Total Maximum Daily Load for Sediment/Siltation

Moon Lake

Coahoma and Tunica Counties, Mississippi

[FINAL Report – SEPTEMBER 2003]

Prepared for:

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

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Foreword

This report has been prepared in accordance with the schedule contained within the federal consent decree dated December 22, 1998. The report contains a Total Maximum Daily Load (TMDL) for water body 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 TMDL may be updated. Such additional information may include water quality and quantity data, changes in pollutant loadings, 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

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TMDL Summary

Total Maximum Daily Load (TMDL) for Sediment/Siltation in Moon Lake MS320MLM, Coahoma and Tunica Counties, Mississippi

TMDL AT A GLANCE

State:	Mississippi
County:	Coahoma and Tunica Counties
303(d) Listed Water Body:	Yes
Year Listed:	1996
303 (d) List Segment ID:	MS320MLM – Moon Lake
HUC:	08030204 – Coldwater River Basin
Constituents Causing Impairment:	Sediment/Siltation
Source of Pollutants:	Agriculture, aquaculture, and natural Background
Data Source:	Clean Lake Assessments
Designated Uses:	*Lake:* Aquatic Life Support and Recreation
Applicable Water Quality Standard:	*Sediment*: Narrative water quality criteria
Water Quality Target:	*Sedimentation/Siltation*: Average annual sediment sedimentation rate of 0.28 cm/year or 0.19 cm/year
Technical Approach:	*Sedimentation/Siltation:* GWLF watershed model
TMDL:	*Sedimentation/Siltation:* 0.51 / 0.34 ton/acre/year
WLA:	*Sedimentation/Siltation:* 0.51 / 0.34 ton/acre/year
LA:	*Sedimentation/Siltation:* 0.51 / 0.34 ton/acre/year
Margin of Safety:	Implicit

Executive Summary

Moon Lake, located in Coahoma and Tunica Counties, Mississippi, is an oxbow lake formed by an abandoned meander of the Mississippi River. Mississippi Department of Environmental Quality (MDEQ) has identified Moon Lake as not meeting its designated use of Aquatic Life Support. Water bodies not meeting 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 MS320MLM) is on the Mississippi Section 303(d) list as impaired due to sediment/siltation.

Section 303(d) requires the development of total maximum daily loads (TMDLs) for water bodies on the impaired waters list. 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 standard for sedimentation/siltation is narrative.

To evaluate the relationship between the sources, their loading characteristics, and the resulting conditions in the lake a combination of analytical tools was used. Assessments of the nonpoint source loading into the lake were developed for the Moon Lake watershed using the Generalized Watershed Loading Function (GWLF) computer program. GWLF provided estimates of sediments transported to the lake for individual land use categories.

Model results were evaluated for the period 1991–2000, which presented a range of climatic conditions. The target selected for sedimentation/siltation was selected as a range of values, from 0.28 cm/year to 0.19 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 Moon Lake. Watershed management scenarios other than those included in this report are possible. There is little hydrological and water quality data available for Moon Lake, and the management scenarios could be modified based on a reevaluation of the data and modeling if additional 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, reduced tillage on croplands, forest management, and stream restoration.

The TMDLs for sedimentation/siltation have been expressed in terms of ton/acre/year. According to 40 CFR Part 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 TMDL as the tons of sediment that can be discharged from an acre of a subwatershed per year (ton/acre/year) and still attain the applicable water quality standard. This results in a range of acceptable reference yields of 0.51 to 0.34

ton/acre/year. For this TMDL, 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 this sediment TMDL is expressed as a yield, as long as all activities, permitted or unpermitted, meet the same yield, the TMDL will be met, regardless of the relative load contribution.

Wet weather sources of sediment, which are discharged to a receiving water body as a result of the storm events, are considered to be the primary concern for this sediment TMDL. These wet weather sources can be broadly defined, for the purposes of this TMDL, into two categories: wet weather sources regulated by the National Pollutant Discharge Elimination System (NPDES) program, and wet weather sources *not* regulated by NPDES. Wet weather sources regulated by the NPDES program include industrial activities (including certain construction activities) and discharges from Municipal Separate Storm Sewer Systems (MS4s). The wet weather NPDES-regulated sources are provided a WLA in this TMDL, and all other wet weather sources of sediment (those not regulated by NPDES) are provided a LA.

There are no municipal, industrial, or commercial facilities in the Moon Lake watershed with NPDES permits that are permitted for total suspended solids (TSS). If present, it would not be appropriate to include these facilities since these sources provide negligible loadings of sediment to the receiving waters compared with wet weather sources (e.g., NPDES regulated construction activities, 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-permitted municipal and industrial 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 and ES-2. The margin of safety (MOS) has been addressed through implicit assumptions.

Table ES-1. TMDL for Sedimentation rate of 0.28 cm/year for Moon Lake

Pollutant	WLA (ton/acre/year)	LA (ton/acre/year)	MOS (ton/acre/year)	TMDL (ton/acre/year)
Sediment	0.51	0.51	Implicit	0.51

Table ES-2. TMDL for Sedimentation rate of 0.19 cm/year for Moon Lake

Pollutant	WLA (ton/acre/year)	LA (ton/acre/year)	MOS (ton/acre/year)	TMDL (ton/acre/year)
Sediment	0.34	0.34	Implicit	0.34

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 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 the Mississippi Department of Environmental Quality (MDEQ) has identified Moon Lake as being impaired as reported in the Mississippi 1998 Section 303(d) List of Water Bodies. The lake (water body MS320MLM) is listed as impaired due to sediment/siltation. This report presents the approach undertaken to develop TMDLs for Moon Lake 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 Wicander, 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 illustrates this process. Over time, oxbow lakes naturally fill with sediment.

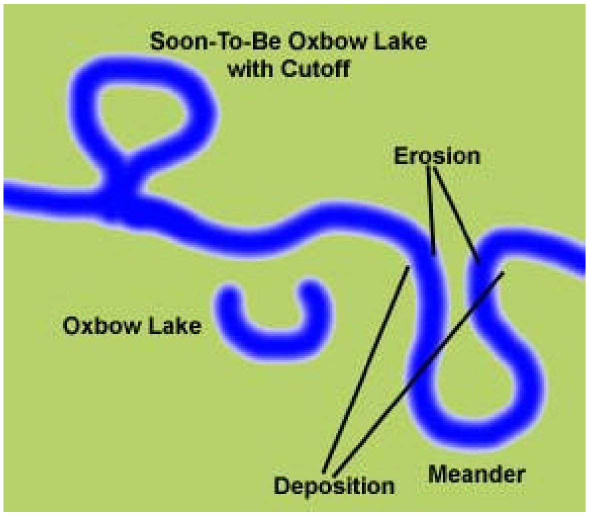

Figure 1-1. Oxbow Lake Creation Process

Moon Lake, located in Coahoma County, Mississippi, is a 2,342-acre oxbow lake formed by an abandoned meander of the Mississippi River. Runoff from the lake's 57,456-acre drainage area (estimated from topographic data) enters Moon Lake through a series of relic oxbow drainages. Phillips Bayou, the primary inflow, enters at the northern tip of Moon Lake. Yazoo Pass, the primary outflow, breaches the natural levee on the eastern perimeter of Moon Lake approximately one-third of the way down the lake. The lower two thirds of the lake have minimal flow-through current (FTN Associates, 1991). Land use in the watershed is predominantly agricultural (80 percent). Morphometric and hydraulic data for Moon Lake are shown in Table 1-1.

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

Parameter	**Measured (acres)**
Surface area	2,342
Drainage area	57,456

Sources: Surface area – 1994, 1995 Clean Lakes Surveys
Drainage area – topographic data

1.2 303 (d) Listed Water Bodies

Moon Lake experienced a historic decline in fishery productivity and recreational activity due to a reduction in depth and water clarity and the presence of pesticides (FTN Associates, 1991). In response to these concerns an investigation of Moon Lake was conducted by the National Sedimentation Laboratory from June 1982 to May 1983 and resulted in the publication of *An Environmental Assessment of Moon Lake, Mississippi and Its Watershed* in 1989. In addition, a Phase I Diagnostic/Feasibility study was conducted in 1991. The results of these studies indicate that sedimentation rates decreased in response to a change in crops from cotton to less intensive soybean or rice, and that pesticide levels in the water and sediments did not pose an environmental problem. However, despite decreased sedimentation rates, elevated turbidity levels after storms continue to prevent the lake from achieving its recreational and fishery potential

(Cooper, 1989; FTN Associates, 1991). Moon Lake (MS320MLM) is 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
Moon Lake	MS320MLM	Coahoma	Aquatic Life Support	Sediment/Siltation

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, 1999a). Suspended sediment can impact 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 light penetration necessary for photosynthesis in aquatic plants, reduces the feeding efficiency of visual predators and filter feeders, and lowers the respiratory capacity in 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.

1.3 Water Quality Standards and Beneficial Uses

The beneficial use identified for Moon Lake are Aquatic Life Support and Recreation (MDEQ, 2002). Although there are no specific applicable criteria for the beneficial use of Aquatic Life Support, the criteria listed in Table 1-3 apply to all surface waters in Mississippi. The water quality objectives provide a narrative basis for identifying an appropriate TMDL endpoint for sedimentation/siltation.

Table 1-3. Relevant Water Quality Objectives

Section	Water Quality Objective
Section II.1	Waters shall be free from substances attributed to municipal industrial, agricultural, or other discharges that will settle to form putrescent or otherwise objectionable sludge deposits.
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.

1.4 Watershed Description

The Moon Lake watershed, which is part of United States Geological Survey (USGS) Hydrologic Unit Code (HUC) 08030204, encompasses approximately 90 square miles (57,456 acres). It is located in Coahoma and Tunica Counties north of Clarksdale, Mississippi (Figure 1-2).

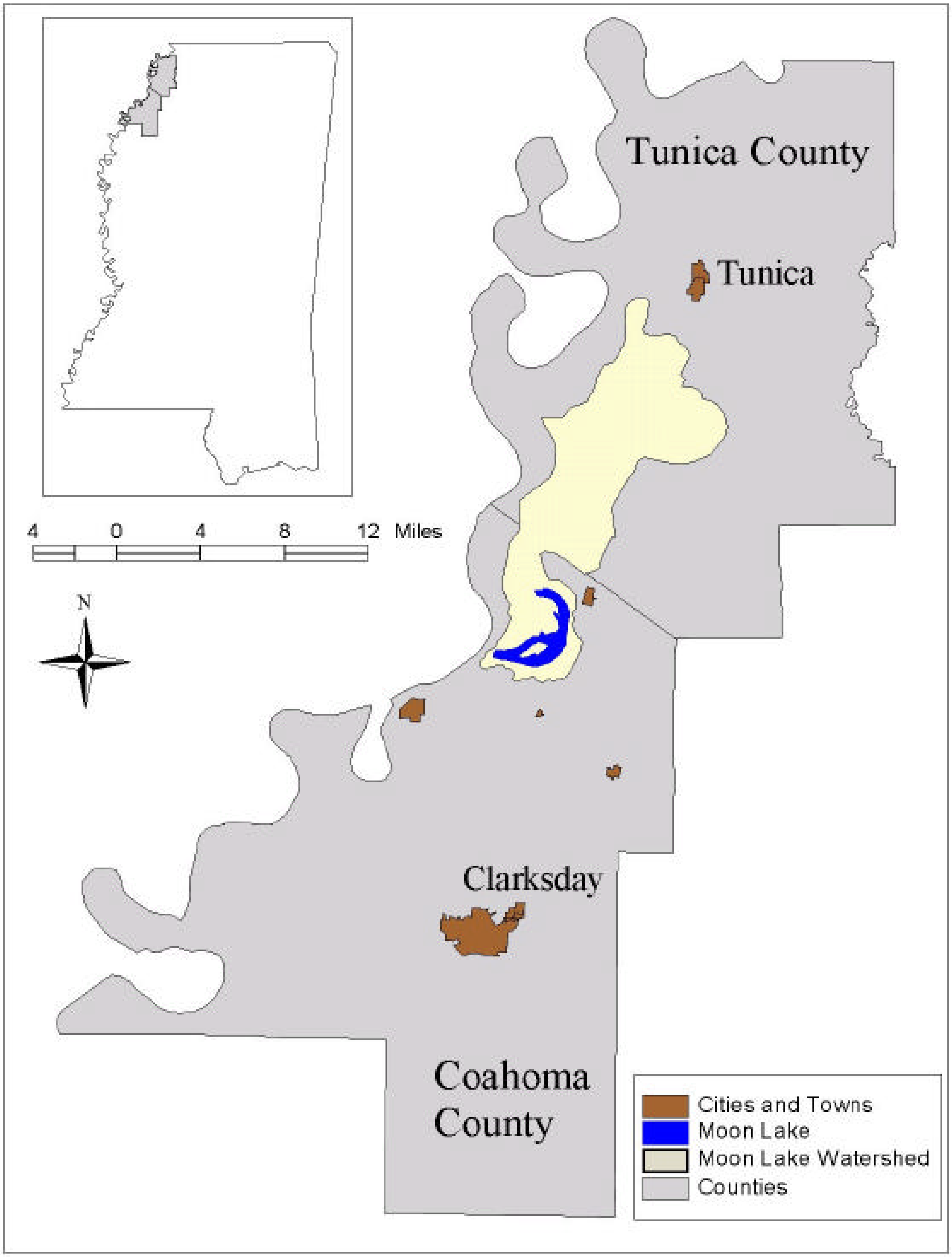

Figure 1-2. Watershed Location

1.4.1 Topography

The Moon Lake watershed is located a flat expanse of flood plain along the Mississippi River. Figure 1-3 presents the digital elevation model (DEM) for the watershed. The elevation of the watershed ranges from approximately 154 feet above mean sea level (MSL), in the east central portion of the watershed, to approximately 219 feet above MSL, at the crest of the levees that parallel the Mississippi River and form the western edge of the watershed. Generally, the southern portion of the watershed has the lowest elevations, especially around Moon Lake, which is approximately 160 feet above MSL.

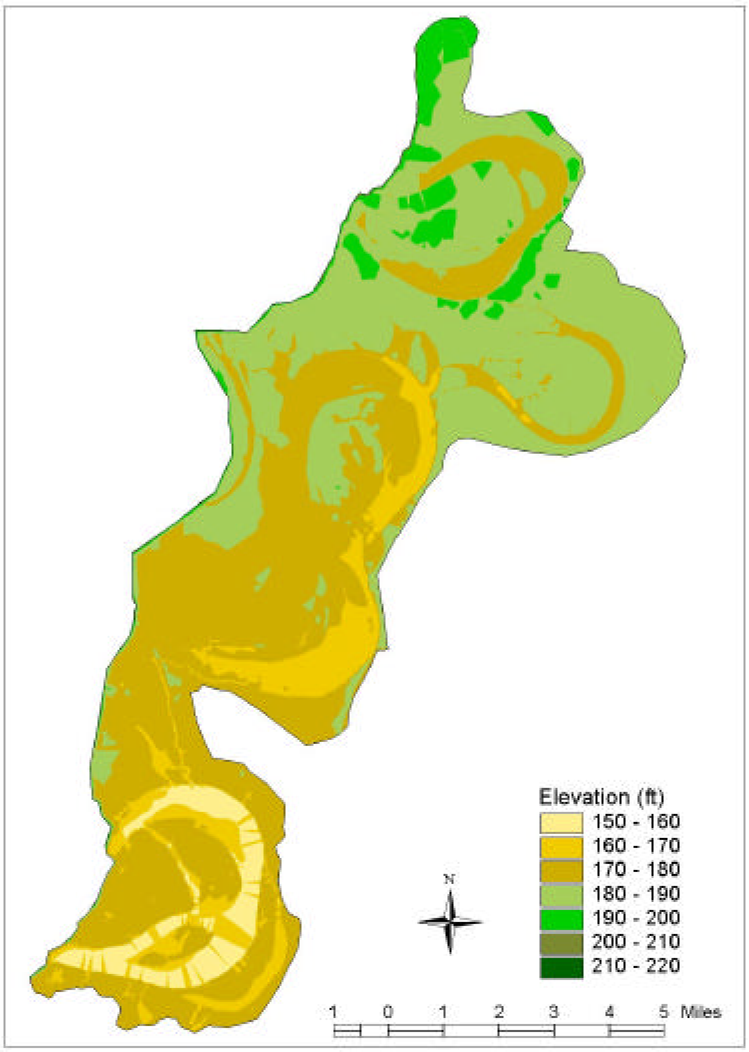

Figure 1-3. Digital Elevation Map

1.4.2 Soil Type

The watershed consists of six major soil types, which are shown in Figure 1-4 and Table 1-4. The Dundee-Forestville-Dubbs and Sharkey-Tunica-Dundee are the main soil groups in the watershed. 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.

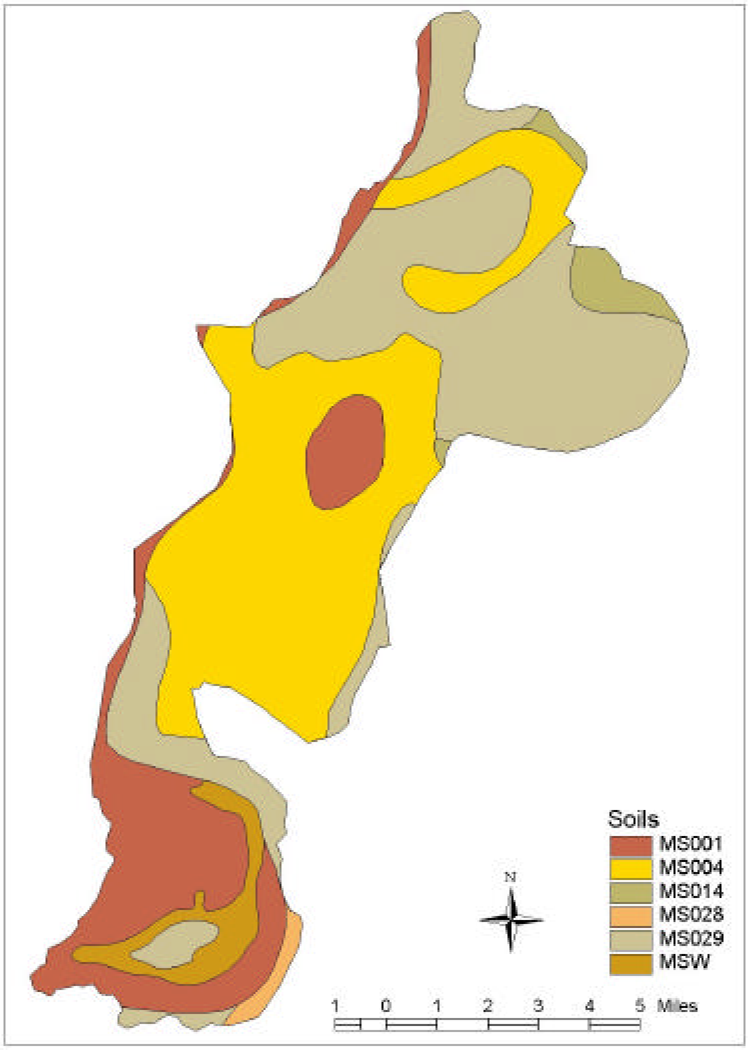

Figure 1-4. Soil Type

Table 1-4. Soil Types

Soil Type	Soil Name	Area (acres)
MS001	Commerce-Robinsonville-Crevasse	10,921
MS004	Sharkey-Tunica-Dundee	20,706
MS014	Forestdale-Dundee-Sharkey	1,403
MS028	Sharkey-Alligator-Tunica	523
MS029	Dundee-Forestville-Dubbs	21,631
MSW	Hydric	2,272
Total		57,456

1.4.3 Land Use

The Lake Moon watershed is predominantly rural. Figure 1-5 and Table 1-5 present the land use in the watershed. The main land use in the watershed is cropland (about 80 percent). Cropland, bottomland hardwood forests, and water make up almost 90 percent of the watershed. Bottomland hardwood forests, water, and riverine swamps are the main land uses in the low-lying areas.

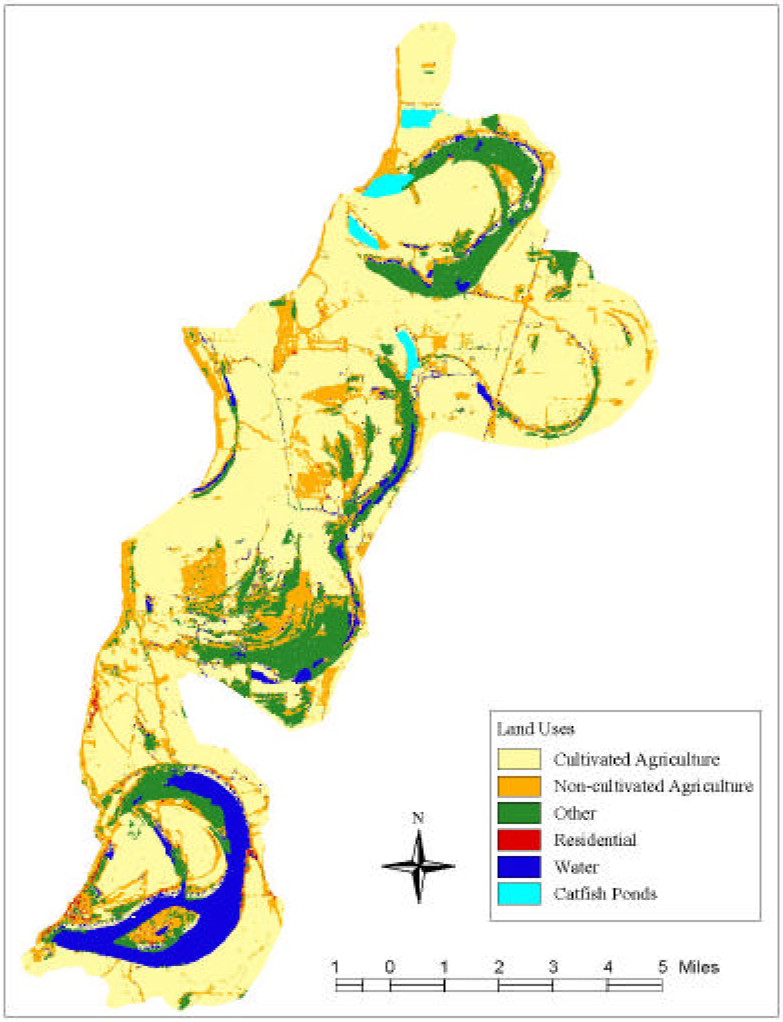

Figure 1-5. Mississippi Automated Resource Information System Land use

Table 1-5. Land Use in Watershed

Land Use	**Area (acres)**
Catfish Ponds	587
Cultivated Agriculture	35,573
Noncultivated Agriculture	9,273
Other	11,798
Residential	225
Total	57,456

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

Moon Lake watershed is located in Coahoma County and Tunica County, Mississippi. The region is generally a rural area covering 1,009 square miles, with 39 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.

Four industry sectors, services, government, retail trade, and manufacturing account for almost 86 percent of regional employment. However, the services sector alone account for 62 percent of total employment, primarily attributed to casino gaming and resort developments in Tunica County. Moon Lake also contributes to the services sector of the region’s economy. The lake offers good fishing for many species of fish, including crappie, bream, channel fish, bowfin, common carp, and flathead catfish (Mississippi Outfitters, 2001). The recreational visitors to Moon Lake contribute to the local economy through expenditures on food, lodging, and sporting goods.

1.7 Threatened or Endangered Species Within the Watershed

Information on endangered species found within the Moon Lake watershed was obtained from the Mississippi Department of Wildlife, Fisheries, and Parks. There is one species of concern, the Black Buffalo (*Ictiobus Niger*), found in Moon 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
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
Flow	
Historical Flow Record	USGS (gage sites located near but not in watersheds)
Meteorological Data	
Rainfall	NOAA-NCDC, Earth Info
Temperature	NOAA-NCDC, Earth Info
Water Quality Data (surface water, groundwater)	
Water Quality Monitoring Data	U.S. Agricultural Research Service, 1983 MS Office of Pollution Control, 1991 Clean Lakes Survey (FTN Associates, 1991)

2.2 Monitoring Data Assessment of Moon Lake

The most recent tributary and storm water data were collected from June 1982 through May 1983 (U.S. Agricultural Research Service, 1989) and from February 1989 through February 1990 (FTN Associates, 1991). The U.S. Agricultural Research Service sampled six sites from June 1982 through May 1983 on a bi-weekly basis. FTN Associates sampled five sites twice a month from May through October and once a month for the remainder of the year from February 1989 to February 1990 for the Clean Lakes Study. Figure 2-1 shows the routine water quality monitoring stations. Results of the data collection are summarized in the following subsections.

2.2.1 Tributary Inflow

The U.S. Agricultural Research Service sampled tributary flow at a single station on Phillips Bayou (A-1) and FTN Associates sampled tributary flow at a single station on Phillips Bayou (ML-1) (Figure 2-1). Although this tributary is not listed as impaired due to sediment/siltation the data can serve as a guide for model validation. Tables 2-3 and 2-4 summarize collected data that have relevance to this TMDL.

Table 2-3. Inlet Tributary (A-1) Water Quality Data (1982–1983)

Parameter	Count	Min.	Max.	Mean	Median
Total Solids (mg/L)	24	162	711	291.08	235.5
Total Solids (mg/L)	24	37	160	86.71	74.5
Secchi Depth (m)	24	0.05	0.51	0.18	0.15
Water Depth (m)	24	0.45	2.83	1.39	1.335

Source: U.S. Agricultural Research Service, 1989

Table 2-4. Inlet Tributary (ML-1) Water Quality Data (1989–1990)

Parameter	Count	Min.	Max.	Mean	Median
Total Suspended Solids (mg/L)	17	17	900	133	50
Total Dissolved Solids (mg/L)	17	76	296	147.6	127

Source: FTN, 1991

The Clean Lakes Study found that the highest TSS values occurred in the spring, with the highest value of 900 mg/L occurring on the same day as a large rainfall event. Generally TSS declined over the summer and then remained constant through the end of the sampling period. Total dissolved solids were found to decrease over the summer and then increase in the fall and winter. The largest dissolved solids measurement occurred on the same day as the largest TSS measurement.

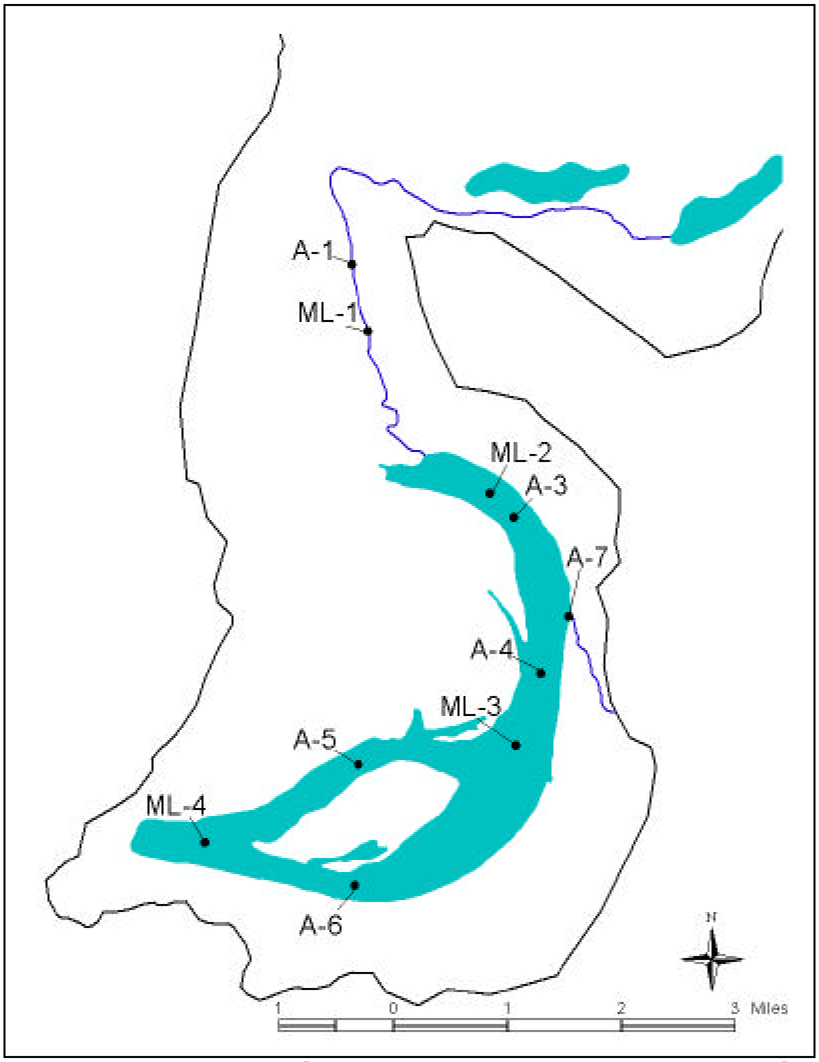

Figure 2-1. USARS and FTN Associates Approximate Sampling Locations

2.2.2 Inlake Water Quality of Moon Lake

The U.S. Agricultural Research Service (USARS) collected samples of total solids, dissolved solids, and Secchi depths at four inlake stations, A-3, A-4, A-5, and A-6, on a biweekly basis from June 1982 through May 1983 (Figure 2-1). Several parameters were measured during this study. Table 2-5 summarizes collected data that have relevance to this study.

Table 2-5. Inlake (A-3, A-4, A-5 and A-6) Water Quality Data (1982–1983)

Parameter by Sample Location	Count	Min	Max	Mean	Median
A-3					
Total Suspended Solids (mg/L)	23	119	419	201	192
Total Dissolved Solids (mg/L)	23	49	123	90	92
Secchi Depth (m)	23	0.11	0.94	0.27	0.17
A-4					
Total Suspended Solids (mg/L)	23	112	264	176	188
Total Dissolved Solids (mg/L)	23	66	135	95	99
Secchi Depth (m)	23	0.11	1.35	0.36	0.24
A-5					
Total Suspended Solids (mg/L)	23	23	257	166	159
Total Dissolved Solids (mg/L)	23	55	130	94	101
Secchi Depth (m)	23	0.13	0.97	0.31	0.25
A-6					
Total Suspended Solids (mg/L)	23	116	251	176	183
Total Dissolved Solids (mg/L)	23	66	130	96	102
Secchi Depth (m)	23	0.13	0.85	0.29	0.24

Source: U.S. Agricultural Research Service, 1989

The U.S. Agricultural Research Service study concluded that the suspended and deposited sediment gradient declined with increased distance from the inflow and that suspended sediment was excessive only during major runoff events.

Monthly inlake water quality was measured at multiple sites and depths in Moon Lake from February 1989 through February 1990 (FTN Associates, 1991) (Figure 2-1). The study measured several parameters. Table 2-6 summarizes collected data that have relevance to this TMDL.

Table 2-6. Inlake (ML-2, ML-3, and ML-4) Water Quality Data (1989–1990)

Parameter by Sample Location	Count	Min	Max	Mean	Median
ML-2					
Total Suspended Solids (mg/L)	17	4.0	46.0	20.3	15.5
Total Dissolved Solids (mg/L)	17	65.0	226.0	123.4	109.5
Secchi Depth (cm)	17	10.0	60.0	25.2	16.0
ML-3 (surface)					
Total Suspended Solids (mg/L)	17	7.0	36.0	16.1	14.0
Total Dissolved Solids (mg/L)	18	64.0	183.0	118.9	110.5
Secchi Depth (cm)	17	10.0	60.0	27.6	15.0
ML-3 (mid-depth) Sample Depth = 3.0 ft					
Total Suspended Solids (mg/L)	17	7.0	42.0	18.2	14.5
Total Dissolved Solids (mg/L)	18	66.0	196.0	126.2	111.5
Secchi Depth (cm)	-	-	-	-	-
ML-3 (0.5 m off of bottom) Sample Depth = 5.5 ft					
Total Suspended Solids (mg/L)	17	10.0	77.0	28.5	18.5
Total Dissolved Solids (mg/L)	18	66.0	193.0	127.5	117.0
Secchi Depth (cm)	-	-	-	-	-
ML-4					
Total Suspended Solids (mg/L)	17	6.0	42.0	18.2	18.5
Total Dissolved Solids (mg/L)	17	59.0	222.0	127.0	115.0
Secchi Depth (cm)	17	10.0	60.0	26.7	10.0

Source: FTN Associates, 1991.

The Clean Lakes study found TSS concentrations of less than 50 mg/L at the inlake stations. The study also found that, during the late spring and summer, TSS concentrations were higher near the bottom than at the mid-depth or surface of the water column. The study concluded that suspended solids were settling out between ML-1 and ML-2. This conclusion was based on the observation that 65 percent of the reported suspended solids concentrations for ML-1 were greater than or equal to 50 mg/L while none of the observations of TSS at ML-2 were greater than 50 mg/L.

3.0 Source Assessment

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

3.1 Point Sources

Pollutant sources under the CWA are typically categorized as either point or nonpoint sources. Point sources, according to 40 CFR 122.2, are defined as any discernible, confined, and discrete conveyance, including but not limited to, any pipe, ditch, channel, tunnel, conduit, well, discrete fissure, container, 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, the discharge of storm water from construction activities that disturbs between 1 and 5 acres must also be authorized by an NPDES permit in addition to the requirements already in place for 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 given time varies. The target for these areas is the same range as the TMDL target of 0.51 to 0.34 ton/acre/year. The 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 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 the discharge elimination file in Mississippi's automated resource information system determined that no permitted point source discharges are located within the watershed. The towns within the Moon Lake watershed are small, and according to the final Phase II Storm water NPDES regulations, are not considered regulated small MS4s at the present time. However, the potential for sediment loadings from NPDES regulated construction activities and 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, nonpermitted sources. Exceptions to this are some aquaculture facilities (which are discrete and nonpermitted 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 nonprecipitation-driven events such as contributions from groundwater; septic systems; and direct deposition of pollutants from wildlife, livestock, or atmospheric fallout. Nonpoint sources contribute sediment loads into the waters of the Moon Lake watershed. The net loading into the lake 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 non-cultivated agricultural lands cover 66 percent and 18 percent, respectively, of the Moon Lake watershed area. Cotton is the major crop in the Moon Lake watershed representing 72 percent of the total cultivated agriculture land. Other crops include: corn, soybean, sorghum, snap beans, other small grains, rice, and winter wheat.

3.2.2 Aquaculture

The production of catfish in the Mississippi Valley is the largest aquaculture enterprise in the United States. Catfish ponds located in the Mississippi Valley account for approximately 78 percent of the total U.S. land area devoted to catfish production (USEPA, 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 six 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. 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). Catfish ponds covering approximately 587 acres, about 1 percent of the watershed area, are located in the upper portion of the Moon Lake Watershed.

3.2.3 Background Sources

TMDL load allocation must take into account, the natural background loading of a pollutant. For this TMDL, the contributions of sediment from forested areas were considered the background load. Forested land, including bottomland hardwood forest, upland scrub, and riverine swamp, covers 15 percent of the Moon 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 Moon Lake watershed were insufficient to separate natural forest loadings from other forest sources.

4.0 Technical Approach

This section will 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 an evaluation of the following criteria (USEPA, 1991)

- Technical Criteria
- Regulatory Criteria

Technical criteria refer to the model's simulation of the physical system in question, including watershed and stream 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 are a cause of cumulative contributions.
- The monitoring data available for the watershed are insufficient for an evaluation of the magnitude of stream channel and bank erosion.

A properly designed and applied technical approach provides the source-response linkage component of the TMDL and makes it possible to accurately assess a water body's assimilative capacity and to propose allocations. 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, presented earlier in this report provided the basis for establishing appropriate TMDL targets. For sediment/siltation, the standard is narrative.

Based on the considerations identified above, the technical approach for addressing sediment/siltation in Moon Lake includes a combination of watershed and lake water quality models:

- A simplified watershed model to predict runoff and loadings of sediment to the tributaries and lake to address sediment/siltation impairments.
- Siltation rate analysis for the lake.

The technical approach to TMDL development must consider the dominant watershed and inlake processes. Pollutant loading in Moon Lake watershed is primarily from nonpoint or diffuse sources, which are typically rainfall-driven and relate to surface runoff and subsurface discharge to a stream. No point sources exist in the watershed. The approach provides a hydrologic, and sediment loading budget for the watershed.

4.2 Modeling

A watershed model was used to identify the TMDL for sediment. The Generalized Watershed Loading Function (GWLF) model (Haith and Shoemaker, 1987) was selected to simulate the loading of sediment from the Moon 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 Nonpoint 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 Moon Lake can be assessed using trap efficiency calculations. The Brune method (USACE, 1989) provides a widely used trap efficiency estimation method for lakes and reservoirs. It employs 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.

4.2.1 Modeling Assumptions

The following are some of the major underlying assumptions used in this analysis:

General

- Meteorological data from Arkabutla Dam, Mississippi, and Memphis, Tennessee, were assumed to be representative of the entire watershed contributing to the lake, although these stations are located outside of the watershed.

- The watersheds were delineated based on topographic data and available stream and channel coverages. Data regarding flow diversions to or from other watersheds were not available and 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 between sand, silt, and clay particles.
- The sedimentation at the land use level was predicted using the USLE, and only a portion of this load was delivered to the lake. The percentage of eroded sediment delivered to the lake was based 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.
- 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.

4.2.2 Limitations

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

- Stream-bank erosion was not explicitly considered in the analysis. 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.

4.2.3 Recommendations

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

- 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.
- The sediment monitoring data available were insufficient 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 estimation of the life span.
- Further analysis of stream channel morphology and evolution is recommended to identify the significance of stream-bank erosion on 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.

5.0 TMDL Development

A total maximum daily load (TMDL) for a given pollutant and water body is comprised of the sum of individual WLAs for point sources, and 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 the receiving water body can assimilate and remain within water quality standards. In TMDL development, allowable loadings from all pollutant sources that cumulatively amount to no more than the TMDL must be established and thereby provide the basis to establish 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.

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 Wicander, 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.

5.2 Critical Condition and Seasonality

40 CFR Section 130 require TMDLs to 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 to take into account changes in stream flow and loading characteristics that result from hydrological or climatological variations. These conditions are important because they describe the factors that combine to cause violations of water quality standards and can help identify necessary remedial actions.

The sediment analysis considered the seasonality in the loading through the simulation of monthly watershed loadings based on historic precipitation records. Daily precipitation and temperature data were obtained from local National Climatic Data Center (NCDC) weather stations and are shown in Figure 5-1. The period of record for model runs, April 1, 1990 through March 31, 2000, was selected because daily precipitation and temperature data were available for that period. The evaluation of sediment impacts on the lake was considered 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 recommended in order to meet water quality standards.

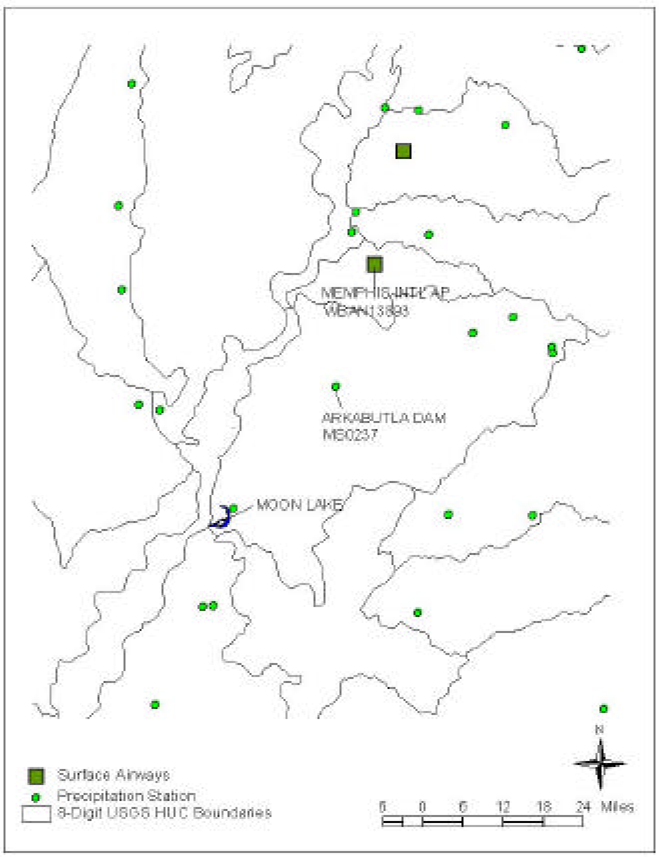

Figure 5-1. Precipitation and Temperature Gage Locations

The critical conditions for the sediment TMDL are selected to evaluate the type of impairment (siltation) and the type of water body (oxbow lake). Protection of the lake's condition requires the control of long-term loadings and accumulation of sediment. The lakes condition is evaluated based on mean siltation rates, in selected locations, in response to long-term annual loading and trapping of sediments in the lake.

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, (2) conventional tillage, (3) 50 percent wooded and moderate tillage, (4) no tillage, (5) 50 percent wooded no tillage, (6) 100 percent wooded. The life span of the lake under these six conditions is presented in Figure 5-2.

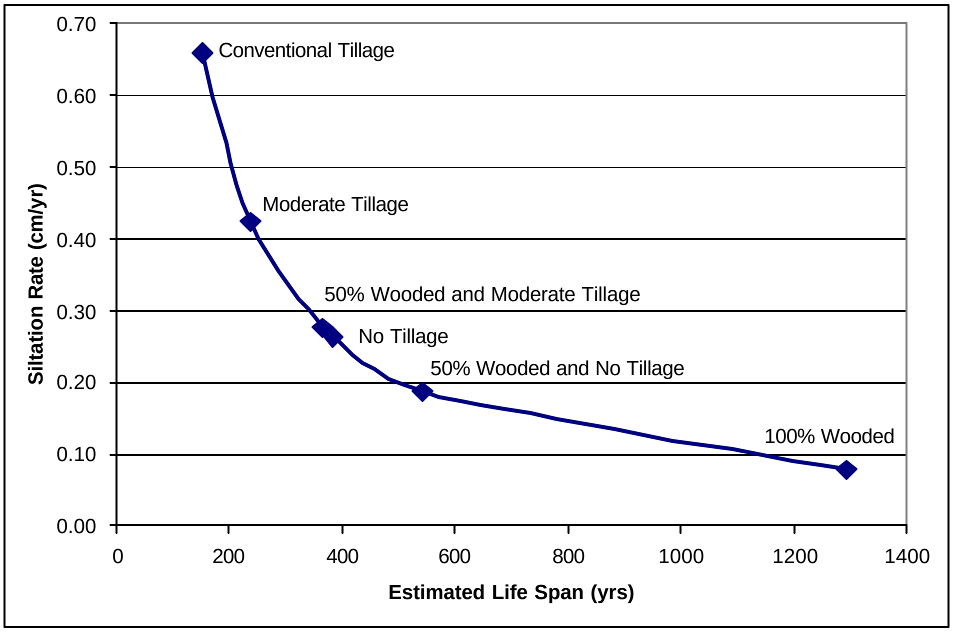

Figure 5-2. Estimated Lifespan for Scenarios

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 0.28 cm/year to 0.19 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, this TMDL is 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 Moon Lake watershed. This TMDL encourages 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 Moon Lake.

5.4 TMDL Allocations of Sediment

According to the model, a sedimentation rate of 0.28 cm/year occurred when the sediment load from the watershed was reduced by 35 percent. A sediment load reduction of 56 percent gave an estimated sedimentation rate of 0.19 cm/year. This range of sedimentation rates is estimated to extend the life span of the lake from approximately 240 years under existing conditions to between 360 and 540 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. In addition no reduction was applied to the "residential" or "aquaculture" category since residential land use in the Moon Lake watershed was negligible and comprised less than 1 percent of the total land use in the watershed.

Table 5-1. Load Reduction Scenario - Sedimentation Rate of 0.28 cm/year

LAND USE	BASELINE (ton/yr)	REDUCTION (ton/yr)	REDUCTION (%)
Agriculture Cultivated	35,888	12,965	36
Agriculture Noncultivated	7,489	2,706	36
Aquaculture	0	0	0
Residential	53	0	0
Other	1,419	0	0
Total	**44,850**	**15,671**	35

Table 5-2. Load Reduction Scenario - Sedimentation Rate of 0.19 cm/year

LAND USE	BASELINE (ton/yr)	REDUCTION (ton/yr)	REDUCTION (%)
Agriculture Cultivated	35,888	20,805	58
Agriculture Noncultivated	7,489	4,352	58
Aquaculture	0	0	0
Residential	53	0	0
Other	1,419	0	0
Total	**44,850**	**25,147**	56

The TMDL 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 achieve a sedimentation rate of 0.28 cm/year is 0.51 ton/acre/year, and the sediment load to achieve a sedimentation rate of 0.19 cm/year is approximately 0.34 ton/acre/year. It should be stressed that these numbers are only approximations, based on an interpretation of the limited data available for Moon Lake. Many assumptions and limitations were 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 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 0.51 to 0.34 ton/acre/year.

Table 5-3. TMDL for Sedimentation Rate of 0.28 cm/year for Moon Lake

Pollutant	WLA (ton/acre/year)	LA (ton/acre/year)	MOS	TMDL (ton/acre/year)
Sediment	0.51	0.51	Implicit	0.51

Table 5-4. TMDL for Sedimentation Rate of 0.19 cm/year for Moon Lake

Pollutant	WLA (ton/acre/year)	LA (ton/acre/year)	MOS	TMDL (ton/acre/year)
Sediment	0.34	0.34	Implicit	0.34

5.5 Margin of Safety

The 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 was expressed implicitly through implicit conservative assumptions that provide a margin of safety. Specific conservative assumptions include

- 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.

5.6 Reasonable Assurance

This component of TMDL development does not apply. There are no point sources requesting a reduction based on LA components and reductions.

5.7 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 TMDL 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 this TMDL. All comments will be considered in the submission of this TMDL to EPA Region 4 for final approval.

5.8 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, Moon Lake may receive additional monitoring to identify any change in water quality. The additional monitoring may allow refinements of the assumptions used to calculate this TMDL.

5.9 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. The sediment load estimates from the GWLF model were used in analyzing 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 0.28 cm/year to 0.19 cm/year was identified as a long-term average sedimentation endpoint based on the example land management scenarios included in this TMDL. A 35 to 56 percent reduction of sediment load was also recommended to address the siltation loading. The sediment TMDL was computed to be approximately 0.51 ton/acre/year to 0.34 ton/acre/year of sediment for the range of selected endpoints.

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Definitions

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 assemblages (e.g. , fish, macroinvertabrates, or algae) indicates less than full support with moderate to severe modification of biological community noted.

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 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.

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.

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 that is in runoff from the land. Rainfall, snowmelt, and other water that does not evaporate become surface runoff and either drains into surface waters or soaks into the soil and finds its way into groundwater. This surface water may contain pollutants that come from land use activities such as agriculture; construction; silvaculture; surface mining; disposal of wastewater; hydrologic modifications; and urban development.

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.

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 leak 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.

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.

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

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 which may pollute or tend to pollute any waters of the State.

Wasteload Allocation (WLA): The portion of receiving water's 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

7Q10..............Seven-Day Average Low Stream Flow with a Ten-Year Occurrence Period
BASINS.....................Better Assessment Science Integrating Point and Nonpoint Sources
BMP .... Best Management Practice
CWA .... Clean Water Act
EPA ....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
NPDES ....National Pollution Discharge Elimination System
RBA.. Rapid Biological Assessment
USGS.. United States Geological Survey
WLA...Waste Load Allocation

APPENDIX A

Watershed Model and Siltation Analysis for Moon Lake Watershed

1.0 Model Selection

The Generalized Watershed Loading Function (GWLF) model was selected to estimate sediment loadings to Moon Lake. Key characteristics of the GWLF model include:

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

The sediment loads from all land uses in the lower Moon Lake watershed, below sampling location A-1, were generated using the GWLF model (Figure A-1). The sediment loads from all land uses in the upper Moon Lake watershed, above sampling location A-1, were generated from daily sediment data collected from May 1982 through April 1983 at sampling location A-1 (Cooper, 1989).

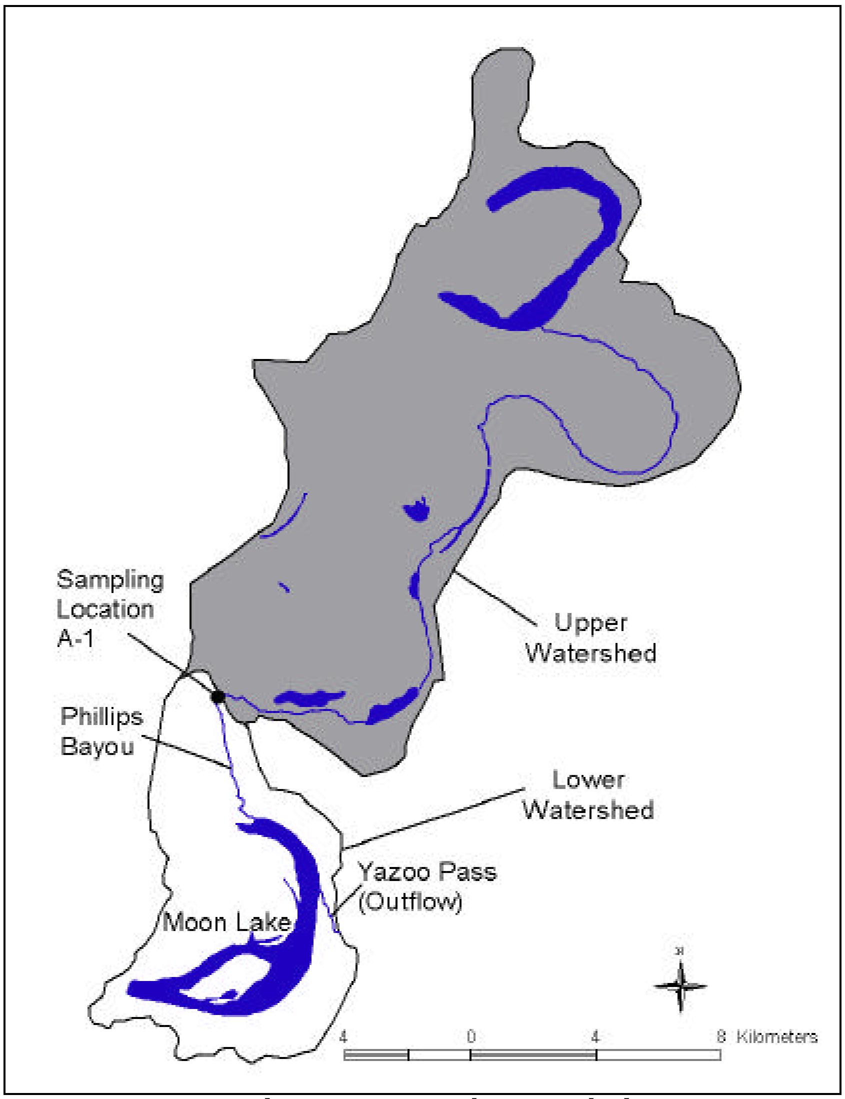

Figure A-1. Upper and Lower Moon Lake Watershed.

The sediment load from catfish ponds, which represent approximately 1 percent of the Moon Lake watershed area, was assumed to be negligible. The upper and lower watershed sediment loads were applied to a siltation and life span analysis for assessment of siltation/sediment impairments.

2.0 Model Framework

The GWLF model, which was originally developed by Cornell University (Haith and Shoemaker, 1987: Haith et al., 1992), provides the ability 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, also can 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 two separate input files, one containing transport parameters, and the other, containing 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-2. 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	21	75	0.0376
Cotton	3030	78	0.0503
Other Small Grains	49	73	0.1821
Rice / Mixed Water Crops	41	74	0.0295
Snap Beans	2	80	0.2153
Sorghum	2	76	0.0359
Soybeans	75	80	0.0423
Fallow Idle Cropland	41	85	0.0349
Winter Wheat	9	73	0.0233
Pasture/Range	907	66	0.0388
Aquaculture	0	100	0.0000
Bottomland Hardwood Forest	204	58	0.0075
Freshwater	67	100	0.0000
Freshwater Scrub/Shrub	23	58	0.0026
Riverine Swamp	161	57	0.0074
Upland Scrub/Shrub	53	66	0.0097
Woods	167	58	0.0202
Urban Pervious	69	71	0.0036
Urban Impervious	8	98	0.0000

Figure A-2. 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 Moon 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 of the lower portion of the Moon Lake watershed were grouped into five categories for model result presentation (Table A-1).

Table A-1. Land Use Categories for the Lower Moon Lake Watershed

Category	**Land Use/Land Cover**	**Area (ha)**	**Area (% of Total)**
Cultivated Agriculture	Cotton, Rice, Corn, Soybeans, Sorghum, Snap Beans, Other Small Grains, Winter Wheat, Fallow	3,383	66%
Noncultivated Agriculture	Pasture, Range	907	18%
Catfish Ponds	Catfish Ponds	0	0%
Residential	Pervious Residential, Impervious Residential	77	1%
Other*	Bottomland Hardwood Forest, Riverine Swamp, Upland Scrub, Woods, Freshwater Scrub, Open Water	741	15%

* Excluding the 948 ha surface area of Moon Lake

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 coverages. 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 USLE 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 each land use area.

- *LS factor:* This factor is a function of the length and grade of the slope from a source area to the water body. The average slope was calculated for each land use area 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-3. 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 (hrs)	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-3. Seasonal Transport Parameters

3.1.3 Global Transport Parameters

Model inputs for the global parameters are shown in Figure A-4. Critical global parameters include the unsaturated water capacity, seepage coefficient, recession coefficient, and sediment delivery ration (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.

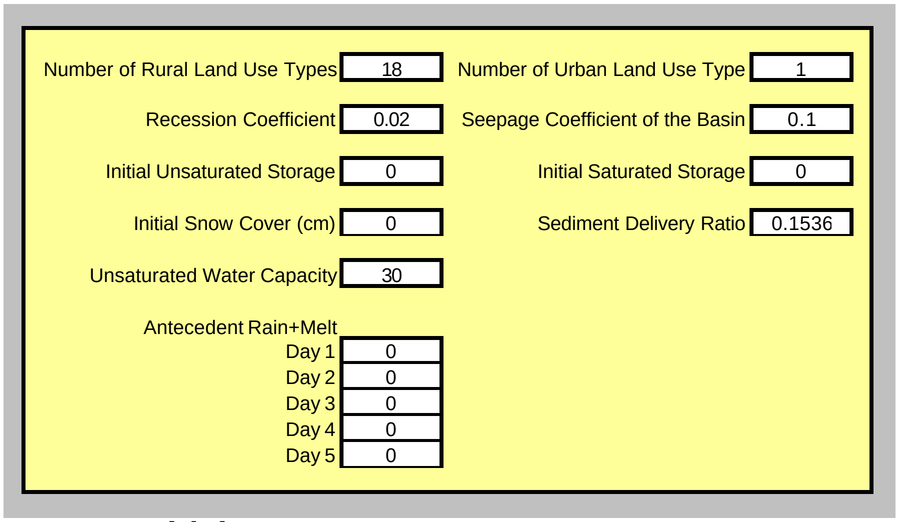

Figure A-4. Global Transport Parameters

3.2 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
Arkabutla Dam	MS0237	Daily Precip	1947 – 2000
Memphis International Airport	WBAN 13893	Daily Max/Min Temp	1948 – 2000

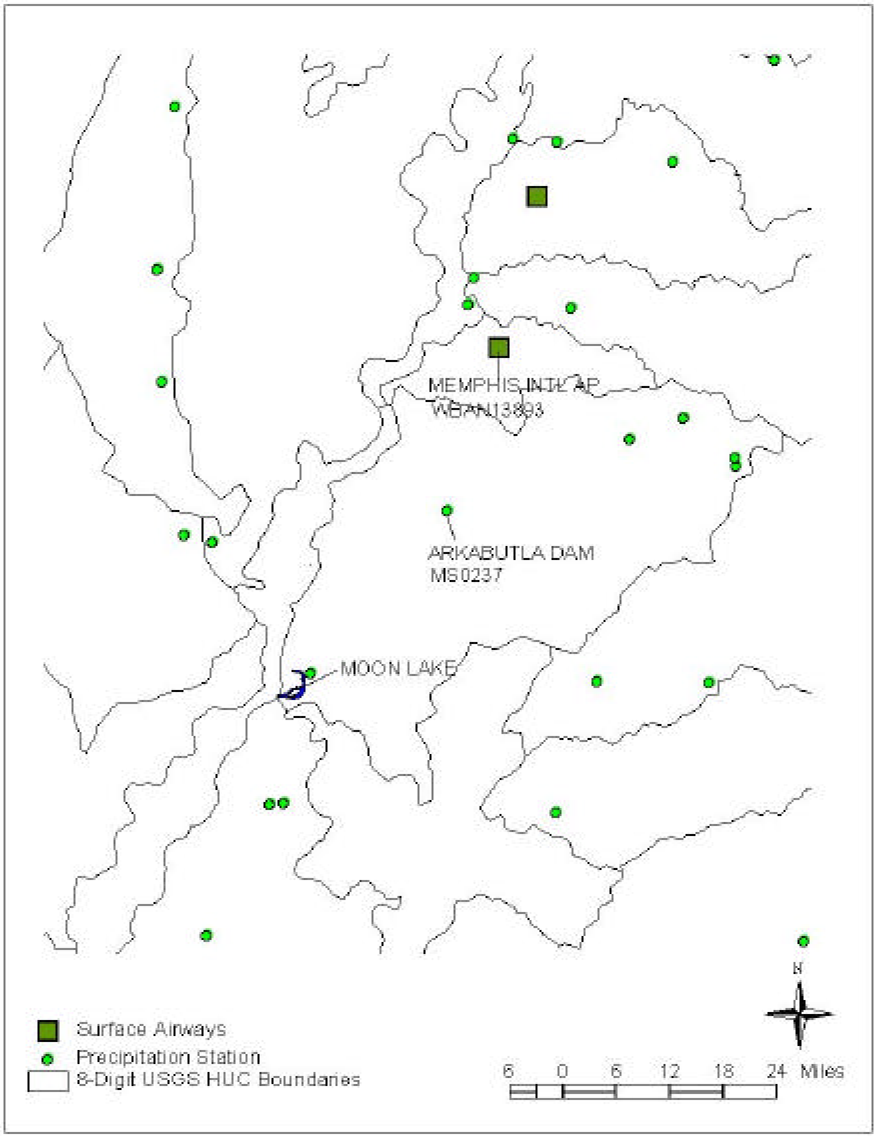

Figure A-5. Precipitation and Temperature Gage Locations

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. The model predicted sedimentation rates that were comparable to those described in Cooper (1989).

5.0 Upper Moon Lake Watershed

The upper portion of the Moon Lake watershed (Figure A-1) covers 17,205 hectares and contains Beaverdam Lake, Beaverdam Bayou, Cypress Lake, Bear Lake, Willow Swamp, and Phillips Bayou. The GWLF model was not used to predict sediment loads for the upper portion of the Moon Lake watershed because of its size and hydrologic complexity.

An average annual sediment load from the upper Moon Lake watershed was derived from daily sediment load and flow measurements taken at sampling location A-1 (Figure A-1) between May 1982 and April 1983 (Cooper, 1989). The total monthly stream flow, total monthly sediment load, and number of observations based on the daily data are presented in Table A-3.

Table A-3. Upper Watershed Observed Stream Flow and Sediment Loads

Month	Stream flow (cm)	Sediment Load (t)	Number of Observations
Jan	34.0	21,528	5
Feb	10.1	3,355	30
Mar	11.8	4,105	26
Apr	6.1	1,426	31
May	0.5	28	30
Jun	0.3	14	31
Jul	0.3	11	30
Aug	3.8	782	31
Sep	1.4	148	31
Oct	1.0	77	28
Nov	1.2	106	31
Dec	28.5	16,590	7
Total	**98.9**	**48,171**	**311**

Source: Cooper, 1989

The monthly precipitation totals during the sampling year (May 1982 through April 1983) show greater variability but are comparable to the average monthly precipitation totals during the modeling period (April 1991 to April 2000) (Figure A-6). The total annual precipitation during the observation year (118 cm) is comparable to the average annual precipitation total during the modeling period (119 cm). December is excluded from the annual precipitation totals for comparison purposes because no precipitation data was available for December 1982 at Arkabutla Dam weather station.

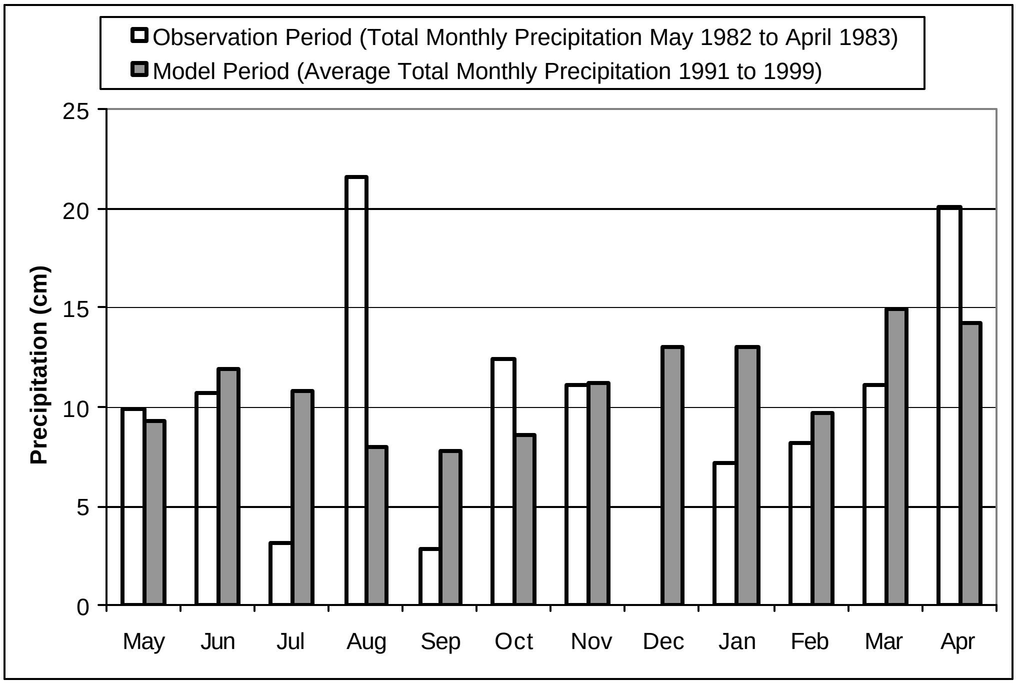

Figure A-6. Total Monthly Precipitation during Observation Year and Modeling Period

The land use and land cover percentages for the upper Moon Lake watershed 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 were grouped into five categories for model results presentation (Table A-4).

Table A-4. Land Use Categories for the Upper Moon Lake Watershed

Category	**Land Use/Land Cover**	**Area (ha)**	**Area (% of Total)**
Cultivated Agriculture	Cotton, Rice, Corn, Soybean, Sorghum, Snap Beans, Other Small Grains, Winter Wheat, Fallow	11,275	66%
Noncultivated Agriculture	Pasture, Range	2,591	15%
Catfish Ponds	Catfish Ponds	238	1%
Residential	Pervious Residential, Impervious Residential	14	<1%
Other	Bottomland Hardwood Forest, Riverine Swamp, Upland Scrub, Woods, Freshwater Scrub, Open Water	3,088	18%

6.0 Upper and Lower Watershed Results

The GWLF model was run for a 9-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 load for April 1991 to March 1999 are shown in Figure A-6. The peak load generally follows the annual precipitation pattern with the highest sediment load occurring in 1997.

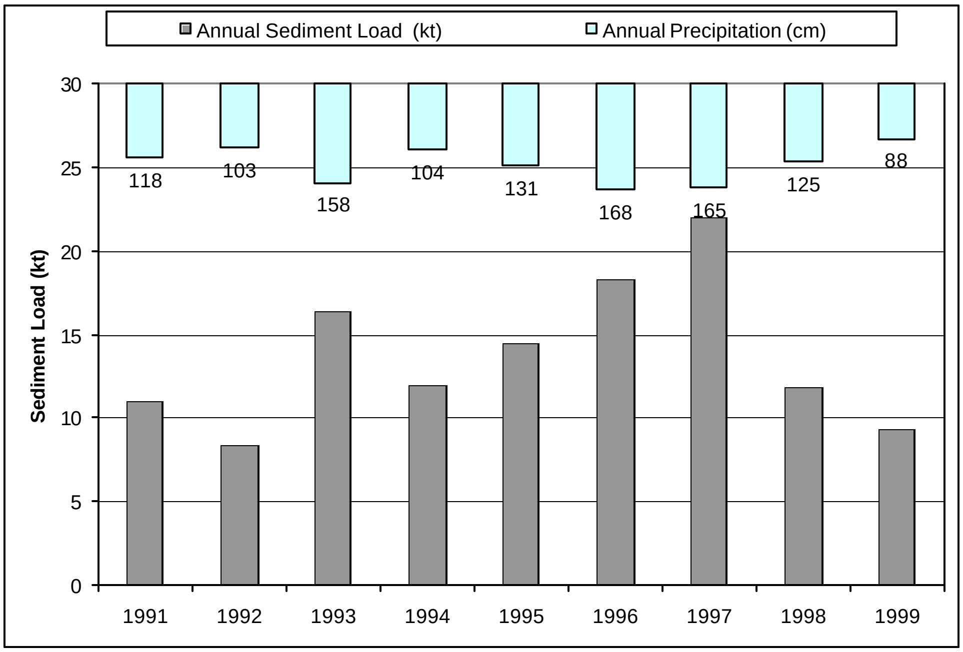

Figure A-7. Predicted Annual Sediment Load and Precipitation for the Lower Watershed

The average monthly sediment loads for the lower watershed, based on the GWLF model results, are shown in Figure A-7. The monthly sediment loads for the upper watershed, based on the daily sediment load observations in 1982 and 1983, are shown in Figure A-8. These are the loads that are assumed to actually reach the lake. The loads from the lower watershed take into account the delivery ratio. These loads generally follow the monthly inflow pattern with the highest sediment load occurring in winter and early spring.

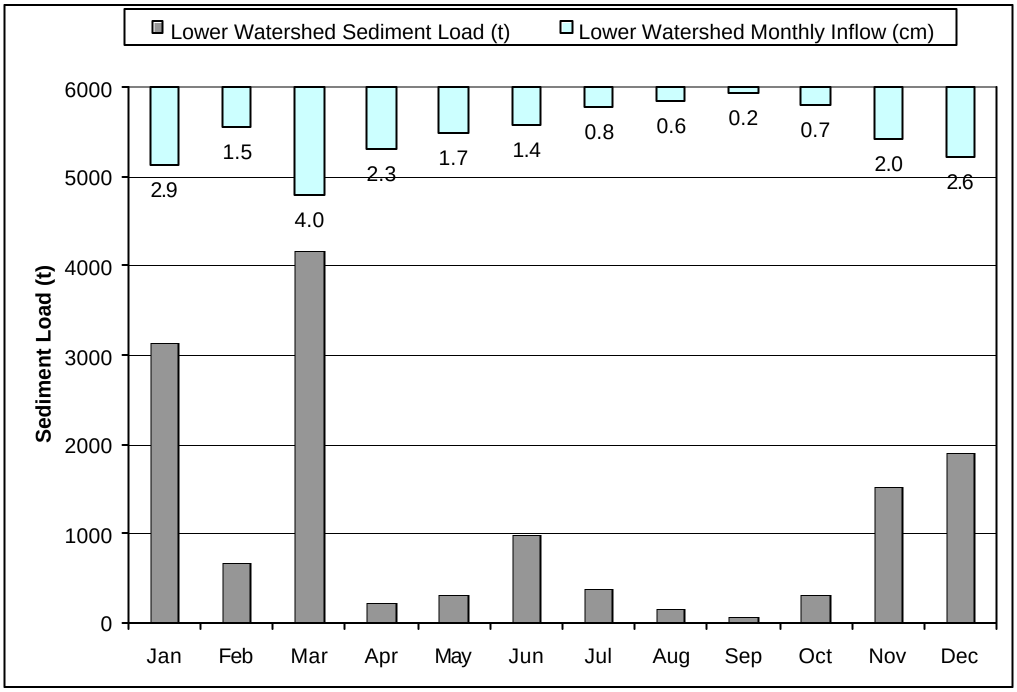

Figure A-8. Predicted Average Monthly Lower Watershed Sediment Load and Inflow

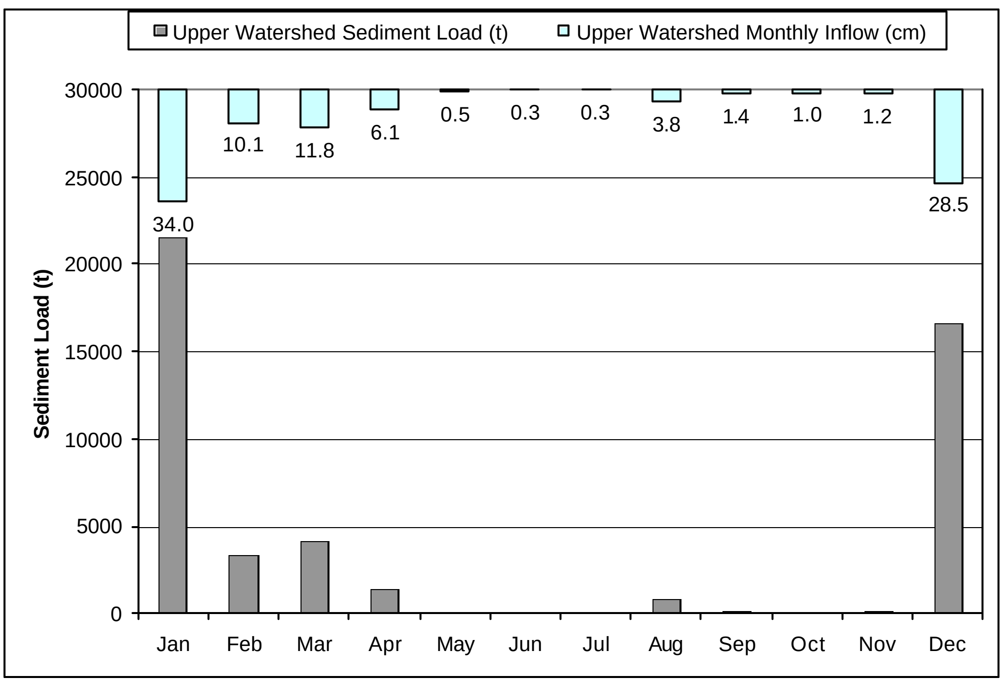

Figure A-9. Observed Average Monthly Upper Watershed Sediment Load and Inflow

7.0 Results

The total annual sediment loads from the lower watershed are based on the GWLF model results. The total annual sediment loads for the upper watershed are based on the sediment load observations described in Section 5.0 and the assumptions described below. The total annual sediment loads by land use category are shown in Table A-5.

The total annual load in the upper watershed is based on observations from the early 1980's. It was assumed that land management practices including reduced tillage, cover crops, and detention ponds were not widely used at this time, therefore the total annual sediment load is assumed to be representative of conventional tillage practices. The GWLF model simulated conventional tillage and moderate tillage scenarios in the lower watershed. The total annual sediment load predicted for moderate tillage practices represents approximately 65 percent of the sediment load predicted for conventional tillage practices. Since the land use distribution in the upper watershed is comparable to the land use distribution in the lower watershed, it was assumed that the total annual sediment loads under current conditions (i.e. moderate tillage practices) represent approximately 65 percent of the total annual sediment loads under conditions during the observation year (i.e. conventional tillage practices) (31,090 t/year of 48,171 t/year).

In order to distribute the sediment contributions to the various land uses in the upper watershed, some assumptions were necessary. The annual sediment load for each land use category in the upper watershed was assumed to represent the same relative percentage of the total annual sediment load in the lower watershed, since the land use distribution in the upper watershed is comparable to the land use distribution in the lower watershed. For example, cultivated agriculture land represents approximately 80 percent of the total annual sediment load in the lower watershed (11,010 t/year of 13,760 t/year). Therefore, cultivated agriculture land was assumed to represent approximately 80 percent of the total annual sediment load in the upper watershed (24,878 t/year of 31,090 t/year).

Table A-5. Lower Watershed, Upper Watershed, and Total Sediment Load

Land Use Category	Lower Watershed Sediment Load (t/year)	Upper Watershed Sediment Load (t/year))	Total Sediment Load (t/year))
Cultivated Agriculture	11,010	24,878	35,888
Noncultivated Agriculture	2,298	5,192	7,489
Catfish Ponds	0	0	0
Residential	16	37	53
Other	435	983	1,419
Total	13,760	31,090	44,850

7.1 Siltation Rate/Estimated Life Span

The siltation rate in Moon 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 until approximately 50 percent of the lake's surface area or approximately 30 percent of the lake volume is lost. At this point the lake in considered "nonfunctioning."

Trap efficiency refers to the ability of lakes and reservoirs to retain a portion of the sediment loading. This efficiency is expressed as the percent of sediment retained compared to 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 trap efficiency for Moon Lake is 89%. The predicted average sedimentation rate for the years 1991 to 1999 is 0.42 cm/year. The estimated lifespan based on the predicted sedimentation rate is 240 years.

Model Scenarios

The GWLF model was run for a total of six 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. The additional scenarios were assumed to have the same relative impact on the sediment loads from the upper and lower watershed. There are many other options available that have not been included in this report. The selected scenarios are described in Table A-6. Table A-7 presents mean annual sediment load and mean annual siltation rate for existing conditions and the additional scenarios.

Table A-6. 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 12% to 50% and agricultural land was reduced from 82% 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 12% to 50% and agricultural land was reduced from 82% to 43% of the watershed area.
	100% Wooded	The wooded area was increased from 12% to 100% of the watershed area.

Table A-7. 1991-1999 Mean Annual Sediment Load

Scenario	Sediment Load (kt)	Siltation Rate (cm/yr)
Conventional Tillage	69.5	0.66
Moderate Tillage (Baseline)	**44.9**	**0.42**
50% Wooded and Moderate Tillage	29.2	0.28
No Tillage	27.8	0.26
50% Wooded and No Tillage	19.7	0.19
100% Wooded	8.2	0.08

The siltation rates and estimated life spans for the existing conditions and additional scenarios are shown in Figures A-9 and A-10, 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).

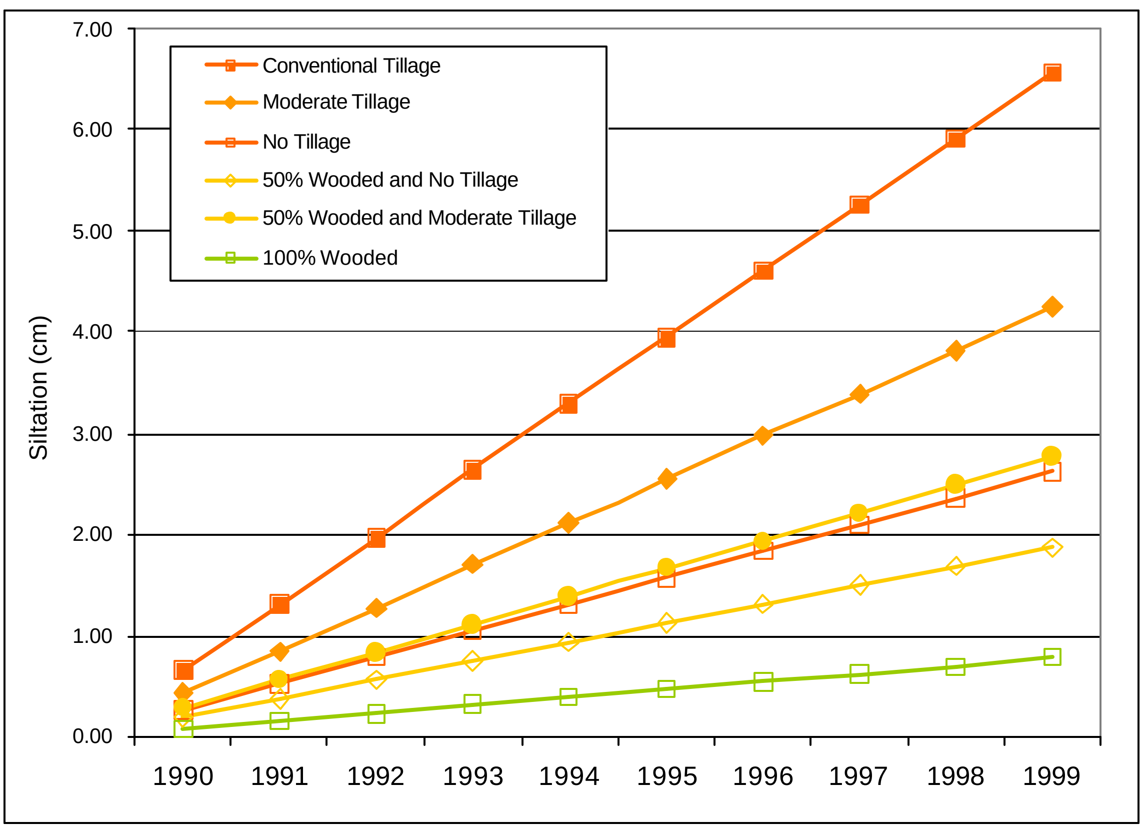

Figure A-10. In-Lake Siltation Existing Conditions and Modeling Scenarios

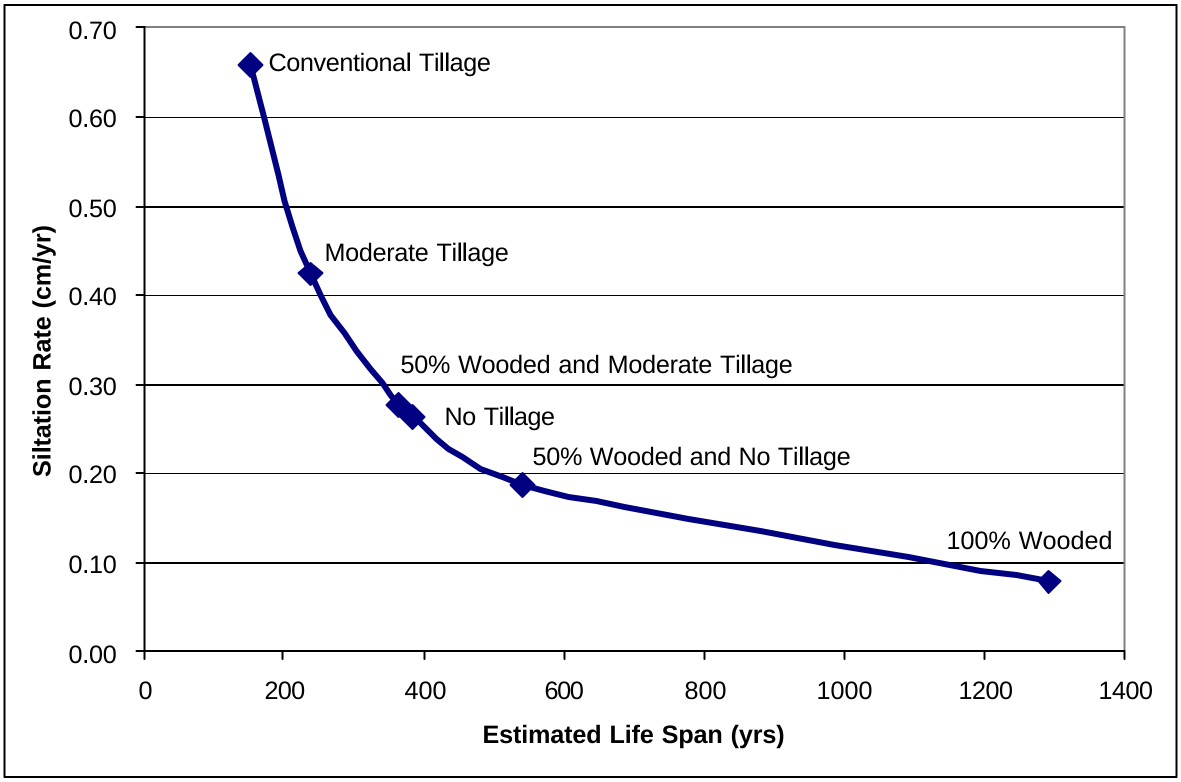

Figure A-11. Estimated Lifespan for Scenarios

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 0.28 cm/year to 0.19 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, this TMDL is 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 Moon Lake watershed. This TMDL encourages 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 A-11, the use of these land management practices will significantly extend the life span of Moon Lake.

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