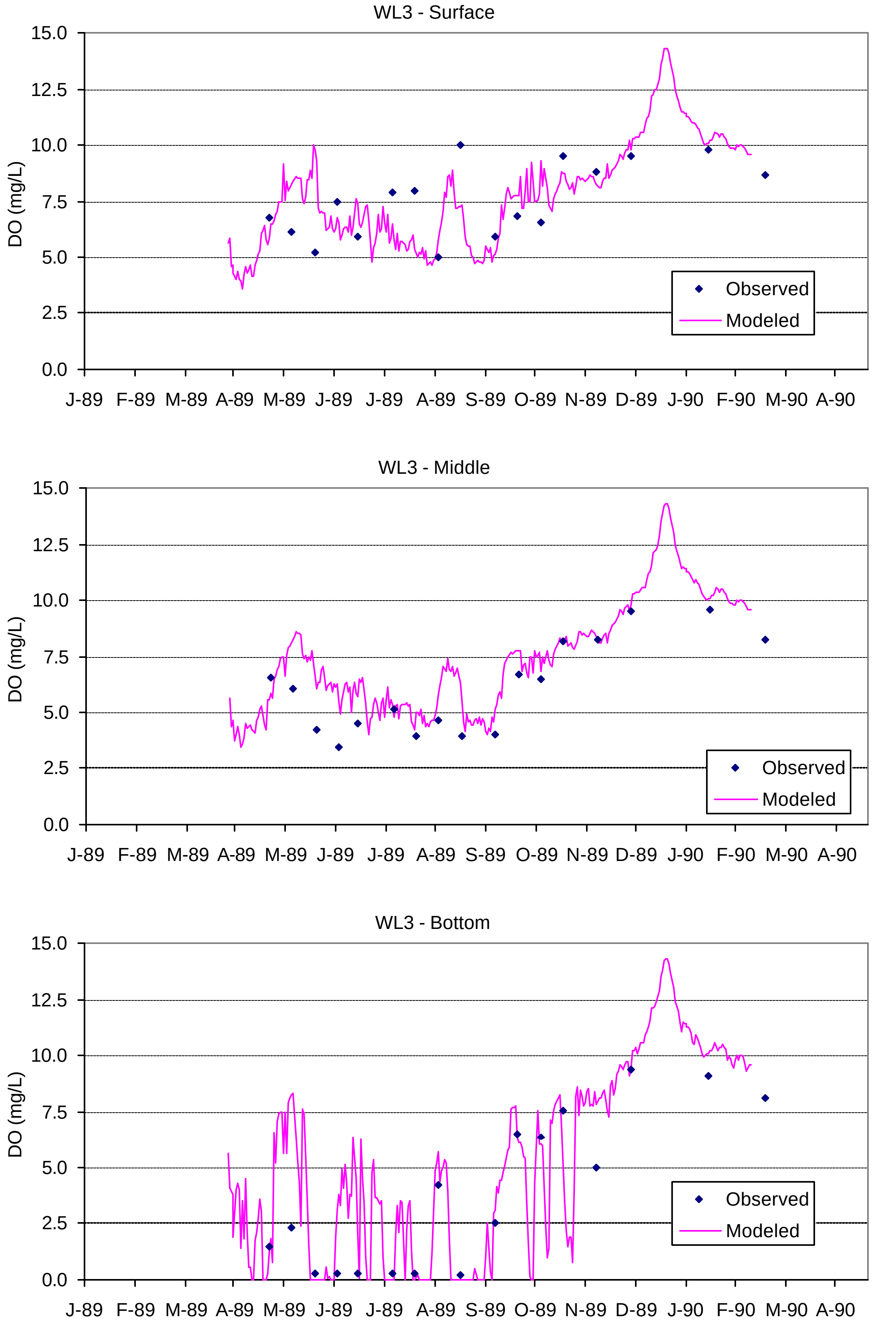

Figure B-6. Dissolved Oxygen (mg/L) Calibration for 1989-1990 at Segment 13

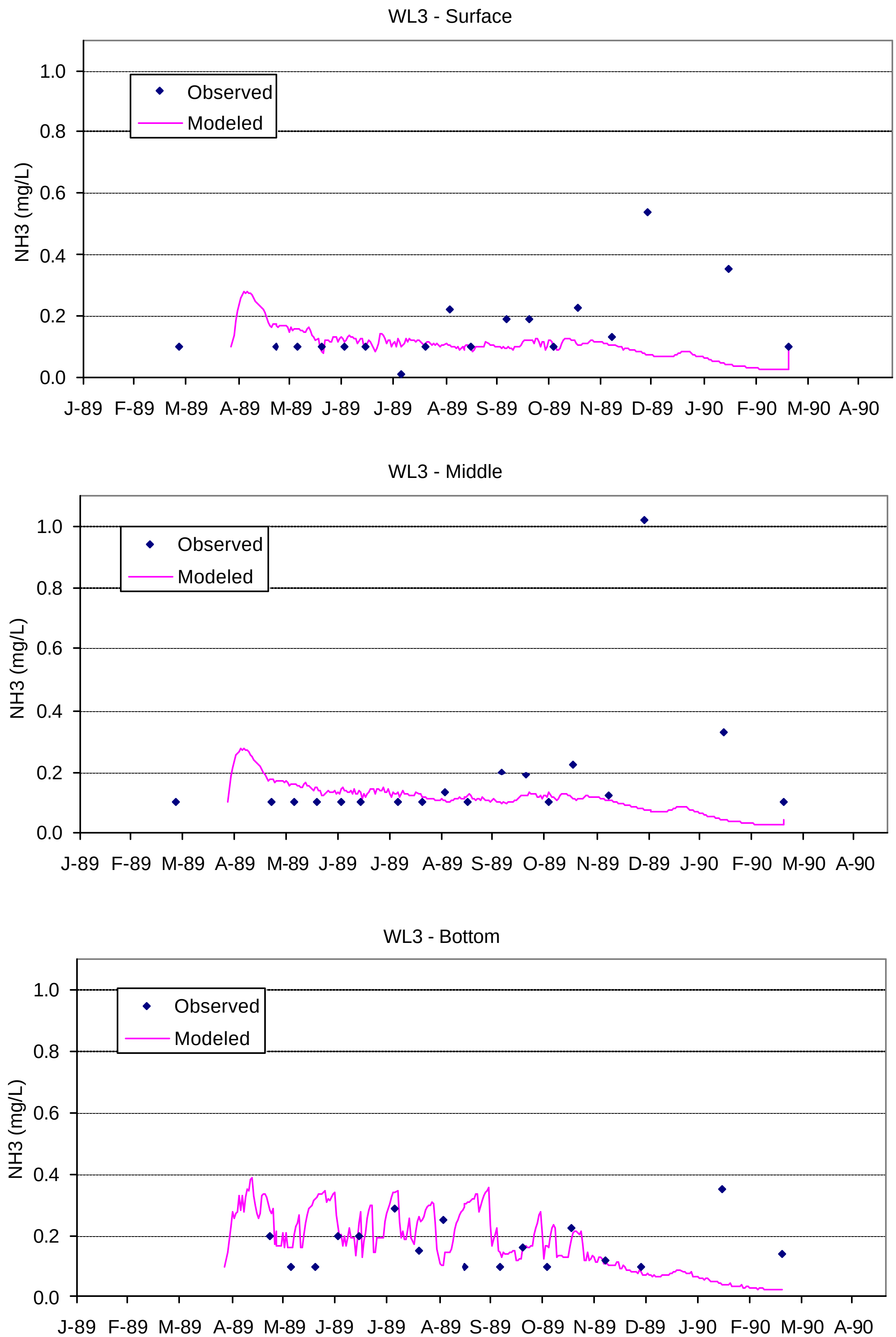

Figure B-7. Ammonium Calibration for 1989-1990 at Segment 13

7.0 References

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