NUTRIENT TMDLS FOR SIX ARKANSAS LAKES

FINAL
JANUARY 16, 2007

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SIX ARKANSAS LAKES

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EXECUTIVE SUMMARY

Section 303(d) of the Federal Clean Water Act requires states to identify waterbodies that do not meet water quality standards and to develop total maximum daily pollutant loads (TMDLs) for those waterbodies. A TMDL is the amount of a pollutant that a waterbody can assimilate without exceeding the established water quality standard for that pollutant. Through a TMDL, pollutant loads can be allocated to point sources and nonpoint sources discharging to a waterbody.

This report presents TMDLs for nutrients for Bear Creek Lake (an upland reservoir), Mallard Lake (a lowland reservoir), First Old River Lake, Grand Lake, Horseshoe Lake, and Old Town Lake (oxbows). All lakes are located in the Mississippi Alluvial Plain ecoregion, with the exception of First Old River Lake, which is located in the South Central Plains ecoregion. All six lakes were identified by the United States (US) Environmental Protection Agency (EPA) to be in violation of Arkansas' narrative water-quality criteria for nutrients. EPA added these six lakes to the final 2002 303(d) list for Arkansas and they were carried forward to the draft 2004 303(d) list and the final 2004 303(d) list.

This report presents an approach to developing target concentrations for nutrient TMDLs for oxbow lakes and small impoundments. This approach is based on the assumption that target levels must be protective of designated uses. The primary use of concern in these lakes is aquatic life (i.e., sport fisheries). This approach employs a quantitative measure of the potential quality of the sport fishery as an indicator of aquatic life support. Since little quantitative data regarding fisheries is available for Arkansas lakes, this approach relied heavily on data collected by the Bureau of Fisheries of the Mississippi Department of Wildlife, Fisheries, and Parks from selected oxbow lakes in that state. Most of these Mississippi lakes are located in close geographic proximity to the Arkansas study lakes and occur in similar habitats and on similar soil types. Information from Mississippi lakes was augmented by information gathered from Arkansas Game and Fish Commission (AGFC) district fisheries biologists concerning the quality of fishing in the lakes considered in this report. The consensus is that nutrient enrichment is not a major problem in regard to fisheries in four of these lakes. The exceptions to generally healthy fisheries are Old Town Lake and Mallard Lake. Old Town Lake is reported to be nutrient impaired with only catfish being noted as providing good fishing during certain seasons of the year. Mallard Lake is rated “medium low” in fishery quality. Furthermore, Mallard Lake is unique (and somewhat problematic) in that it is bounded by levees on all sides, has no inflow, and no outflow structure.

This analysis suggests that, because of the favorable assessment of the sport fisheries of Horseshoe Lake, First Old River Lake, and Grand Lake, target values of total phosphorus (TP) should be obtained from the Mississippi lakes rated “High” in fishery quality. That is, the professional opinion of AGFC fisheries biologists suggests that there are good fisheries in these three lakes. A TP target concentration of 143 μg/L was used for these three lakes.

For Mallard Lake and Old Town Lake, though, the professional opinion of AGFC fisheries biologists suggests that the fisheries in these two lakes are less desirable. Accordingly, a TP target concentration of 80 μg/L was used for these two lakes.

Bear Creek Lake is unique among the lakes examined in this study. This upland impoundment is less nutrient-enriched than others considered here and generally displays excellent water quality. Using the approach described above, a target TP concentration of 90 μg/L was used for Bear Creek Lake. Target TP concentrations are summarized in Table ES.1.

Table ES.1. TP target concentrations and TMDLs for six Arkansas lakes.

Lake Name	**Target TP Conc. (μg/L)**	**Allowable Loads of TP**				**Percent Reduction Needed**
		WLA (kg/yr)	**LA (kg/yr)**	**MOS (kg/yr)**	**TMDL (kg/yr)**	
Bear Creek Lake	90	0	905	100	1,005	0%
First Old River	143	0	427	48	475	21%
Horseshoe Lake	143	0	3,045	338	3,383	0%
Grand Lake	143	0	1,787	199	1,986	11%
Old Town Lake	80	0	2,758	306	3,064	73%
Mallard Lake	80	0	151	17	168	50%

Target concentrations of nitrogen were not developed because analysis of water quality data for these lakes indicated that growth of algae appears to be limited by phosphorus rather than nitrogen in all six lakes.

After the target TP values were developed, each TMDL was calculated using an average annual mass balance. The mass balance assumed that not all of the inflow TP would end up in the water column of the lake due to settling of particulate matter. The fraction of inflow TP that would be lost was based on TP mass budgets for several EPA Clean Lakes studies on oxbow lakes in the Mississippi Alluvial Plain ecoregion.

Ten percent of the allowable TP load for each lake was set aside as an explicit margin of safety (MOS). Because there were no point source discharges in any of the watersheds for these six lakes, the wasteload allocation (WLA) was zero for each lake. The remaining allowable load for each lake was assigned to the load allocation (LA) for nonpoint sources.

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1.0 INTRODUCTION

This report presents total maximum daily loads (TMDLs) for nutrients for Bear Creek Lake, First Old River Lake, Grand Lake, Horseshoe Lake, Mallard Lake, and Old Town Lake. These lakes are located in the southwestern and eastern portions of Arkansas (see Figure A.1 located in Appendix A). The six lakes included in this study were identified by the United States (US) Environmental Protection Agency (EPA) to be in violation of Arkansas' narrative water-quality criteria for nutrients. EPA added these six lakes to the final 2002 303(d) list for Arkansas (EPA 2003) and they were carried forward to the draft 2004 303(d) list (ADEQ 2005a) and the final 2004 303(d) list (EPA 2006). Information from the listing for these six lakes is summarized in Table 1.1.

The purpose of a TMDL is to determine the pollutant loading that a waterbody can assimilate without exceeding the water quality standard for that pollutant and to establish the load reduction that is necessary to meet the standard in a waterbody. The TMDL is the sum of the wasteload allocation (WLA), the load allocation (LA), and a margin of safety (MOS). The WLA is the load allocated to point sources of the pollutant of concern. The LA is the load allocated to nonpoint sources, including natural background sources. The MOS is a percentage of the TMDL that takes into account any lack of knowledge concerning the relationship between pollutant loadings and water quality.

Table 1.1. 303(d) listing for six lakes in this report (ADEQ 2005a).

Lake Name	HUC*	Impaired Use	Sources	Causes	Category	Priority
Bear Creek Lake	08020203	Aquatic Life	Unknown	Nutrients	5A	Medium
First Old River Lake	11140201	Aquatic Life	Unknown	Nutrients	5A	Medium
Grand Lake	08050002	Aquatic Life	Unknown	Nutrients	5A	Medium
Horseshoe Lake	08020203	Aquatic Life	Unknown	Nutrients	5A	Medium
Mallard Lake	08020204	Aquatic Life	Unknown	Nutrients	5A	Medium
Old Town Lake	08020303	Aquatic Life	Unknown	Nutrients	5A	Medium

*Note: The HUCs for Bear Creek Lake, Mallard Lake, and Old Town Lake were specified incorrectly in the 2004 303(d) list.

2.0 DESCRIPTION OF LAKES

The six lakes addressed in this report are listed in Table 1.1. A map showing the locations of these lakes is included as Figure A.1 (Appendix A). Theses lakes are all located in the Mississippi Alluvial Plain ecoregion except for First Old River Lake, which is located in the South Central Plains ecoregion (Omernik and Gallant 1987). Three distinct lake types were evaluated - four lakes are oxbows associated with former channels of the Red and Mississippi Rivers, one lake is a lowland reservoir, and one lake is an upland reservoir. Background information pertaining to each lake is presented in the following sections.

The acreage of each lake mentioned in the following sections generally corresponds to the size of the lake at the normal water surface elevation. The water level in each lake may have been lower or higher than normal when the summer 2004 satellite imagery was generated (the imagery upon which the land use data are based). This caused some of the percentages of open water in the land use tables to be different than what would be calculated based on the lake acreages at normal water surface elevations.

2.1 Bear Creek Lake

Bear Creek Lake is an upland impoundment located on Crowley’s Ridge in the Mississippi Alluvial Plain ecoregion. This lake is within the St. Francis National Forest in eastern Arkansas and located approximately 10 miles southeast of Marianna (Lee County). This upland impoundment is approximately 625 acres in size with a maximum depth of approximately 40 ft. The watershed size is approximately 3,858 acres. A map of the Bear Creek Lake watershed is included as Figure A.2 (Appendix A). Bear Creek Lake was constructed specifically for public fishing with other types of recreation as secondary activities. The Arkansas Game and Fish Commission (AGFC) district fisheries biologist reports that the lake supports moderate to high game fish populations and excellent water clarity (telephone interview with Jeff Farwick, AGFC District 4 fisheries biologist, October 2006).

2.1.1 Land Use

Historical land use within the Bear Creek Lake watershed was oak-hickory upland forest (Shepard et al., 1984). Recent land use and land cover data were obtained from the University of Arkansas Center for Advanced Spatial Technologies and based on 2004 imagery. The current primary land use in this watershed is forest (hardwood and pine) and the majority of acreage is managed by the St. Francis National Forest. A small percentage (4%) is in pasture/grass while only a very small percentage (0.1%) of urban area is located within the watershed. A map of land use for the watershed is included as Figure B.1 (Appendix B). A summary of land use statistics for the watershed is presented in Table 2.1.

Table 2.1. Summary of land use statistics for Bear Creek Lake watershed.

Category	Percentage of watershed
Urban	0.1%
Barren	2.6%
Water	9.7%
Forest	79.3%
Soybeans	3.4%
Rice	0.0%
Cotton	0.0%
Corn	0.1%
Other crops	0.0%
Fallow	0.8%
Pasture/grass	4.0%
Total	**100.0%**

2.1.2 Hydrology, Soils, and Topography

Average annual precipitation at Bear Creek Lake is approximately 51 inches per year; annual runoff is estimated at 21 inches per year (Freiwald 1984). Bear Creek Lake is located on Crowley’s Ridge, an upland ridge system occurring in the Mississippi Alluvial Plain. Soils within the watershed are reported to be moderate in natural fertility. Soils are mapped as Memphis-Natchez association; soils in this association are loamy, and formed in thick, wind-laid sediments (loess) on uplands characterized by narrow ridge tops with steep sides. The major soils types occurring within the Bear Creek Lake watershed are Memphis silt loam and Loring silt loam. Memphis silt loam (MeF) is described as well drained, moderately permeable, with slopes ranging from 15 to 40%. Loring silt loam (LoC2) is described as well drained to moderately well drained, with slopes ranging from 3 to 8 percent (USDA 1977).

2.1.3 Nonpoint Sources

There is no published documentation for anthropogenic or background nonpoint sources of nutrients for Bear Creek Lake. Based on land use data, anthropogenic nonpoint sources of nutrients should be minimal for Bear Creek Lake.

2.1.4 Point Sources

There are no point source discharges in the Bear Creek Lake watershed according to information in the Arkansas 2004 305(b) report (ADEQ 2005b) and EPA's Permit Compliance System web site (PCS 2006).

2.2 First Old River Lake

First Old River Lake is an oxbow located in the South Central Plains ecoregion near the Red River, approximately 15 miles east of Texarkana, Arkansas. The county line between Miller and Hempstead Counties bisects the lake. This oxbow is approximately 227 acres in size with a maximum depth of approximately 14 ft. The watershed size is approximately 1,188 acres. A map of the First Old River Lake watershed is included as Figure A.3 (Appendix A). The primary public activities on this lake are recreational and commercial fishing. The AGFC district fisheries biologist reports that the lake supports good game fish populations and features exceptional crappie fishing. A special commercial fishing season is in effect for this lake from November to February (telephone interview with Drew Wilson, AGFC District 7 fisheries biologist, October 2006).

2.2.1 Land Use

Historical land use within the First Old River Lake watershed was bottomland hardwood (Justus 2006). Recent land use and land cover data were obtained from the University of

Arkansas Center for Advanced Spatial Technologies and based on 2004 imagery. The current primary land uses in this watershed are cropland and pasture/grass. A small amount of the watershed is forested and no urban areas are located within the watershed. A map of land use for the watershed is included as Figure B.2 (located in Appendix B). A summary of land use statistics for the watershed is presented in Table 2.2.

Table 2.2. Summary of land use statistics for First Old River Lake watershed.

Category	Percentage of watershed
Urban	0.0%
Barren	0.3%
Water	20.7%
Forest	12.4%
Soybeans	6.5%
Rice	0.8%
Cotton	0.0%
Corn	0.0%
Other crops	35.8%
Fallow	0.2%
Pasture/grass	23.3%
Total	**100.0%**

2.2.2 Hydrology, Soils, and Topography

Average annual precipitation at First Old River Lake is approximately 47 inches per year; annual runoff is estimated at 12 inches per year (Freiwald 1984). Soils located within the watershed are all reported to be high in natural fertility. The Hempstead County portion of the watershed is mapped as Oklared fine sandy loam. These soils are reported to be well drained, moderately rapidly permeable, nearly level soils on flood plains of the Red River (USDA 1979). Predominate soils located within the Miller County portion of the watershed are mapped as Severn silt loam. This soil type is described as deep, well drained, and level to gently undulating. Latanier clay soils also occur within the watershed. These soils are described as deep, somewhat poorly drained with slopes ranging from 0 to 3 percent (USDA 1984).

2.2.3 Nonpoint Sources

Based on land use data, nonpoint sources of nutrients for First Old River Lake include runoff from cropland and pastures as well as waste generated by cattle production.

2.2.4 Point Sources

There are no point source discharges in the First Old River Lake watershed according to information in the Arkansas 2004 305(b) report (ADEQ 2005b) and EPA's Permit Compliance System web site (PCS 2006).

2.3 Horseshoe Lake

Horseshoe Lake is an oxbow located in the Mississippi Alluvial Plain ecoregion near the Mississippi River in Crittenden County, Arkansas. This lake is located approximately 20 miles southwest of West Memphis. The lake is approximately 2,447 acres in size with a maximum depth of approximately 30 ft. The watershed size is approximately 9,296 acres. A map of the Horseshoe Lake watershed is included as Figure A.4 (Appendix A). The primary public activities on this lake are recreational fishing, water skiing, and swimming. A small lakeside community is located near the southeast terminus of the lake. The AGFC district fisheries biologist reports that fishing is generally good in this lake, but fluctuations in lake levels are common and fish recruitment/spawning success is directly affected by lake depth (telephone interview with Jeff Farwick, AGFC District 4 fisheries biologist, October 2006).

2.3.1 Land Use

Historical land use within the Horseshoe Lake watershed was bottomland hardwood (Justus 2006). Recent land use and land cover data were obtained from the University of Arkansas Center for Advanced Spatial Technologies and based on 2004 imagery. The current primary land uses in this watershed are cropland and forest. A small amount of urban area (approximately 1.8%) is located within the watershed. A map of land use for the watershed is included as Figure B.3 (located in Appendix B). A summary of land use statistics for the watershed is presented in Table 2.3.

Table 2.3. Summary of land use statistics for Horseshoe Lake watershed.

Category	Percentage of watershed
Urban	1.8%
Barren	2.0 %
Water	28.9%
Forest	33.7%
Soybeans	15.7%
Rice	0.4%
Cotton	14.6%
Corn	0.8%
Other Crops	0.0%
Fallow	0.4%
Pasture/grass	1.7%
Total	**100.0%**

2.3.2 Hydrology, Soils, and Topography

Average annual precipitation at Horseshoe Lake is approximately 51 inches per year; annual runoff is estimated at 21 inches per year (Freiwald 1984). Major soil associations located within the watershed are mapped as Sharkey and Commerce-Robinsonville. These soils are reported to be high in natural fertility. The Sharkey association is comprised of poorly drained, clayey soils; these soils are level to gently undulating. The Commerce-Robinsonville association is characterized by somewhat poorly drained to well drained loamy soils on young natural levees; these soils feature level topography. Specific soil types in the watershed include Tunica clay (Tu), Bowdre silty clay (Bw), Commerce silt loam (Cm) and Sharkey silty clay (Sk) (USDA 1974a).

2.3.3 Nonpoint Sources

Based on land use data, nonpoint sources of nutrients for Horseshoe Lake include runoff from fertilized cropland. A small lakeside community is present near the southeast end of the lake; this area is a likely source of stormwater runoff and septic system effluent.

2.3.4 Point Sources

There are no point source discharges in the Horseshoe Lake watershed according to information in the Arkansas 2004 305(b) report (ADEQ 2005b) and EPA's Permit Compliance System web site (PCS 2006).

2.4 Grand Lake

Grand Lake is an oxbow located in the Mississippi Alluvial Plain ecoregion near the Mississippi River in Chicot County, Arkansas. The lake is located about three miles southeast of Eudora, Arkansas. Grand Lake is approximately 1,130 acres in size with a maximum depth of approximately 16 ft. The watershed size is approximately 5,150 acres. A map of the Grand Lake watershed is included as Figure A.5 (Appendix A). The primary public activity on Grand Lake is recreational fishing. The AGFC district fisheries biologist reports that crappie populations have been studied at the lake over the past five years and that Grand Lake is one of the best crappie fishing lakes in Arkansas. Good populations of other fish species are also reported to be present in the lake (telephone interview with Diana Andrews, AGFC District 5 fisheries biologist, October 2006).

2.4.1 Land Use

Historical land use within the Grand Lake watershed was bottomland hardwood (Justus 2006). Recent land use and land cover data were obtained from the University of Arkansas Center for Advanced Spatial Technologies and based on 2004 imagery. The current primary land use in this watershed is cropland. A map of land use for the watershed is included as Figure B.4 (located in Appendix B). A summary of land use statistics for the watershed is presented in Table 2.4.

2.4.2 Hydrology, Soils, and Topography

Average annual precipitation at Grand Lake is approximately 53 inches per year; annual runoff is estimated at 17 inches per year (Freiwald 1984). Soils within the watershed are reported to be high in natural fertility. Soils within this watershed are mapped as Sharkey-Bowdre association on general soil maps. These soils are described as level to gently undulating, poorly drained and moderately well drained clayey soils that formed in Mississippi River alluvium. Predominant soil types within the watershed include Bowdre silty clay loam (BoA and BoU) and Sharkey clay (ShA). BoA soils are described as moderately well drained silty clay loam with slopes ranging from 0 to 1 percent while BoU soils are similar to BoA soils except that topography is gently undulating. ShA soils are poorly drained clay soils with 1 to 3 percent slopes (USDA 1967).

Table 2.4. Summary of land use statistics for Grand Lake watershed.

Category	Percentage of watershed
Urban	0.0%
Barren	0.0%
Water	23.0%
Forest	19.4%
Soybeans	44.8%
Rice	0.1%
Cotton	6.4%
Corn	2.4%
Other crops	0.6%
Fallow	2.8%
Pasture/grass	0.5%
Total	**100.0%**

2.4.3 Nonpoint Sources

Based on land use data, nonpoint sources of nutrients for Grand Lake include runoff from fertilized cropland.

2.4.4 Point Sources

There are no point source discharges in the Grand Lake watershed according to information in the Arkansas 2004 305(b) report (ADEQ 2005b) and EPA's Permit Compliance System web site (PCS 2006).

2.5 Mallard Lake

Mallard Lake is a lowland impoundment located on the east side of Big Lake National Wildlife Refuge and the south side of Big Lake Wildlife Management Area. The location of Mallard Lake is approximately four miles east of Manila, Arkansas (Mississippi County). This lake is in the Mississippi Alluvial Plain ecoregion. Mallard Lake is approximately 320 acres in size with a maximum water depth of approximately 11 ft. Since the lake is bounded by man-made levees on all sides, the watershed size is essentially the same as the lake size. A map of the Mallard Lake watershed is included as Figure A.6 (Appendix A). The lake was constructed as a public fishing lake. Historically Mallard Lake was a productive fishery, producing the state record largemouth bass in 1976. Since that time, the lake has declined as a fishery and several projects have been completed in an attempt to improve this resource. The AGFC district fisheries biologist reports that species composition in Mallard Lake has shifted away from sport fish with “rough” fish such as drum and shad being predominant. Tilapia has also been recently introduced to the lake. The overall fishing quality in the lake is reported at medium to low with some large game fish present, but low overall numbers (telephone interview with Sam Barkley, AGFC District 3 Fisheries Biologist, October 2006).

2.5.1 Land Use

Historical land use within the Mallard Lake watershed was bottomland hardwood (Justus 2006). This area is part of the sunken lands region of northeast Arkansas, a low elevation area formed by the New Madrid earthquake in the winter of 1811-1812 (Shelford 1974). This unique geologic condition resulted in the formation of lakes and forested wetlands dominated by bald cypress (*Taxodium distichum*) and water tupelo (*Nyssa aquatica*). Since levees form the lake and watershed boundaries, water is the only land use within the watershed except a thin strip of land consisting of the inside slope of the levees. A map of land use for the watershed is included as Figure B.5 (located in Appendix B). A summary of land use statistics is not shown for the Mallard Lake watershed because it consists almost entirely of open water.

2.5.2 Hydrology, Soils, and Topography

Average annual precipitation at Mallard Lake is approximately 47 inches per year; annual runoff is estimated at 21 inches per year (Freiwald 1984). There are no surface water connections between Mallard Lake and other waters. Water in Mallard Lake is supplied by rainfall and pumping from a large drainage ditch located on the west side of the impoundment. Soils at Mallard Lake are mapped as Sharkey and Steele (Sn). These soils are reported to have moderate to high natural fertility. This mapping unit consists of poorly drained Sharkey soils and moderately well drained Steele soils. These soils are found in the sunken lands area near Big Lake in northeast Arkansas. These soils are mainly level with some moderate undulations present (USDA 1971).

2.5.3 Nonpoint Sources

There is no published documentation for anthropogenic or background nonpoint sources of nutrients for Mallard Lake.

2.5.4 Point Sources

There are no point sources discharges draining into Mallard Lake.

2.6 Old Town Lake

Old Town Lake is an oxbow located in the Mississippi Alluvial Plain ecoregion near the Mississippi River in Phillips County, Arkansas. The lake is located about 15 miles southwest of Helena. Old Town Lake is approximately 1,600 acres in size with a maximum depth of approximately 6 ft. The watershed size is approximately 12,700 acres. A map of the Old Town Lake watershed is included as Figure A.7 (Appendix A). The primary public activity on this lake is recreational fishing. Several older residences are located along the shoreline of the lake. AGFC fisheries biologists report that the lake is eutrophic, with low water clarity, and that fishing for channel catfish is good during certain seasons of the year (telephone interview with Jeff Farwick, AGFC District 4 fisheries biologist, October 2006).

2.6.1 Land Use

Historical land use within the Old Town Lake watershed was bottomland hardwood (Justus 2006). Recent land use and land cover data were obtained from the University of Arkansas Center for Advanced Spatial Technologies and based on 2004 imagery. The current primary land use in this watershed is row crop farming with over 70% of the watershed in cotton, soybeans, rice, and corn. About 13% of the watershed is forested, primarily in lower elevation areas not suited for agricultural operations. Approximately 1% of the watershed is classified as urban, with the majority of residential structures occurring along the shoreline of the lake. A map of land use for the watershed is included as Figure B.6 (located in Appendix B). A summary of land use statistics for the watershed is presented in Table 2.5.

Table 2.5. Summary of land use statistics for Old Town Lake watershed.

Category	Percentage of watershed
Urban	0.9%
Barren	2.7%
Water	9.8%
Forest	13.7%
Soybeans	37.2%
Rice	1.1%
Cotton	26.9%
Corn	6.0%
Other crops	0.3%
Fallow	0.6%
Pasture/grass	0.8%
Total	**100.0%**

2.6.2 Hydrology, Soils, and Topography

Average annual precipitation at Old Town Lake is approximately 51 inches per year; annual runoff is estimated at 21 inches per year (Freiwald 1984). A complex array of soil types occurs in the Old Town lake watershed. Most of these soils are reported to be high in natural fertility. Major soil associations are the Sharkey association and the Dubbs-Dundee association. The Sharkey association is described as poorly drained, clayey soils with level topography.

Dubbs-Dundee association soils are well drained to somewhat poorly drained loamy soils with level to gently undulating topography (USDA 1974b).

2.6.3 Nonpoint Sources

Several older residences are present in the immediate vicinity of the lake. Some of these structures are permanent dwellings while others serve as fishing camps. Due to the age of these structures, it is likely that inadequate septic systems are a potential source of nonpoint nutrient inputs to Old Town Lake. Additionally, intensive agricultural production in the watershed is a likely source of nutrient inputs via runoff from fertilized cropland.

2.6.4 Point Sources

There are no point source discharges in the Old Town Lake watershed according to information in the Arkansas 2004 305(b) report (ADEQ 2005b) and EPA's Permit Compliance System web site (PCS 2006).

2.7 Water Quality Standards

Water quality standards that apply to each of these six lakes are given in Arkansas Regulation No. 2 (Arkansas Pollution Control and Ecology Commission (APCEC) 2006). The designated uses for each lake are primary contact recreation; secondary contact recreation; domestic, industrial and agricultural water supply; and perennial fishery. According to Section 2.302 (F)(2) of Regulation No. 2, the designated use of fisheries for lakes and reservoirs is described as follows:

> "Water which is suitable for the protection and propagation of fish and other forms of aquatic life adapted to impounded waters. Generally characterized by a dominance of sunfishes such as bluegill or similar species, black basses and crappie. May include substantial populations of catfishes such as channel, blue and flathead catfish and commercial fishes including carp, buffalo and suckers. Forage fishes are normally shad or various species of minnows. Unique populations of walleye, striped bass and/or trout may also exist."

For nutrients, the Arkansas water quality standards have narrative criteria but not numeric criteria. The narrative criteria for nutrients in Arkansas are as follows:

> "Materials stimulating algal growth shall not be present in concentrations sufficient to cause objectionable algal densities or other nuisance aquatic vegetation or otherwise impair any designated use of the waterbody. Impairment of a waterbody from excess nutrients are dependent on the natural waterbody characteristics such as stream flow, residence time, stream slope, substrate type, canopy, riparian vegetation, primary use of waterbody, season of the year and ecoregion water chemistry. Because nutrient water column concentrations do not always correlate directly with stream impairments, impairments will be assessed by a combination of factors such as water clarity, periphyton or phytoplankton production, dissolved oxygen values, dissolved oxygen saturation, diurnal dissolved oxygen fluctuations, pH values, aquatic-life community structure and possibly others. However, when excess nutrients result in an impairment, based upon Department assessment methodology, by any established, numeric water quality standard, the waterbody will be determined to be impaired by nutrients."

Regulation No. 2 also includes requirements concerning phosphorus from point source dischargers in nutrient surplus areas, but none of the six lakes in this report is within nutrient surplus areas that have been designated by the Arkansas Natural Resources Commission (ANRC 2005).

As specified in EPA's regulations 40 CFR 130.7(b)(2), applicable water quality standards include antidegradation requirements. Arkansas' antidegradation policy is listed in Sections 2.201 through 2.204 of Regulation No. 2. These sections impose the following requirements:

- Existing instream water uses and the level of water quality necessary to protect the existing uses shall be maintained and protected.
- Water quality that exceeds standards shall be maintained and protected unless allowing lower water quality is necessary to accommodate important economic or social development, although water quality must still be adequate to fully protect existing uses.

- For outstanding state or national resource waters, those uses and water quality for which the outstanding waterbody was designated shall be protected.
- For potential water quality impairments associated with a thermal discharge, the antidegradation policy and implementing method shall be consistent with Section 316 of the Clean Water Act.

2.8 Previous Studies

2.8.1 ADEQ Five Year Lake Studies

ADEQ has conducted water quality studies of significant publicly owned lakes every five years since 1989. All six lakes addressed in this TMDL report were included in the ADEQ studies. The ADEQ studies provide background information and discussions of each lake, as well as results from one water quality-sampling event at each lake every five years (ADEQ 2000). Data were collected in 2004 but no report has been published yet.

2.8.2 USGS Water Quality Study of Eleven Lakes

This report documents methods used and describes the results for a water quality study at 11 lakes in Arkansas, including the six lakes addressed in this TMDL report. The study was conducted by the US Geological Survey (USGS) in cooperation with EPA. The scope of the project included lake reconnaissance, selection of the two reference lakes, a 48-hour dissolved oxygen investigation, water quality sampling in the 11 lakes between August 2004 - July 2005, and a basic interpretation of the data (Justus 2006). EPA used the results of this study to confirm their determination of impairment for the six lakes addressed in this TMDL report.

2.8.3 Arkansas Water Resources Research Center Report 1981

This report documents water quality and aquatic life resources at Old Town Lake and provides insight into previous conditions at this lake (Arkansas Water Resources Research Center 1981).

3.0 EXISTING WATER QUALITY

3.1 Overview

The available water quality and fisheries data that are relevant to the nutrient TMDLs in this report consist of diurnal in situ data collected by the USGS, water quality sampling data from the USGS and ADEQ studies (nutrients and chlorophyll), and qualitative fisheries information from AGFC biologists. These data and information are summarized in the following sections.

3.2 USGS Diurnal In Situ Data

During August 2004, the USGS conducted 48-hour investigations of dissolved oxygen and pH at the six lakes addressed in this TMDL report plus Stave Lake, which was selected as a reference lake and is located near the Mississippi River in northeastern Arkansas. Results from these investigations state:

> "Dissolved-oxygen (and, to a lesser extent, pH) data for the 48-hour investigation demonstrate large diurnal fluctuations at five of the seven nutrient lakes, and concentrations declined below the State standard of 5 mg/L for six of the seven lakes. Large diurnal fluctuations were apparent at First Old River, Grand, Horseshoe, Mallard, and Old Town Lakes. Dissolved-oxygen concentrations also declined below 4 mg/L for varying periods at those same five lakes, and were less than 1.5 mg/L at Mallard Lake and Grand Lake for short periods near daybreak. Dissolved-oxygen fluctuations were smaller at Stave Lake and Bear Creek Lake, and never declined below 4 mg/L. Heavy cloud cover that was prevalent for the first 24-hours of the 48-hour investigation may have influenced dissolved oxygen at Mallard Lake and concentrations never exceeded 5 mg/L.
>
> Comparing data collected in the 48-hour monitoring period to ADEQ criteria, dissolved-oxygen concentration declined below the State standard of 5 mg/L at some time in the monitoring period at all lakes (including Stave Lake) except Bear Creek Lake. The State pH standard of "9" was exceeded at all lakes except Stave Lake" (Justus 2006).

Appendix C1 shows an excerpt from the USGS report including plots of continuous in situ data collected during 48-hour investigations.

3.3 Nutrients and Chlorophyll

Measured concentrations of total phosphorus (TP), total nitrogen (TN) and chlorophyll a were compiled from the ADEQ and USGS studies and are summarized in Table 3.1. Individual values are listed in Appendix C2. These TP and TN data are reported here in units of mg/L rather than μg/L because the ADEQ and USGS reports published the data in units of mg/L. Ratios of TN to TP were plotted to determine which nutrient was limiting in each lake (Figure 3.1). Old Town Lake had the highest average concentrations for TN, TP, and chlorophyll a. High concentrations for TN and TP were also observed at First Old River Lake. TN, TP, and chlorophyll a concentrations were lowest at Bear Creek Lake.

The analysis of TN:TP ratios at each lake revealed that phosphorus is the limiting nutrient for algal growth in all of the lakes addressed in this report. Median values for TN: TP ratios above 10 indicate phosphorus limited conditions, while values less than four indicate nitrogen limited conditions (Wetzel 1983).

3.4 Fisheries Information

Little quantitative data are available to characterize the fisheries in these lakes. Because of this, personal interviews were conducted with various AGFC district fisheries biologists. The consensus is that nutrient enrichment is generally not a major problem in regard to fisheries in these lakes. In fact, exceptional crappie fisheries are reported for Grand Lake and First Old River Lakes (telephone interviews with Diana Andrews, AGFC District 5 fisheries biologist and Drew Wilson, AGFC District 7 fisheries biologist, October 2006). The exceptions to generally healthy fisheries are Old Town Lake and Mallard Lake. Old Town Lake is reported to be “eutrophic, shallow, and soupy green” at certain times, with only catfish being noted as providing good fishing during certain seasons of the year (telephone interview with Jeff Farwick, AGFC District 4 fisheries biologist).

Mallard Lake is rated “medium low” in fishery quality and has experienced a shift in species composition from desirable game fish (i.e. bass, crappie, bream) to less desirable “rough fish” such as drum and shad (telephone interview with Sam Barkley, AGFC District 3 Fisheries Biologist, October 2006).

Table 3.1. Water quality statistics based on combined data from USGS and ADEQ.

	Total N (mg/L)	Total P (mg/L)	Chlorophyll a (μg/L)*
Bear Creek Lake			
Number of data	9	13	12
Mean	0.95	0.04	25.1
Maximum	1.56	0.12	72.2
Minimum	0.66	0.03	9.8
First Old River Lake			
Number of data	10	13	12
Mean	2.09	0.18	86.7
Maximum	3.63	0.45	264
Minimum	0.98	0.03	13.4
Grand Lake			
Number of data	19	22	21
Mean	1.85	0.16	108
Maximum	3.29	0.33	344
Minimum	0.73	0.05	34.0
Horseshoe Lake			
Number of data	18	22	21
Mean	1.21	0.08	60.9
Maximum	1.88	0.18	170
Minimum	0.69	0.03	13.4
Mallard Lake			
Number of data	10	13	12
Mean	2.11	0.16	70.0
Maximum	3.05	0.28	227
Minimum	1.30	0.08	7.3
Old Town Lake			
Number of data	9	13	12
Mean	3.06	0.30	167
Maximum	4.98	0.68	409
Minimum	0.82	0.11	55.3

*ADEQ chlorophyll data from 2004 were omitted due to laboratory error.

A few small, isolated fish kills over a period of 15-20 years were reported for Horseshoe Lake, Old Town Lake, and First Old River Lake (telephone interviews with Jeff Farwick, AGFC District 4 fisheries biologist and Drew Wilson, AGFC District 7 fisheries biologist, October 2006). Most of the fisheries biologists interviewed suggest that fish recruitment and spawning success appear to be linked to water levels during spawning rather than nutrient concentrations in the lakes.

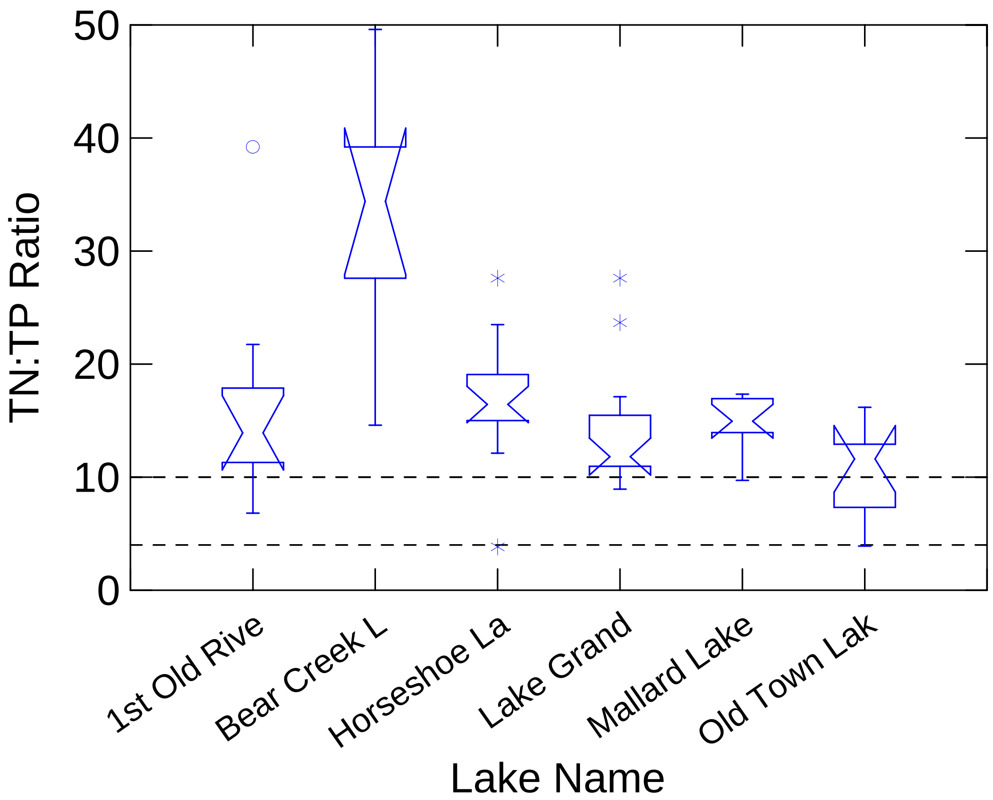

Figure 3.1. TN: TP Ratios.

4.0 TMDL DEVELOPMENT

4.1 Seasonality and Critical Conditions

EPA's regulations at 40 CFR 130.7 require the determination of TMDLs to take into account critical conditions for stream flow, loading, and water quality parameters. Also, both Section 303(d) of the Clean Water Act and regulations at 40 CFR 130.7 require TMDLs to consider seasonal variations for meeting water quality standards. Aquatic life impairments typically occur as a result of longer term exposure to elevated nutrient concentrations rather than short-term fluctuations in nutrient concentrations. Because of this, these nutrients TMDLs were developed based on average annual conditions. The most obvious result of nutrient enrichment, particularly excess phosphorus, is algal blooms. Algal blooms can produce an array of negative effects in lakes, including production of toxic chemicals and shading of submerged aquatic vascular plants. When algal populations crash following a bloom the resultant increase in biological oxygen demand results in hypoxia or anoxia, which also adversely affects aquatic life (Wehr and Sheath 2003). These effects often occur in a short time period but the build-up of nutrients and establishment of conditions that stimulate algal blooms may occur over an extended time.

4.2 Establishing Water Quality Targets

Because there are no numeric criteria for phosphorus in the Arkansas water quality standards, numeric target concentrations (endpoints) were developed to be protective of designated uses. It was assumed that aquatic life is the most important designated use to be protected for the six lakes addressed in this report. Arkansas water quality standards for streams (APCEC 2006) include specific designated uses stated in terms of key and indicator fish species that are expected in streams in various ecoregions of the state. There are, however, no analogous criteria for lakes and reservoirs.

For these TMDLs, it was determined that a quantitative measure of the relative quality of sport fisheries was requisite as an indicator of aquatic life use support. Unfortunately, little quantitative data is available to correlate nutrient concentrations in oxbows and small impoundments in Arkansas to relative fishery quality. As a substitute for quantitative sport fishing data from Arkansas, quantitative data collected by the Bureau of Fisheries of the Mississippi Department of Wildlife, Fisheries, and Parks from selected oxbow lakes in Mississippi were used. Mississippi utilizes a quantitative fisheries index (MSFish) based on the Sport Fishing Index developed by the Tennessee Valley Authority. MSFish indices are used to indicate relative quality for bass, crappie, and bream sport fisheries for most major lakes and reservoirs in Mississippi.

Approximately 30 of the lakes and reservoirs with MSFish indices were also intensively sampled during 2003 and 2004 as part of Mississippi Department of Environmental Quality's effort to develop nutrient criteria for Mississippi lakes. Analysis of these data revealed that numerous water quality parameters, including those associated with nutrients and productivity, occur in characteristic, statistically different levels in oxbows when compared to large reservoirs and likewise in waterbodies supporting higher and lower quality fisheries. Therefore, separate analyses of relationships between the MSFish indices and water quality data were performed for each type of waterbody and three categories of fishery quality. These analyses compared measurements of TP, TN, chlorophyll a, and Secchi transparency in reservoirs and oxbows with low, medium, and high MSFish indices. Targets for Arkansas lakes supporting higher quality fisheries were developed by comparing average TP concentrations in Mississippi lakes with high MsFish scores; conversely, targets for Arkansas lakes supporting lower quality fisheries were developed by comparing average TP concentrations in Mississippi lakes with low MsFish scores. A detailed discussion of these analyses and their associated assumptions is provided in Appendix D.

Target TP concentrations for the six lakes addressed in this report resulting from the analyses described above are summarized in Table 4.1. Target concentrations were developed only for phosphorus because the lakes addressed in this TMDL report are primarily phosphorus limited (see Section 3.3).

Table 4.1. Target TP concentrations (μg/L) for six Arkansas lakes.

Lake Name	Target TP (μg/L)
Horseshoe Lake	143
First Old River Lake	143
Grand Lake	143
Mallard Lake	80
Old Town Lake	80
Bear Creek Lake	90

4.3 TMDLs

The first step in developing the components of the TMDLs was to calculate the total allowable TP load for each lake. The total allowable TP load for each lake was calculated by multiplying the target TP concentration for the lake by the average annual inflow to the lake and then multiplying by an estimated ratio of average inflow TP concentration to average in-lake TP concentrations from previous studies of Mississippi oxbow lakes.

Average annual inflow for the Arkansas lakes was estimated by multiplying the average annual runoff per square mile in the watershed times the drainage area of the lake. Mallard Lake is a unique case among the lakes considered here because of its extremely small watershed. Historically, water levels in this impoundment were maintained by pumping water from an adjacent drainage ditch. However, pumping water to Mallard Lake was suspended in 2003 and has not been resumed since that time. This lake has reportedly maintained its water level since 2003 even without pumping. Inflow to Mallard Lake was therefore estimated based on the average annual lake evaporation rate for northeast Arkansas, which is 40 inches per year. This figure was multiplied by the lake size and converted to cubic feet and liters. This approach assumes that there is enough inflow from various sources (precipitation and possibly groundwater seepage at times) to balance the amount of water leaving the lake (assumed here to be only evaporation). Table 4.2 lists the estimated average annual inflows for the six lakes addressed in this report.

Table 4.2. Estimated average annual lake inflows

Lake Name	Drainage Area (acres)	Lake Area (acres)	Non-lake Area (acres)	Runoff (inches/year)	Inflow (ft3/year)	Inflow (L/year)
Bear Creek Lake	3,858	625	3,233	21	2.46E+08	6.98E+09
First Old River Lake	1,188	227	961	12	7.33E+07	2.07E+09
Horseshoe Lake	9,296	2,447	6,849	21	5.22E+08	1.48E+10
Grand Lake	5,150	1,130	4,020	17	3.06E+08	8.68E+09
Old Town Lake	12,700	1,611	11,089	21	8.45E+08	2.39E+10
Mallard Lake	350	320	30	*	4.64E+07	1.31E+09

*Inflows based on yearly evaporation rate rather than runoff

The ratio of average inflow TP concentration to average in-lake TP concentration was based on data reported in three EPA Clean Lakes studies for Mississippi Alluvial Plain lakes in Mississippi (FTN 1991a, b, c). Ratios calculated from these studies were 1.6, 2.5, and 3.7. To provide a conservative calculation of allowable loads for the TMDLs in this report, the lowest ratio (1.6) was used. Appendix E contains additional information concerning the data and calculations for these ratios. Inflow volumes, target TP concentrations, ratios, and total allowable TP loads are presented in Table 4.3

Table 4.3. Calculations for total allowable TP loads.

Lake Name	Inflow (L/year)	Target TP conc (μg/L)	Inflow to In-lake TP Ratio	Total Allowable Load (kg/year)
Bear Creek Lake	6.98E+09	90	1.6	1,005
First Old River Lake	2.07E+09	143	1.6	475
Horseshoe Lake	1.48E+10	143	1.6	3,383
Grand Lake	8.68E+09	143	1.6	1,986
Old Town Lake	2.39E+10	80	1.6	3,064
Mallard Lake	1.31E+09	80	1.6	168

4.4 Margin of Safety

The next step was to account for the MOS. Both Section 303(d) of the Clean Water Act and regulations at 40 CFR 130.7 require TMDLs to include a MOS to account for lack of knowledge concerning the relationship between pollutant loadings and water quality. The MOS may be expressed explicitly as unallocated assimilative capacity or implicitly through conservative assumptions used in establishing the TMDL. Ten percent of the total allowable load was set aside as an explicit MOS for these TMDLs.

4.5 Wasteload Allocation

The WLA was set to zero for each lake because there are no point source discharges in the watersheds of these lakes.

4.6 Load Allocation

Because the WLA was zero for each lake, the LA for nonpoint sources for each lake was set to the TMDL minus the MOS.

In order to calculate a percent reduction that would be needed for nonpoint source loads, the existing nonpoint source load for each lake was calculated as the mean concentration of TP measured in the lake times the average annual volume of inflow for the lake times the ratio of 1.6. Table 4.4 summarizes the TMDL components and the percent reductions that are needed to decrease existing nonpoint source loads to the allowable nonpoint source loads (LAs) for these lakes.

4.7 Future Growth

Compliance with these TMDLs is based on keeping TP concentrations in the lakes below the target concentrations rather than keeping the loads below certain amounts. Future growth for new point sources discharging to the lakes would not be limited by these TMDLs as long as the point sources do not cause in-lake concentrations of TP to exceed the target concentrations.

Table 4.4. Summary of TMDLs.

Lake Name	Target TP Conc. (μg/L)	Allowable Loads of TP				Percent Reduction Needed
		WLA (kg/yr)	LA (kg/yr)	MOS (kg/yr)	TMDL (kg/yr)	
Bear Creek Lake	90	0	905	100	1,005	0%
First Old River	143	0	427	48	475	21%
Horseshoe Lake	143	0	3,045	338	3,383	0%
Grand Lake	143	0	1,787	199	1,986	11%
Old Town Lake	80	0	2,758	306	3,064	73%
Mallard Lake	80	0	151	17	168	50%

5.0 OTHER RELEVANT INFORMATION

In accordance with Section 106 of the federal Clean Water Act and under its own authority, ADEQ has established a comprehensive program for monitoring the quality of the State’s surface waters. ADEQ collects surface water samples at various locations, utilizing appropriate sampling methods and procedures for ensuring the quality of the data collected. The objectives of the surface water monitoring program are to determine the quality of the state’s surface waters, to develop a long-term database for long term trend analysis, and to monitor the effectiveness of pollution controls. The data obtained through the surface water monitoring program is used to develop the state’s biennial 305(b) report (*Water Quality Inventory*) and the 303(d) list of impaired waters which is published as the 2004 Arkansas Integrated Water Quality Monitoring and Assessment Report (ADEQ 2005b).

State-adopted numeric nutrient water quality criteria for lakes were not available for development of these TMDLs. ADEQ is in the process of developing numeric nutrient water quality criteria for lakes. In order to complete these TMDLs within the consent decree deadline, it was necessary to develop target endpoints for TP. The methodology used to derive target endpoints for use in these TMDLs and the variability in the surrogate data may have resulted in target endpoints with some uncertainty. Therefore, these TMDLs may be revised at such time ADEQ adopts numeric nutrient water quality criteria for lakes or when the scientific basis for derivation of target levels improves.

6.0 PUBLIC PARTICIPATION

When EPA establishes a TMDL, federal regulations require EPA to issue a public notice and seek comment concerning the TMDL. Pursuant to a May 2000 consent decree, these TMDLs were prepared under contract to EPA. After development of the draft version of these TMDLs, EPA prepared a notice seeking comments, information, and data from the general public and affected public. No comments, data, or information were submitted during the public comment period. EPA has transmitted the final TMDLs to ADEQ for implementation and for incorporation into ADEQ's current water quality management plan.

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APPENDIX A

Watershed and General Maps

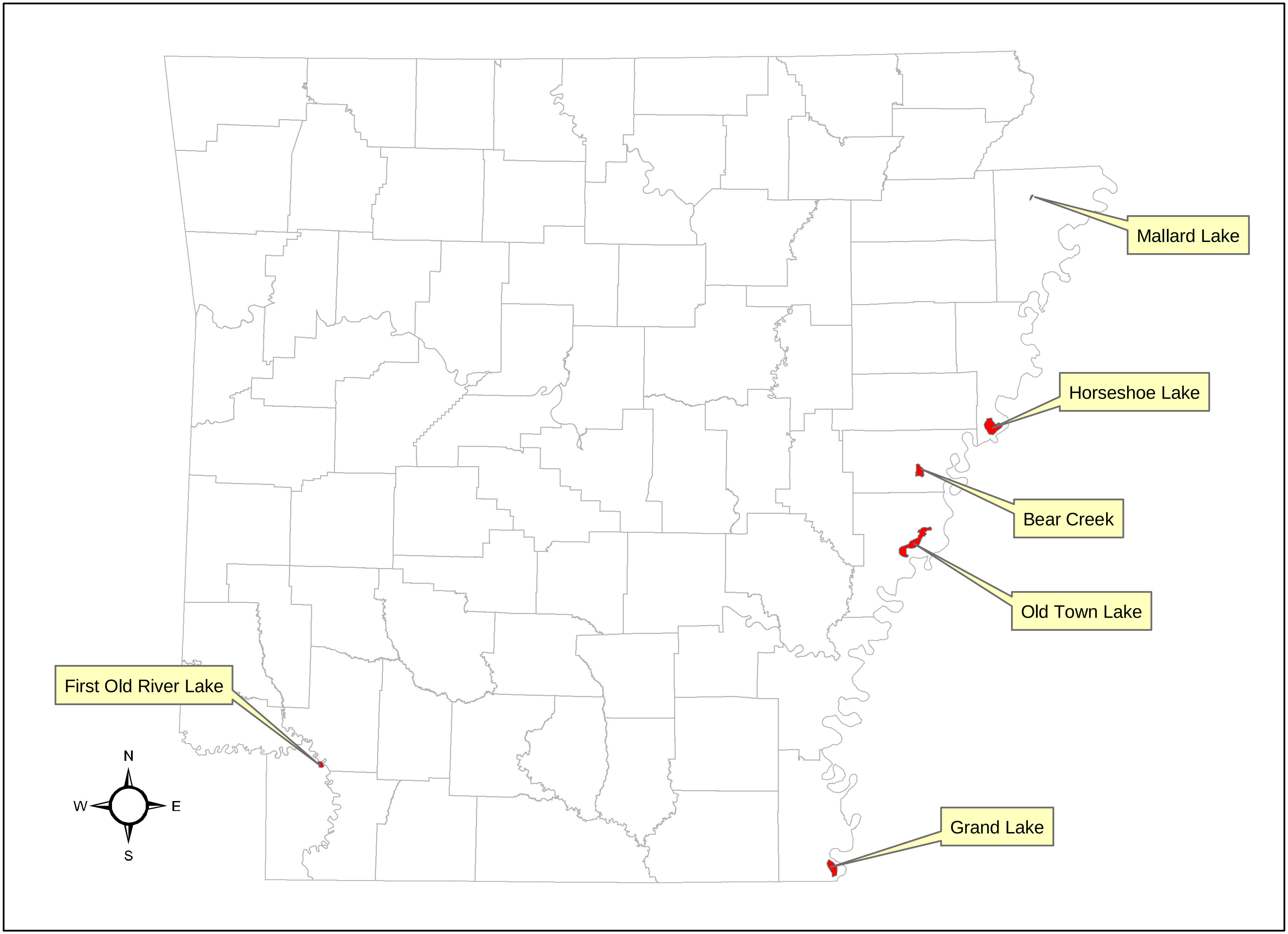

Figure A.1. Map of Arkansas showing locations of watersheds for all six lakes.

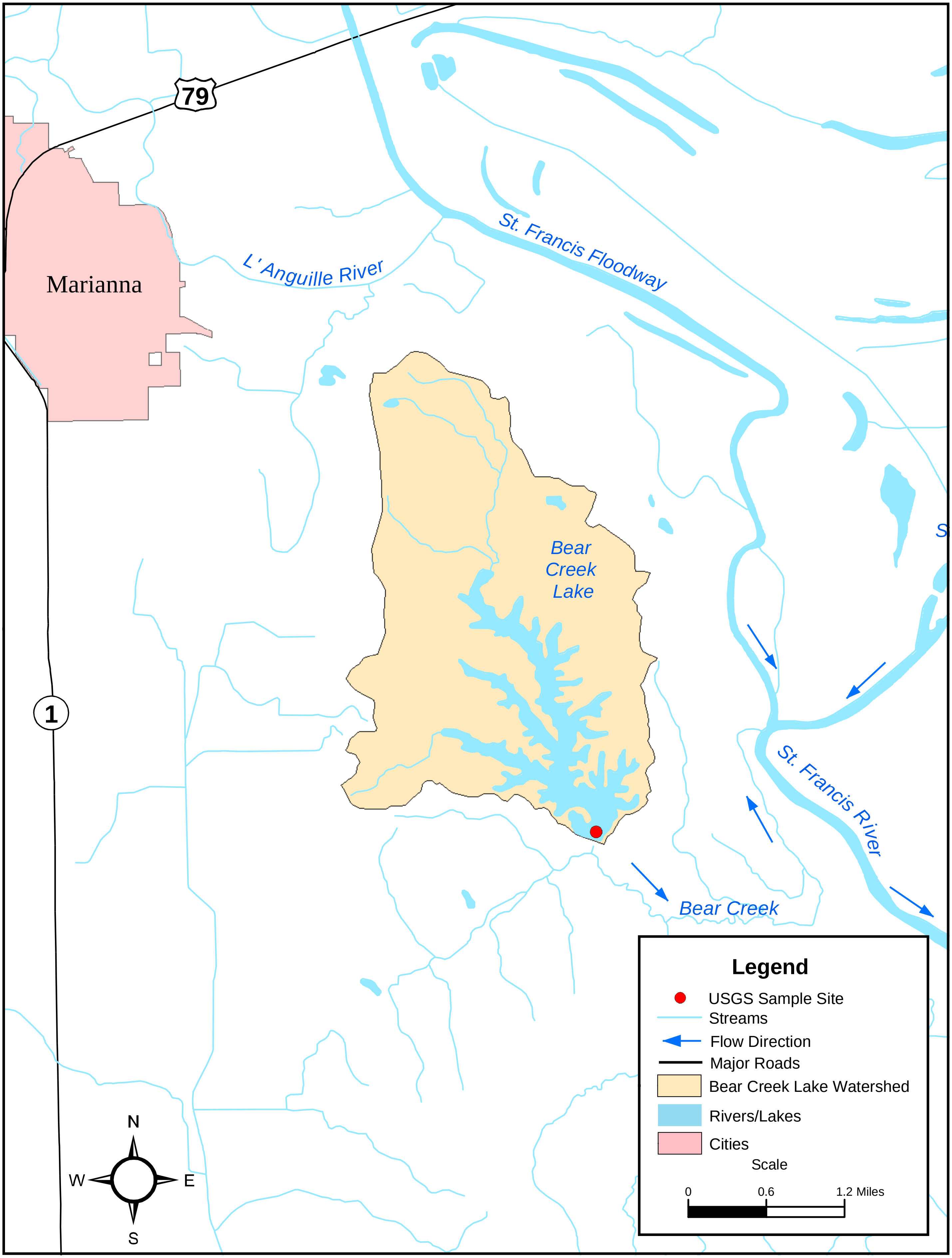

Figure A.2. Watershed Map for Bear Creek Lake

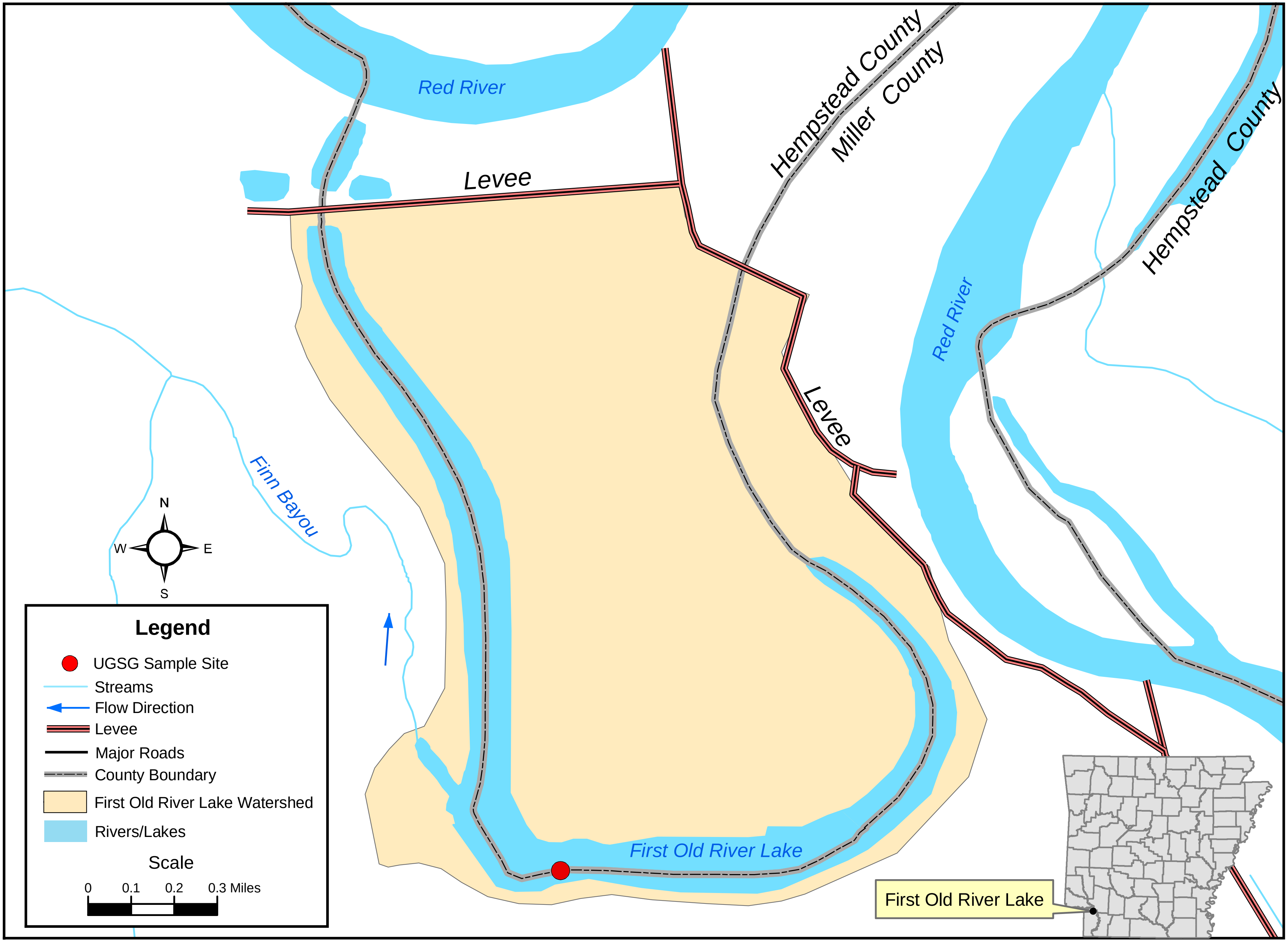

Figure A.3. Watershed map for First Old River Lake

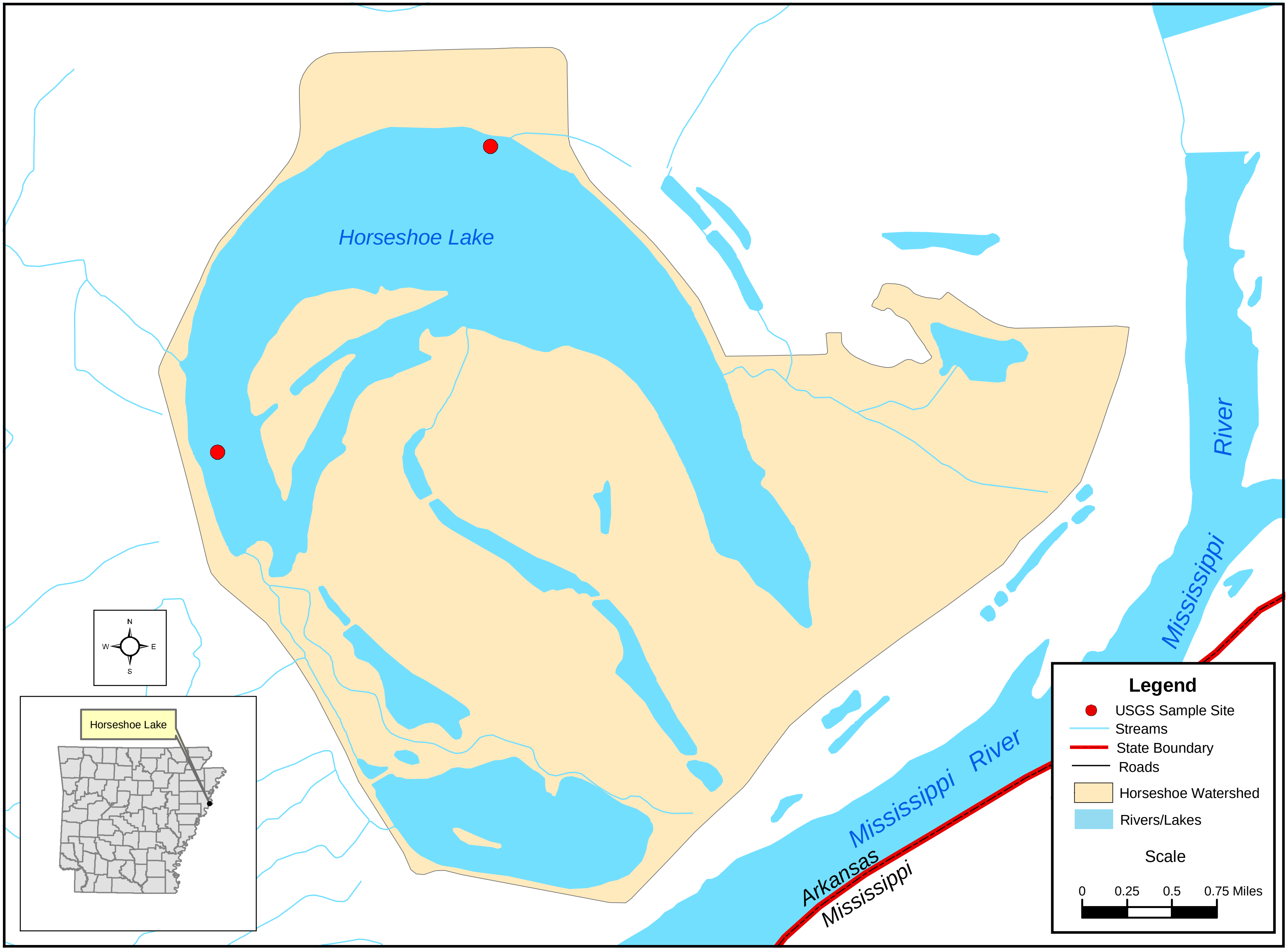

Figure A.4. Watershed Map for Horseshoe Lake

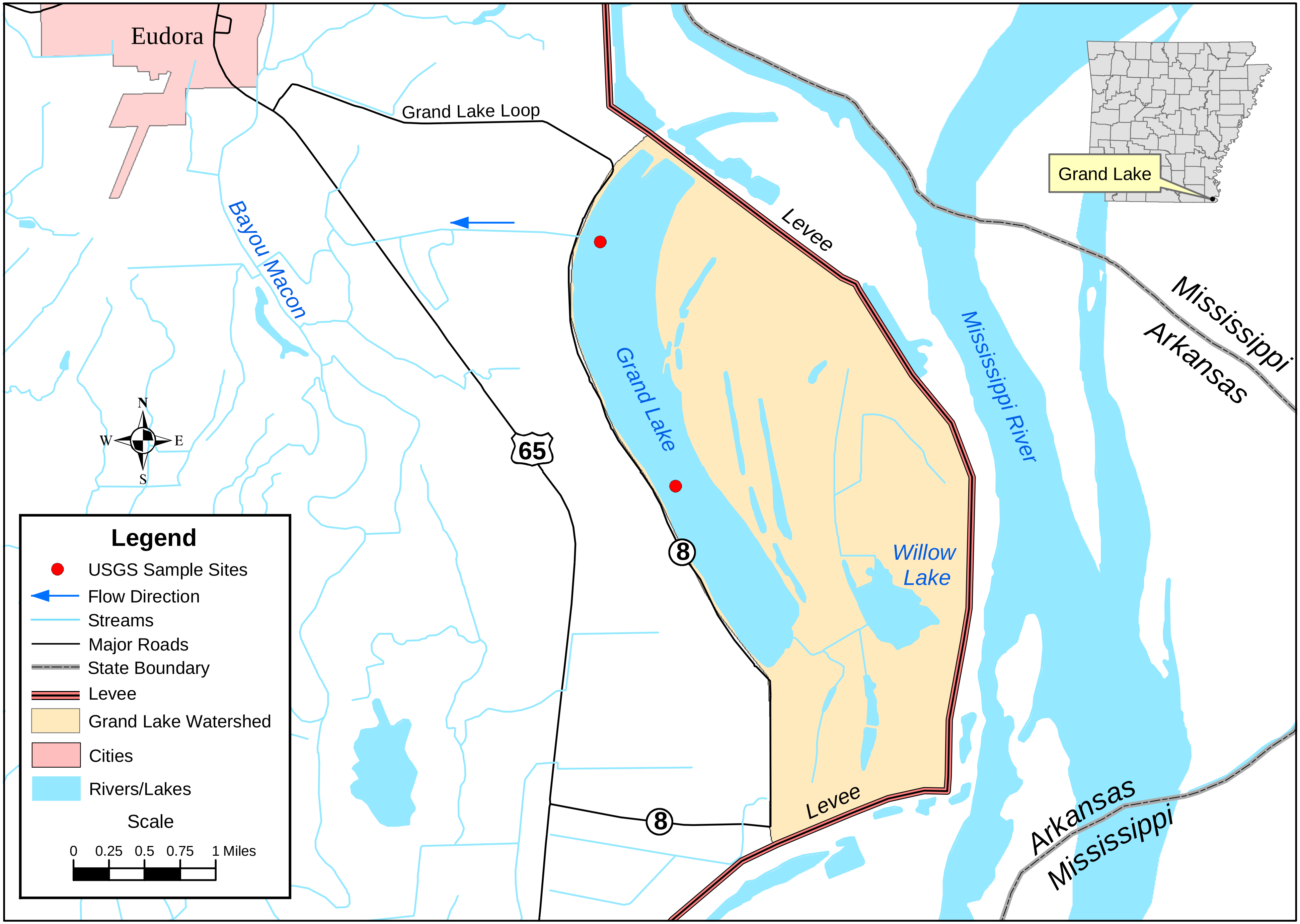

Figure A.5. Watershed Map for Grand Lake

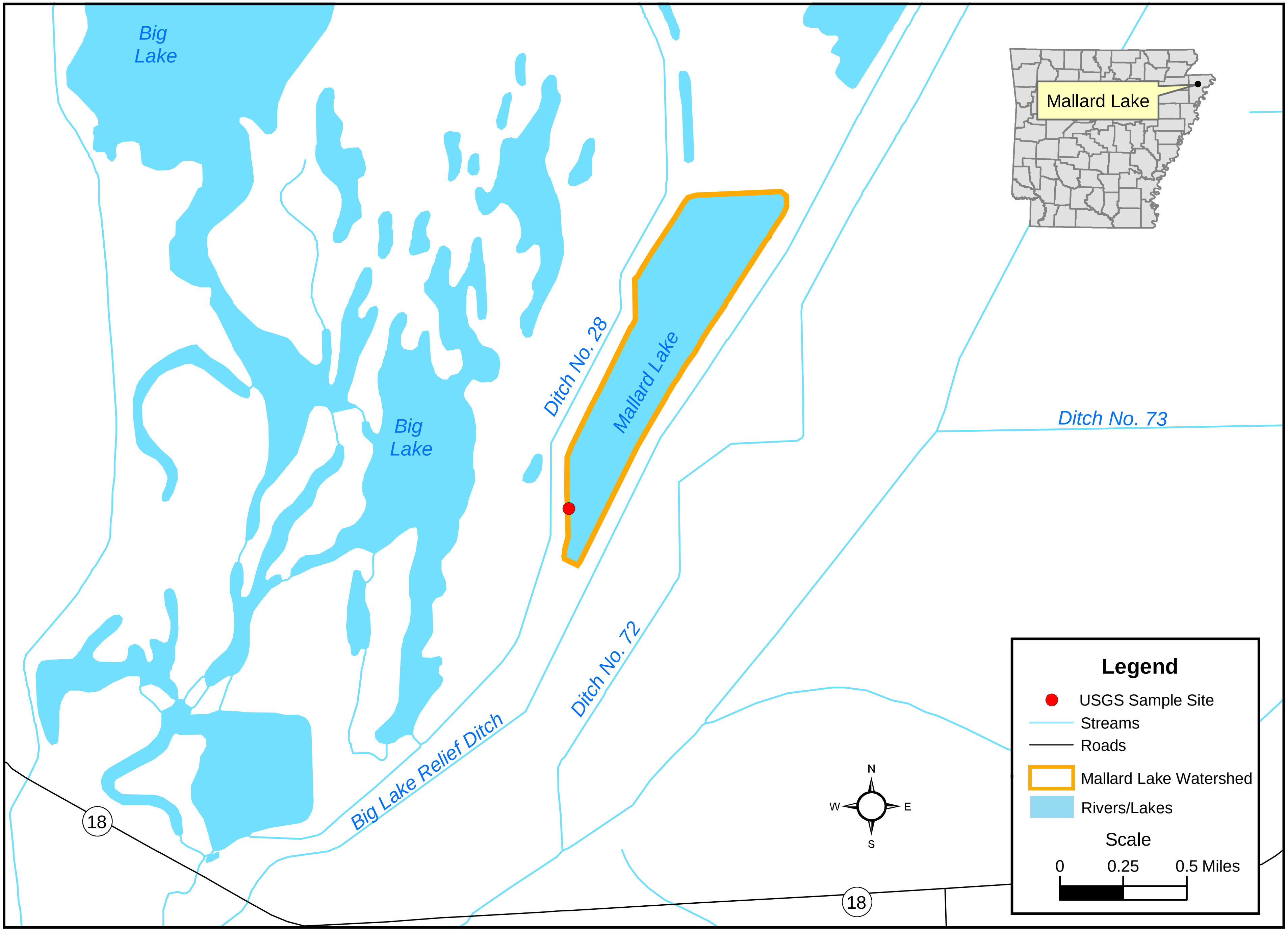

Figure A.6. Watershed Map for Mallard Lake

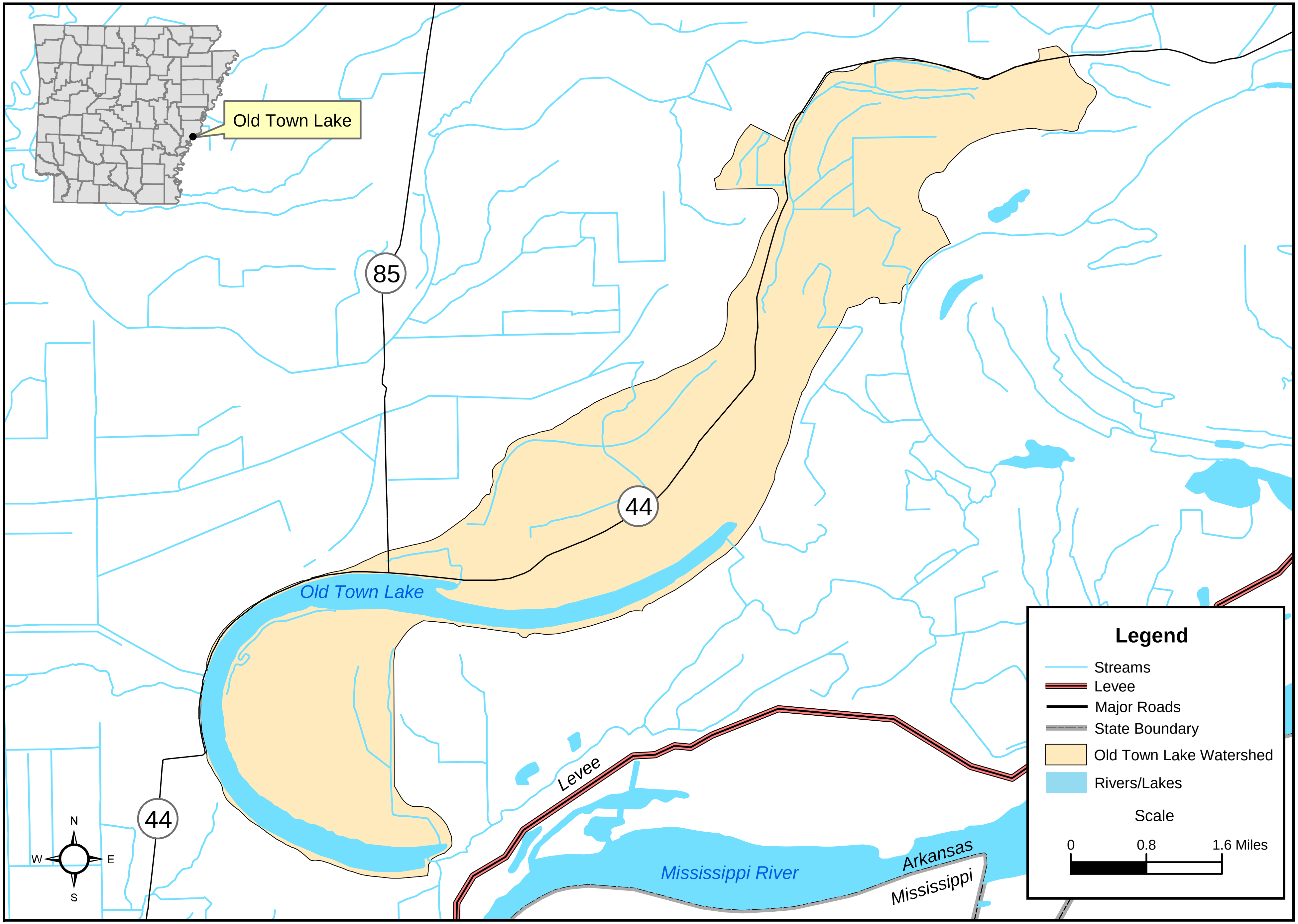

Figure A.7. Watershed map for Old Town Lake

APPENDIX B

Land Use Maps

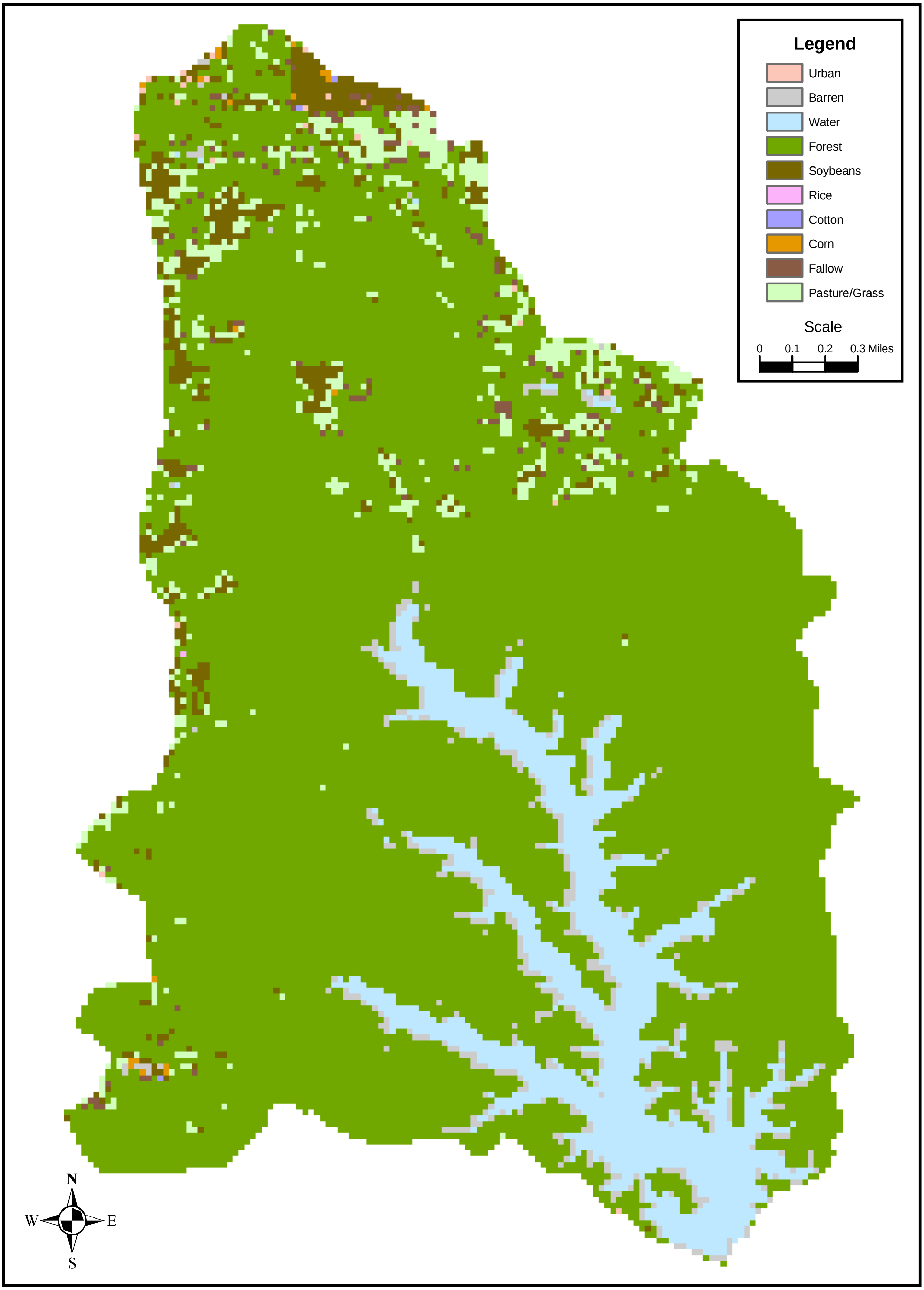

Figure B.1. Land Use Map for Bear Creek Lake

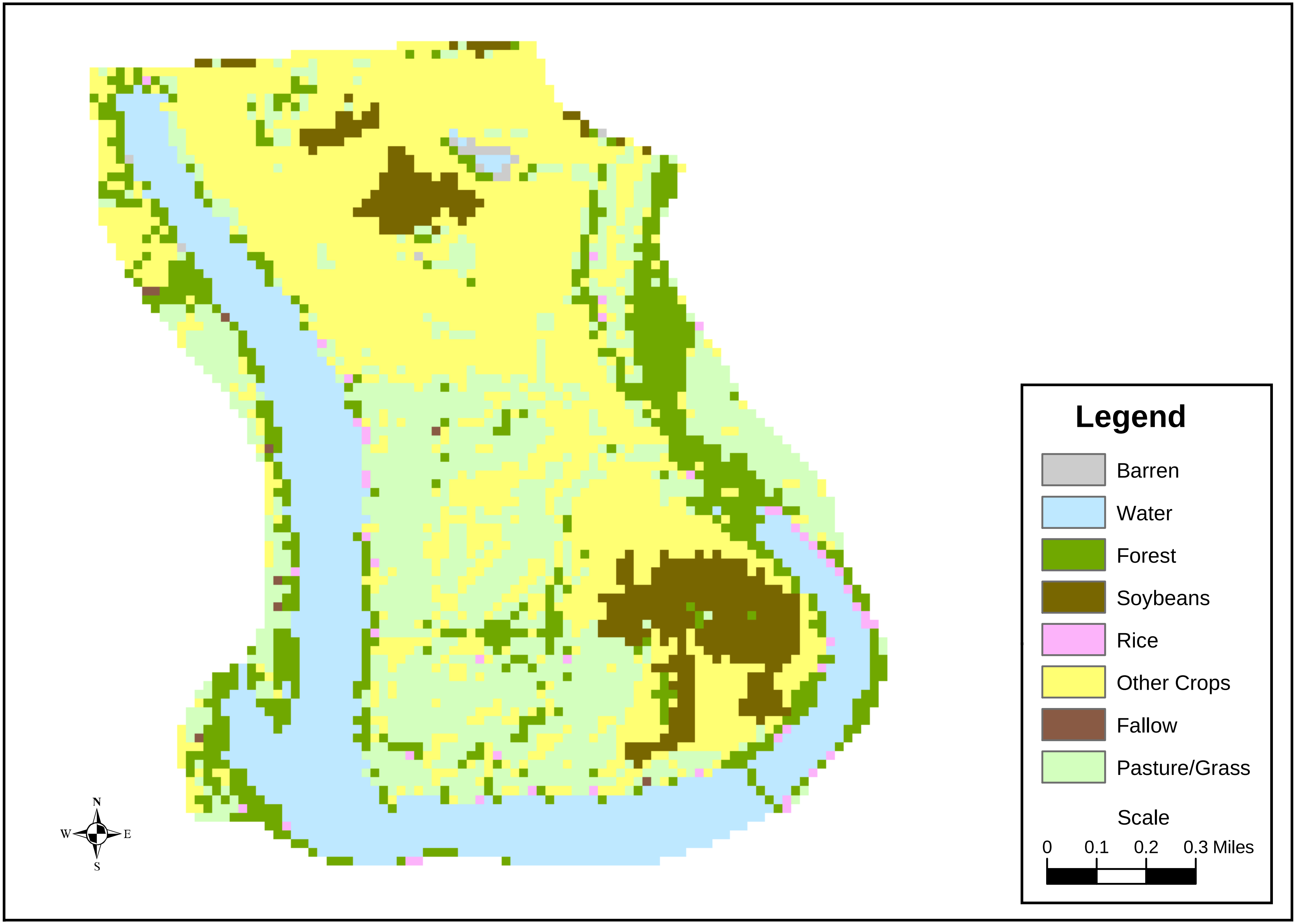

Figure B.2. Land Use Map for First Old River Lake

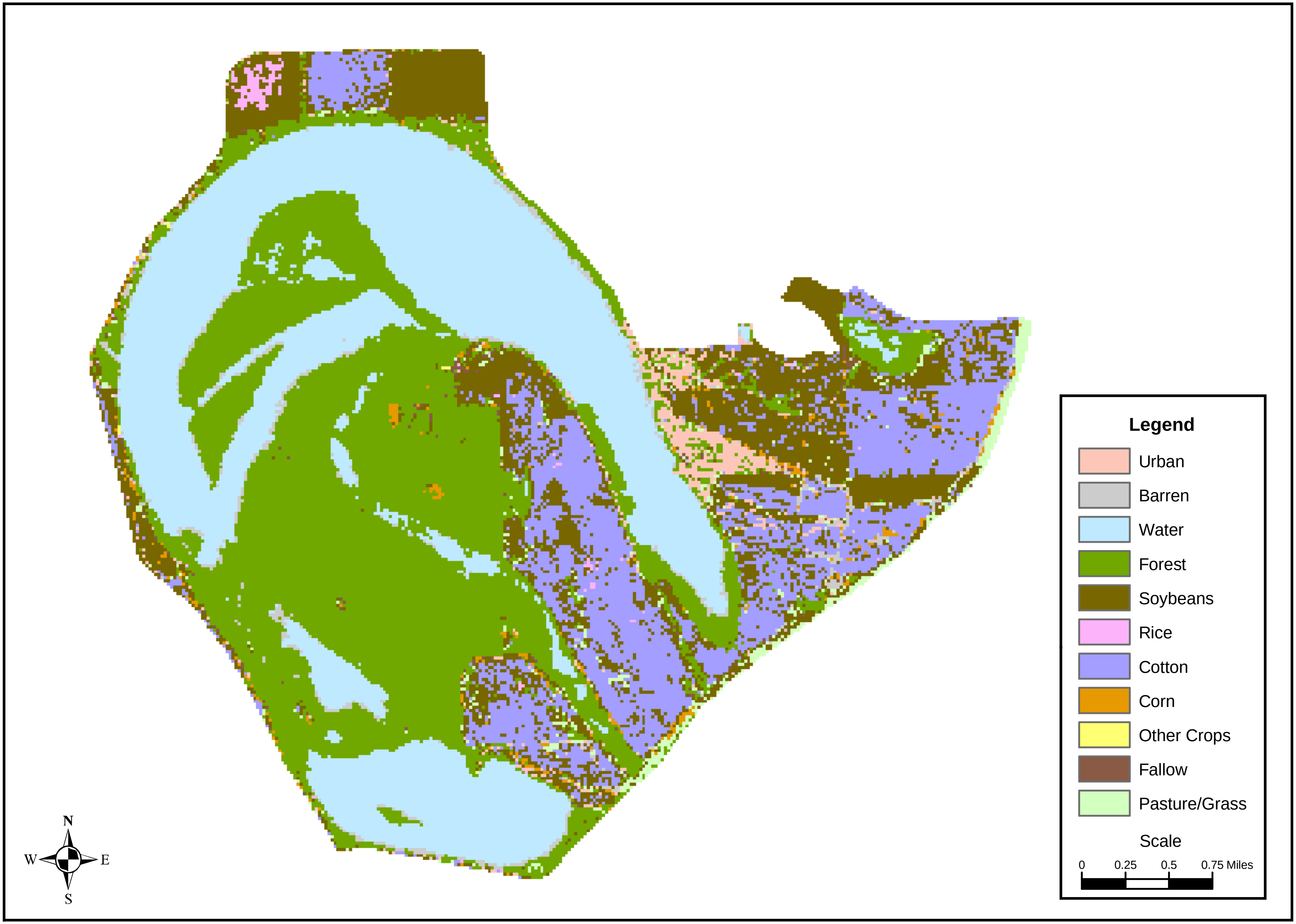

Figure B.3. Land Use Map for Horseshoe Lake

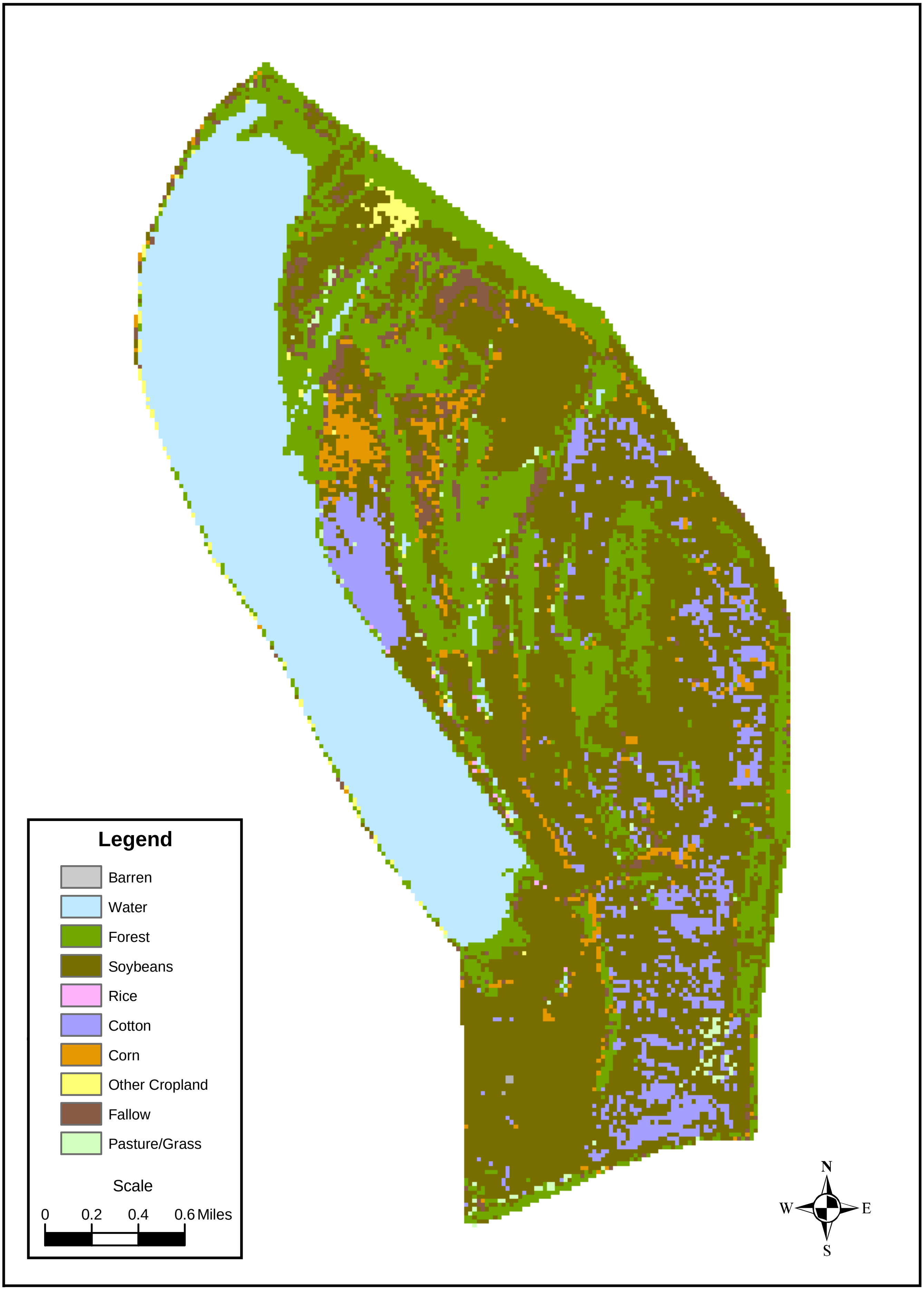

Figure B.4. Land Use Map for Grand Lake

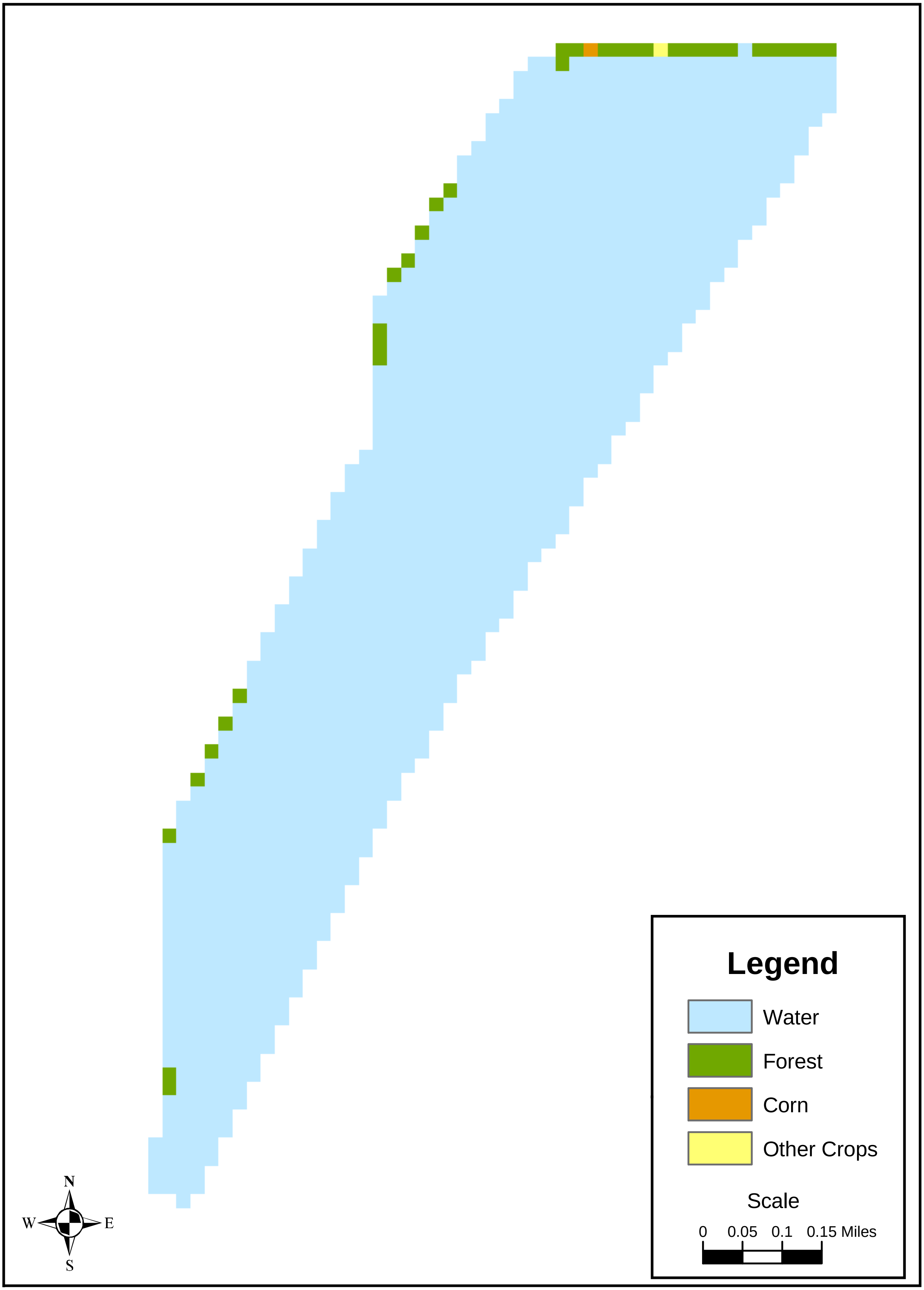

Figure B.5. Land Use Map for Mallard Lake

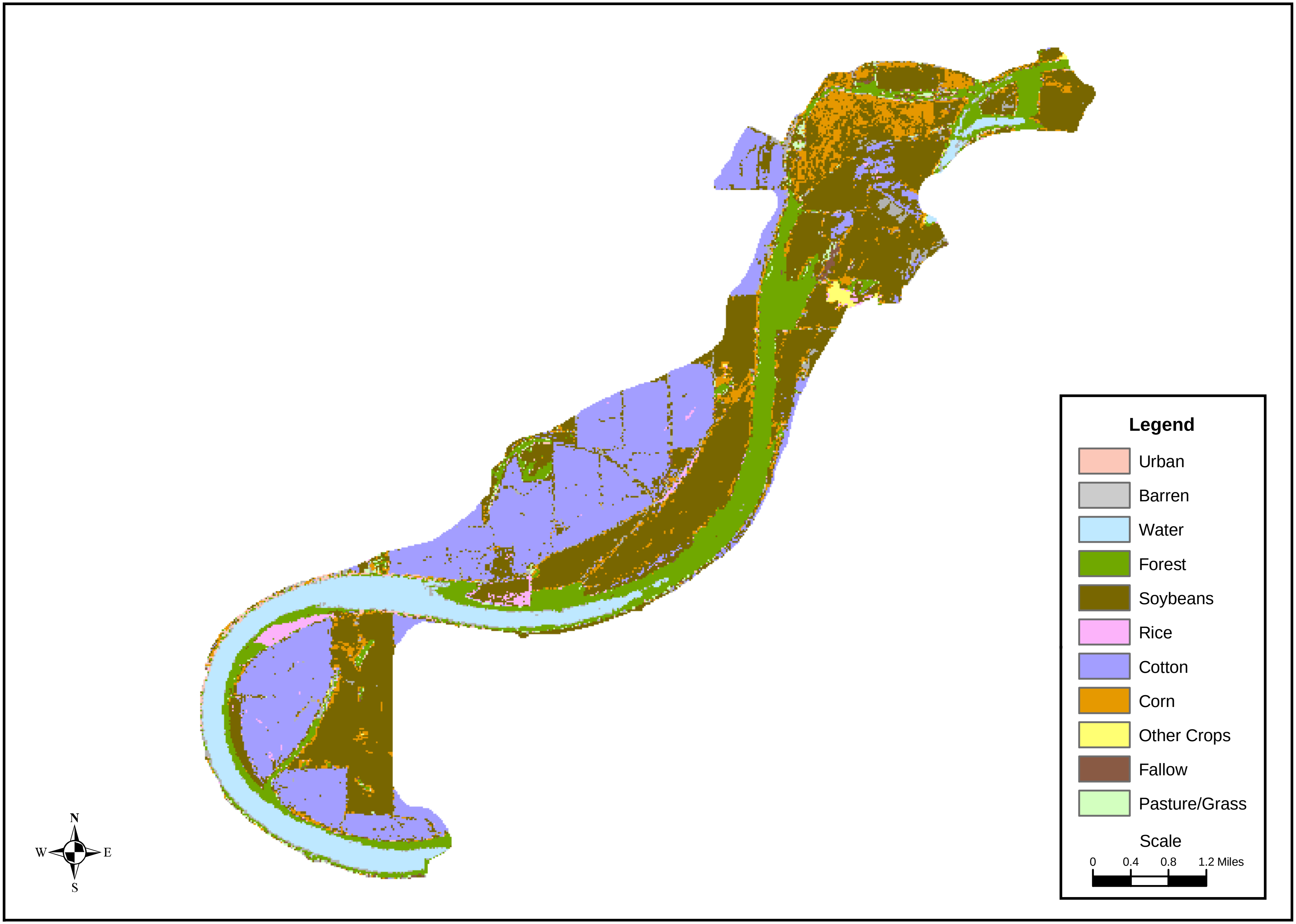

Figure B.6. Land Use Map for Old Town Lake

APPENDIX C1

Excerpt from the USGS report: Water Quality of Eleven Lake in Easter and Southern Arkansas from August 2004-July 2005

Quality Assurance Evaluation

Results of blank and duplicate samples were evaluated to determine the data quality. Blank sample results were evaluated to determine if results were above detection limits. Duplicate samples were compared to environmental samples by determining the percent difference between the duplicate sample result and the environmental sample result. Percent differences were calculated by dividing the result of the sample having the highest value by the result of the sample having the lowest value, subtracting that quotient from 1, and then multiplying that result times 100.

Water Quality of Lakes

Dissolved-Oxygen and pH Fluctuation Investigation

Dissolved-oxygen data (and, to a lesser extent, pH data) for the 48-hour investigation demonstrate large diurnal fluctuations at five of the seven nutrient lakes, and concentrations declined below the State standard of 5 mg/L for six of the seven lakes. Large diurnal fluctuations were apparent at First Old River, Grand, Horseshoe, Mallard, and Old Town Lakes (fig. 2). Dissolved-oxygen concentrations also declined below 4 mg/L for varying periods at those same five lakes, and were less than 1.5 mg/L at Mallard Lake and Grand Lake for short periods near daybreak. Dissolved-oxygen fluctuations were smaller at Stave Lake and Bear Creek Lake, and never declined below 4 mg/L. Heavy cloud cover that was prevalent for the first 24-hours of the 48-hour investigation may have influenced dissolved oxygen at Mallard Lake and concentrations never exceeded 5 mg/L.

Comparing data collected in the 48-hour monitoring period to ADEQ criteria, dissolved-oxygen concentration declined below the State standard of 5 mg/L at some time in the monitoring period at all lakes (including Stave Lake) except Bear Creek Lake. The State pH standard of "9" was exceeded at all lakes except Stave Lake (table 4).

Dissolved-oxygen percent saturation (and concentrations) at Bear Creek Lake near daybreak was substantially higher than at other lakes and was greater than 100 percent for most of the 48-hour monitoring period. Unlike the WQMs at other lakes, the WQM at Bear Creek was deployed beneath, and a few feet from the edge of a large fishing dock; thus, placing it in the shade for most or all of the 48-hour monitoring period. Water temperature at all the lakes monitored for the 48-hour period was comparable (about 30 °C) (appendix 1); however, reduced light penetration at the Bear Creek Lake monitoring site may have negatively affected photoplankton density and (indirectly) photosynthetic processes in the immediate area of the WQM.

Table 4. Minimum and maximum values for pH, dissolved-oxygen concentration, and dissolved-oxygen percent saturation for two 24-hour periods at seven Arkansas lakes.

		pH (standard units)			Dissolved oxygen (milligrams per liter)			Dissolved oxygen (percent saturation)	
Lake	Date	Minimum	Maximum	pH 24-hour fluctuation	Minimum	Maximum	Dissolved oxygen 24-hour fluctuation	Minimum	Maximum
Bear Creek	08/02/04	9.1	9.5	0.4	9.3	12.3	3.0	122	167.1
	08/03/04	9.1	9.6	0.5	9.6	12.6	3.0	126	173.2
First Old River	08/05/04	9.3	9.9	0.6	4.9	14.4	9.5	64.8	201.4
	08/06/04	9.1	9.8	0.7	3.4	13.0	9.7	43.9	176.3
Grand Lake	08/02/04	8.1	9.9	1.8	1.3	13.6	12.3	17.1	185.9
	08/03/04	9.2	10.1	0.9	4.9	14.1	9.2	64.6	192.6
Horseshoe	08/02/04	8.9	9.8	0.9	6.0	14.5	8.6	78.1	195.4
	08/03/04	8.0	9.9	1.9	1.9	15.2	13.4	24.1	216.4
Mallard Lake	07/30/04	7.7	8.5	0.8	1.0	4.7	3.8	12.1	110.0
	07/31/04	8.2	9.5	1.4	3.2	13.7	10.6	40.8	187.5
Old Town Lake	08/04/04	7.5	9.2	1.7	2.3	9.6	7.2	30.6	128.8
	08/05/04	7.3	8.7	1.4	1.9	7.7	5.9	23.4	99.2
Stave Lake	08/02/04	7.3	8.4	1.1	4.0	9.4	5.4	52.1	126.0
	08/03/04	7.3	8.2	0.8	4.5	9.3	4.9	58.3	123.0

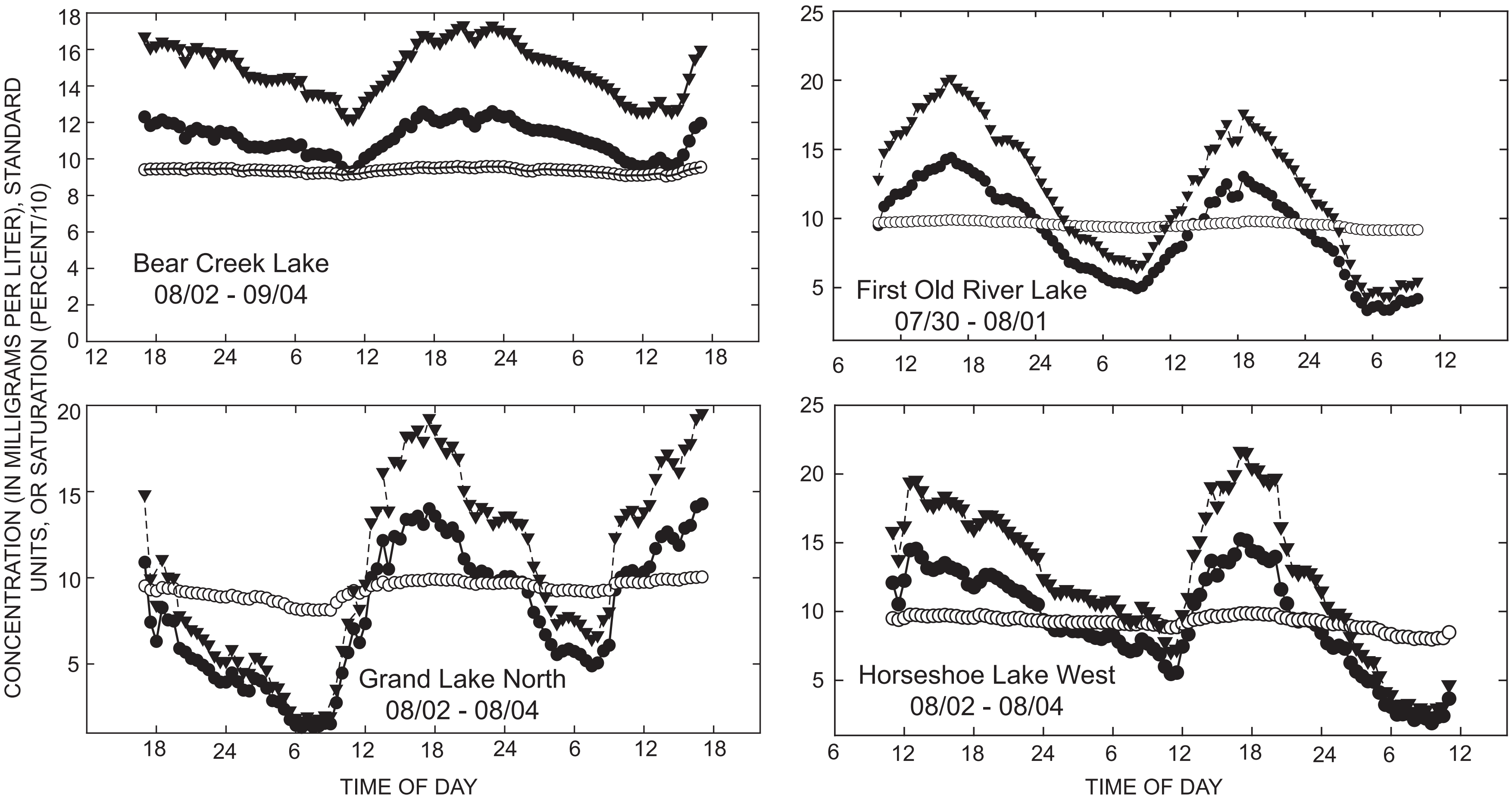

Figure 2. Dissolved-oxygen concentration, pH, and dissolved-oxygen saturation at 30-minute intervals in seven Arkansas lakes for a 48-hour period in August 2004.

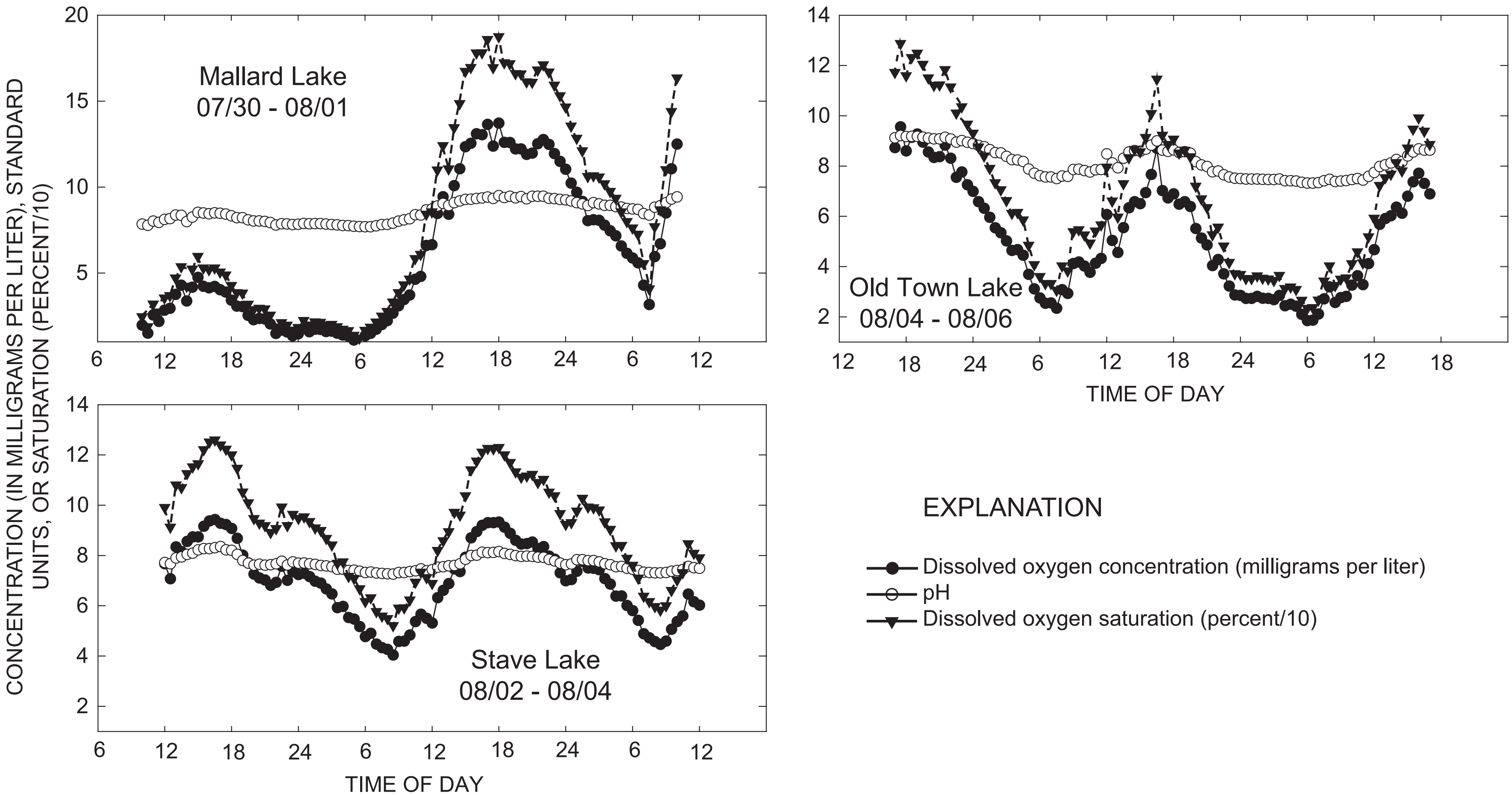

Figure 2. Dissolved-oxygen concentration, pH, and dissolved-oxygen saturation at 30-minute intervals in seven Arkansas lakes for a 48-hour period in August 2004.—Continued

APPENDIX C2

ADEQ and USGS Data for TN, TP and Chlorophyll a

Table C2-1. ADEQ and USGS Data for Total Nitrogen (TN) in mg/L.

Agency	Date	Bear Creek Lake	First Old River Lake	Grand Lake	Horseshoe Lake	Mallard Lake	Old Town Lake
ADEQ [A]	1989						
ADEQ [A]	1994						
ADEQ [A]	1999		1.74	3.01		2.60	
ADEQ [A]	2004						
USGS	08/24/04	1.02	3.50	2.78	1.88	2.72	3.60
USGS	09/21/04	0.83	3.63	2.59	1.34	3.05	4.30
USGS	10/19/04	0.94	2.86	1.34	1.09	2.79	4.65
USGS	12/06/04	1.24	1.72	1.42	1.19	1.49	1.78
USGS	02/08/05	0.89	1.34	0.78	0.69	1.35	1.07
USGS	04/26/05	1.56	0.99	0.92	0.92	1.55	0.82
USGS	05/16/05	0.73	0.98	1.06	1.02	1.30	2.05
USGS	06/07/05	0.66	1.11	1.64	1.26	1.36	4.26
USGS	07/26/05	0.72	3.07	3.29	1.77	2.90	4.98
USGS	08/24/04 [B]			2.60	1.65		
USGS	09/21/04 [B]			2.98	1.47		
USGS	10/19/04 [B]			1.75	1.11		
USGS	12/06/04 [B]			1.38	0.95		
USGS	02/08/05 [B]			0.73	0.69		
USGS	04/26/05 [B]			0.99	0.88		
USGS	05/16/05 [B]			1.22	0.97		
USGS	06/07/05 [B]			1.54	1.11		
USGS	07/26/05 [B]			3.19	1.70		
	n	9	10	19	18	10	9
	mean	0.95	2.09	1.85	1.21	2.11	3.06
	max	1.56	3.63	3.29	1.88	3.05	4.98
	min	0.66	0.98	0.73	0.69	1.30	0.82

Notes: A. ADEQ data collected in the hypolimnion are not included here. TN data are not available for most ADEQ sampling events.
B. Data for repeated dates are from a second sampling site on Grand Lake and on Horseshoe Lake.

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Table C2-2. ADEQ and USGS Data for Total Phosphorus (TP) in mg/L.

Agency	Date	Bear Creek Lake	First Old River Lake	Grand Lake	Horseshoe Lake	Mallard Lake	Old Town Lake
ADEQ [A]	1989	0.09	0.10	0.30	0.10	0.20	0.32
ADEQ [A]	1994	0.12	0.15	0.19	0.15	0.20	0.21
ADEQ [A]	1999	0.046	0.084	0.261	0.093	0.15	0.381
ADEQ [A]	2004	0.039	0.295	0.173	0.145	0.247	0.331
USGS	08/24/04	0.025	0.31	0.20	0.09	0.28	0.31
USGS	09/21/04	0.025	0.28	0.26	0.025	0.18	0.30
USGS	10/19/04	0.025	0.16	0.15	0.07	0.20	0.36
USGS	12/06/04	0.025	0.20	0.06	0.06	0.10	0.11
USGS	02/08/05	0.025	0.09	0.06	0.025	0.09	0.16
USGS	04/26/05	0.025	0.06	0.08	0.06	0.10	0.21
USGS	05/16/05	0.025	0.025	0.09	0.08	0.10	0.20
USGS	06/07/05	0.025	0.09	0.12	0.06	0.08	0.35
USGS	07/26/05	0.025	0.45	0.32	0.10	0.20	0.68
USGS	08/24/04 [B]			0.22	0.08		
USGS	09/21/04 [B]			0.19	0.025		
USGS	10/19/04 [B]			0.15	0.07		
USGS	12/06/04 [B]			0.05	0.06		
USGS	02/08/05 [B]			0.07	0.18		
USGS	04/26/05 [B]			0.06	0.06		
USGS	05/16/05 [B]			0.08	0.08		
USGS	06/07/05 [B]			0.09	0.07		
USGS	07/26/05 [B]			0.33	0.09		
	n	13	13	22	22	13	13
	mean	0.04	0.176	0.159	0.081	0.164	0.302
	max	0.12	0.45	0.33	0.18	0.28	0.68
	min	0.025	0.025	0.05	0.025	0.08	0.11

Notes: A. ADEQ data collected in the hypolimnion are not included here.
B. Data for repeated dates are from a second sampling site on Grand Lake and on Horseshoe Lake.

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Table C2-3. ADEQ and USGS Data for Chlorophyll a in ug/L.

Agency	Date	Bear Creek Lake	First Old River Lake	Grand Lake	Horseshoe Lake	Mallard Lake	Old Town Lake
ADEQ [A]	1989	72.2	52.1	148	87.7	116	174
ADEQ [A]	1994	38.8	13.4	40.0	170	45.4	110
ADEQ [A]	1999	37.6	43.7	37.3	50.5	62.1	123
ADEQ [A]	2004	--- [C]	--- [C]	--- [C]	--- [C]	--- [C]	--- [C]
USGS	08/24/04	23.5	95.0	101	69.4	24.6	82.2
USGS	09/21/04	13.9	254	230	68.4	168	256
USGS	10/19/04	9.8	147	97.5	55.5	101	166
USGS	12/06/04	10.3	69.4	73.2	38.7	7.3	55.3
USGS	02/08/05	23.0	15.0	35.8	13.4	17.8	63.2
USGS	04/26/05	18.7	17.7	34.0	27.4	25.4	91.7
USGS	05/16/05	21.4	39.4	50.7	29.4	28.0	104
USGS	06/07/05	11.2	30.3	100	53.4	17.4	409
USGS	07/26/05	20.3	264	275	123	227	374
USGS	08/24/04 [B]			63.0	67.3		
USGS	09/21/04 [B]			256	84.1		
USGS	10/19/04 [B]			80.1	43.8		
USGS	12/06/04 [B]			56.1	27.4		
USGS	02/08/05 [B]			36.3	20.0		
USGS	04/26/05 [B]			46.7	32.0		
USGS	05/16/05 [B]			63.2	39.4		
USGS	06/07/05 [B]			103	48.1		
USGS	07/26/05 [B]			344	130		
	n	12	12	21	21	12	12
	mean	25.1	86.7	108	60.9	70.0	167
	max	72.2	264	344	170	227	409
	min	9.8	13.4	34.0	13.4	7.3	55.3

Notes: A. ADEQ data collected in the hypolimnion are not included here.
B. Data for repeated dates are from a second sampling site on Grand Lake and on Horseshoe Lake.
C. ADEQ chlorophyll data for 2004 were omitted due to laboratory error.

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APPENDIX D

Nutrient Target Approach and Justification

APPENDIX D. NUTRIENT TARGET APPROACH AND JUSTIFICATION

Overview

The purpose of this document is to present an approach to developing target levels for nutrient TMDLs for six Arkansas Lakes. This approach is based on the assumption that, as with nutrient criteria, the target levels must be protective of designated uses. It is assumed that agricultural and industrial water supply and secondary contact recreation uses are not affected by nutrient conditions commonly encountered in surface water and that none of the lakes in question have a significant domestic water supply use. It is further assumed that primary contact recreation is not a common use of these systems. Therefore the primary use of concern is aquatic life. Arkansas water quality standards for streams (APCEC 2006) include specific designated uses stated in terms of key and indicator fish species that are expected in streams in various ecoregions of the state. There are, however, no analogous aquatic life uses for lakes and reservoirs.

The approach presented herein proposes to use a quantitative measure of the potential quality of the sport fishery as in indicator of aquatic life use support. The major fishery management effort by the Arkansas Game and Fish Commission (AGFC) focuses on small ponds and large reservoirs. The Commission has no systematic program to compile fish production information for oxbows or small impoundments. Therefore, insufficient data exists for the development of a quantitative indicator of sport fishing potential in relation to nutrients in these types of waterbodies. As a substitute for sport fishing data for Arkansas lakes, we propose to use data collected by the Bureau of Fisheries of the Mississippi Department of Wildlife, Fisheries and Parks (MDWFP) from selected oxbow lakes in Mississippi. The data were collected as part of the development of the MsFish index.

MsFish is an index used to provide estimates of relative fishing quality for lakes and reservoirs and is based on the Sport Fishing Index developed by the Tennessee Valley Authority (TVA). The index "…allows anglers to objectively compare waters across the state in terms of potential fishing success" (MDWFP 2006; see references in Section 7 of main body of report). Scores are based on sport fish population quality (fish abundance, size structure and condition of black bass, crappie and “bream”) and angler results (catch rate, fish sizes, targeted effort). Procedures for calculating the MsFish Index from raw data are provided in Appendix D1.

CONCEPTUAL APPROACH TO NUTRIENT TARGET DEVELOPMENT

The approach combines the MsFish index with data describing nutrients (total phosphorus-TP and total nitrogen-TN), water clarity (Secchi disc-SD), and primary productivity (chlorophyll a- Chla) collected by the Mississippi Department of Environmental Quality (MDEQ) for the development of nutrient criteria in Mississippi lakes and reservoirs. The approach uses the MsFish index as an indicator of aquatic life designated use attainment. A lake is considered to be meeting its aquatic life use if any of its three fisheries (bass, crappie, bream) ranked high according to MsFish. The distribution of TP, TN, Chla, and SD for lakes with high MsFish scores (i.e. meeting their aquatic life designated use) is then considered to represent the range of levels of nutrients, clarity, and primary productivity that supports, and does not impair, aquatic life use.

Data Analysis

Of the 42 lakes and reservoirs sampled by MDEQ, 30 were also sampled by MDWFP for MsFish development. Of these 30 waterbodies there were 24 reservoirs > 500 ac. in surface area and 8 oxbow lakes. MDWPF sampled selected waterbodies in Mississippi from 2000 – 2005. However, the same set of waterbodies was not visited each year. Therefore any given lake or reservoir sampled by both MDWFP and MDEQ will have from 1 – 6 years of fisheries data. MsFish indices were calculated (Appendix B) for three sport fisheries: Bass (largemouth, spotted and smallmouth bass combined), crappie (black crappie and white crappie combined) and “bream” (bluegill, redear and longear sunfish combined).

MDEQ water quality data for lakes and reservoirs were collected from the Fall of 2002 through the Fall of 2004. Water quality data used for this analysis were collected

June – September 2003 and 2004. Nutrient samples were collected from 1 ft. below the surface. Chla samples were composites of equal portions of sample collected at 1 ft and from the bottom of the photic zone as estimated by Secchi depth.

Previous analyses of the MDEQ water quality data set has shown that water quality parameters, including those associated with nutrients and productivity show clear differences between oxbows and reservoirs. Figure D.1 provides an example of differences in total phosphorus (TP), total nitrogen (TN), Chlorophyll-a (Chla), and Secchi disc (SD) between oxbows and reservoirs.

Analysis of Fisheries Data

Procedures for combining MsFish scores across years and for comparing scores among the types of fisheries were as follows.

- Scores for each fishery were averaged across years for each lake or reservoir.
- It was then assumed that high quality fisheries exist) in at least some of the lakes and reservoirs sampled by MDWFP and that the highest quality fisheries would be indicated by the highest MsFish scores. Accordingly, the scores for each fishery were scaled such that the score for a particular fishery at a particular waterbody was expressed as a percentage of the highest score from all waterbodies for that fishery. The resulting data set scaled all scores to range between 0 and 100. The result of this scaling was to assure that a particular waterbody could be rated as high (or low) based on any of the three fisheries. The waterbodies were classified as either “oxbows” or “reservoirs” and a separate comparison with MsFish data was performed. The unscaled and scaled scores for each waterbody sampled by MDPWF are presented in Appendix B.
- It was next assumed that, for each waterbody, the fishery with the highest score (i.e. the waterbody’s “strong suit” with respect to its sport fishery) represents the aquatic life attainment status of the waterbody. This analysis assumes that water quality that supports one type of fishery will support either or both of the other two types of fisheries. Furthermore it is not reasonable to expect that, as a prerequisite to aquatic life use attainment, a particular water body support a high level of attainment for all three fisheries (although some waterbodies do). This is

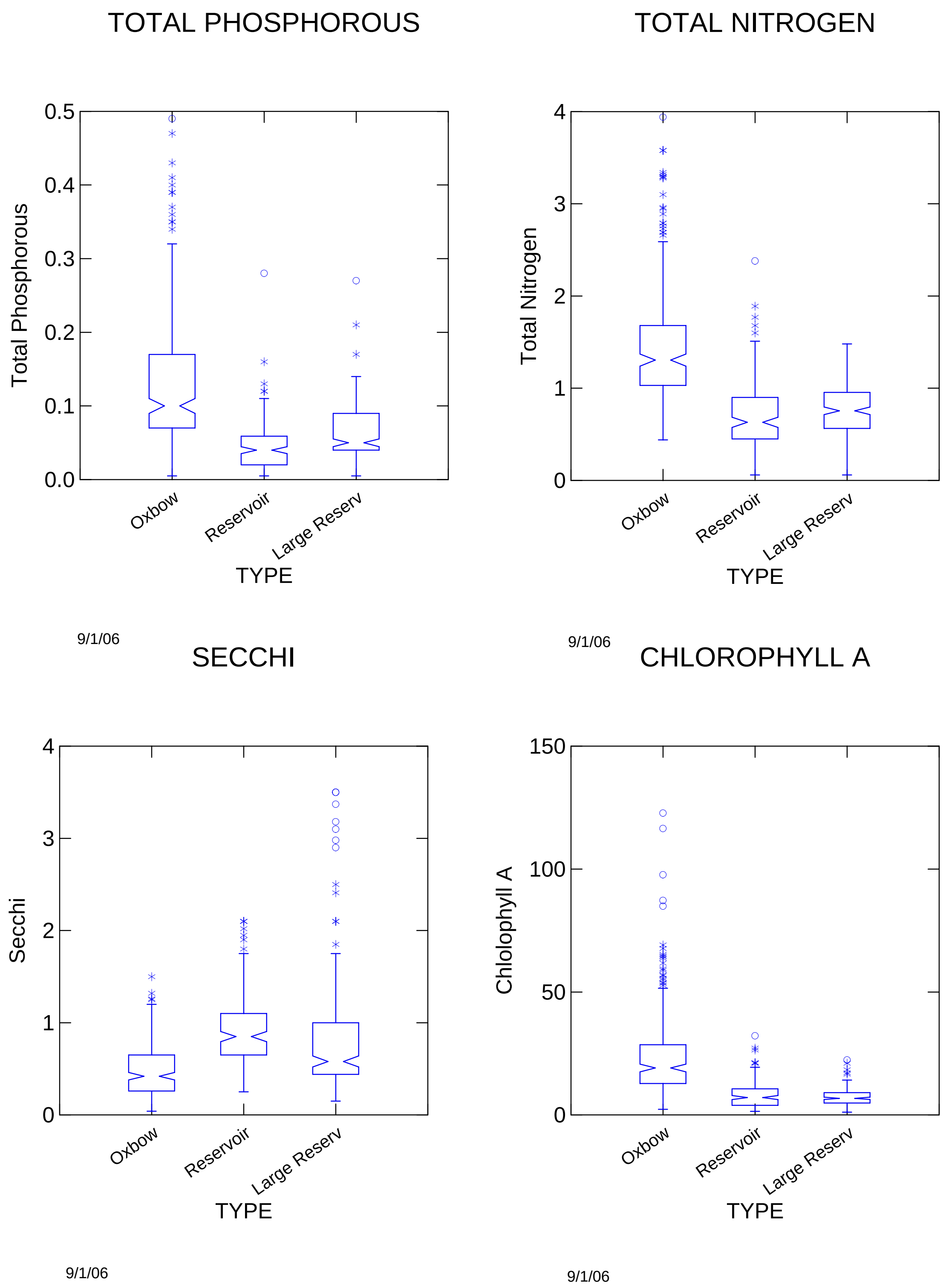

Figure D.1. Box and whisker plots comparing distributions of TP (mg/L), TN (mg/L), Chla (ug/L) and SD (m) between oxbows, reservoirs (500 – 2000 ac), and large reservoirs (> 2000 ac).

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

- Within each classification, the waterbodies and their accompanying final indices were sorted by the value of the final index. The index values were then divided into upper, middle and lower thirds and rated as high, medium and low, respectively.
- Lakes sampled by MDWPF were then divided into oxbow and reservoir classifications and lakes sampled by MDEQ were chosen from these two categories. The results of the data analysis through this step are provided in Table D.1.

ANALYSIS OF MSFISH AND WATER QUALITY DATA

Data Interpretation

A conceptual model illustrating the expected relationship between fish production and habitat, nutrients, chlorophyll, and clarity in lakes and reservoirs is presented in Figure D.2. The figure illustrates how aquatic life use as indicated by sport fish production can be limited by low nutrients, habitat or high nutrients. At the far left hand portion of the figure, low overall productivity caused by low nutrient levels limits fish production. As nutrient levels and chlorophyll increase (and clarity decreases) nutrients become less limiting. However, fish production can range from low to high because of habitat limitation. As nutrients increase even more (in the far right of the figure), impairment of sport fish production can occur due to factors typically associated with eutrophication (low dissolved oxygen, toxic algae blooms, shading of submerged vascular plants) or to light limitation due to non-algal suspended solids that are known to be positively correlated with levels of TP. The model illustrates how low fish production can be associated with either low or high nutrients depending on whether the nutrients are limiting or impairing sport fish production. This conceptual model can be used to interpret the observed relationships between the final MsFish index and TP, TN, Chla, and SD distributions.

Table D.1. Final MsFish index values for oxbows and reservoirs (reservoirs + large reservoirs).

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

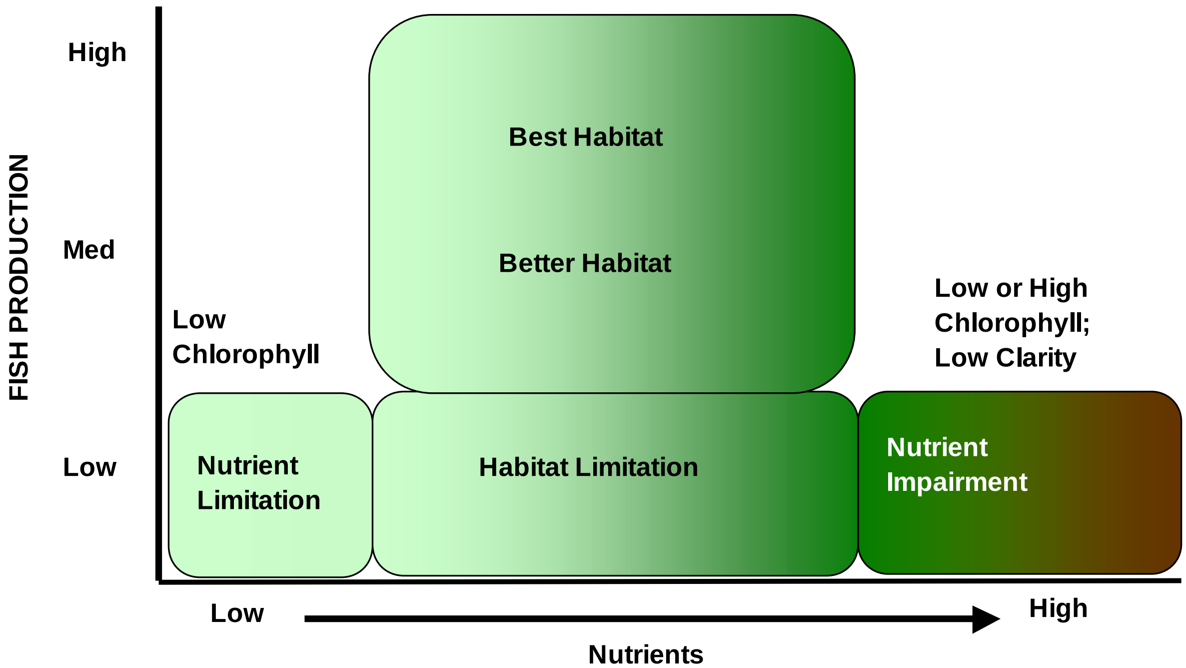

Figure D.2. Conceptual model illustrating the expected relationship between fish production, habitat, nutrients, chlorophyll, and clarity.

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

Distributions of water quality data, particularly TP, TN, Chla, and SD, were examined for reservoirs for the high, medium, and low final MsFish index categories. These distributions are summarized in the box and whisker plots for reservoirs provided in Figure D.3. The distribution of each water quality parameter indicates the range of values that support particular levels of aquatic life use attainment as indicated by the final MsFish index values.

Figure D.3 indicates that the low category of MsFish is associated with lower nutrient and chlorophyll-a concentrations and higher Secchi disc transparency than the medium and high categories. This result suggests a classic nutrient limitation-enrichment response in which the low MsFish category is associated with nutrient limitation, while the medium and high MsFish categories indicate higher

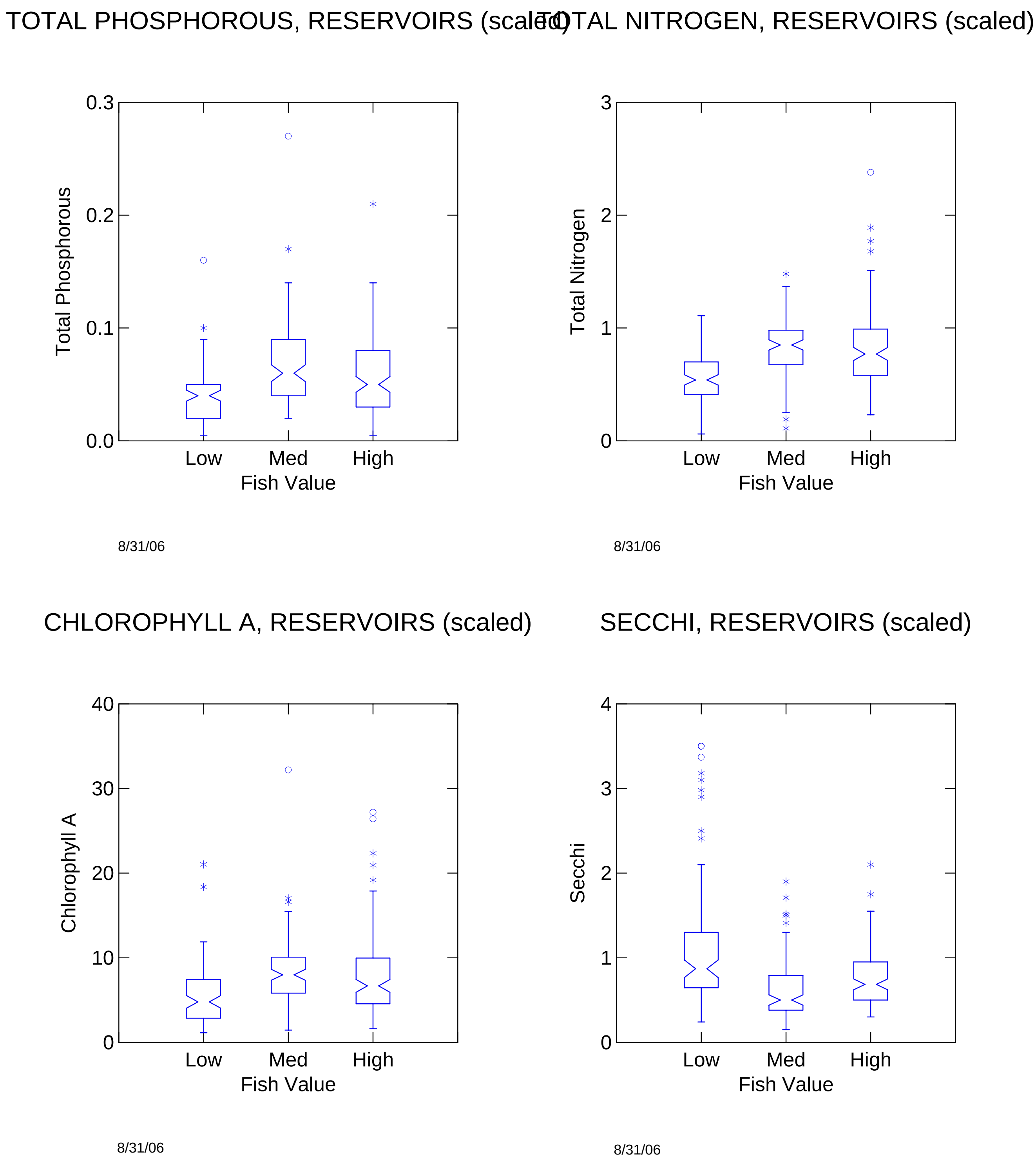

Figure D.3. Box and whisker plots comparing distributions of TP (mg/L), TN (mg/L), Chla (ug/L) and SD (m) among Low, Medium and High final MsFish index values in reservoirs and large reservoirs combined.

productivity in response to higher nutrient levels. In this case nutrient levels are not high enough to cause conditions that impair sport fish production.

TP, TN, Chla, and SD values associated with the high MsFish category provide values for those parameters that support and do not impair aquatic life use as indicated by the quality of the sport fishery. Therefore it is appropriate to use EPA's guidance approach for setting nutrient criteria, which selects the 75th percentile values of TP, TN, and Chla and the 25th percentile SD value from reference waterbodies. Table D.2 summarizes selected percentile values for each MsFish category for TP, TN, Chla, and SD. The 75th percentile values of TP, TN, and Chla and the 25th percentile SD values taken from Table D.2 are summarized below (Table D.3). These values are proposed as target values of these parameters for purposes of TMDL development.

Table D.2. Selected percentile values for total phosphorus, total nitrogen, chlorophyll-a, and Secchi disc in relation to MsFish categories in reservoirs. n = the number of data points on which the percentiles are based.

MsFish Category	Percentile	Parameter			
		Total Phosphorus (ug/L)	**Total Nitrogen (ug/L)**	**Chlorophyll a (ug/L)**	**Secchi Disc (m)**
Low	25th	20	390	3.0	0.58
	50th	35	520	4.9	0.85
	75th	50	683	7.3	1.30
	n	128	128	125	128
Medium	25th	40	680	5.7	0.35
	50th	60	850	8.1	0.48
	75th	90	1010	10.5	0.68
	n	149	149	144	148
High	25th	40	588	4.6	0.48
	50th	50	755	6.5	0.65
	75th	90	1000	10.4	0.95
	n	157	156	154	153

Table D.3. Proposed target values for total phosphorus, total nitrogen, chlorophyll-a and Secchi disc in reservoirs.

Total Phosphorus (ug/L)	Total Nitrogen (ug/L)	Chlorophyll-a (ug/L)	Secchi Disc (m)
90	1000	10.4	0.48

Nutrient, Clarity and Chlorophyll Values Supporting Aquatic Life Uses in Oxbow Lakes

Distributions of water quality data, particularly TP, TN, Chla, and SD, were examined for oxbows for the high, medium, and low final MsFish index categories. These distributions are summarized in plots for oxbows provided in Figure D.4. The distribution of each water quality parameter indicates the range of values that support particular levels of aquatic life use attainment as indicated by the final MsFish index values. In contrast to the patterns seen in the reservoir data, the oxbow data shows low clarity and high nutrients and chlorophyll associated with both high and low MsFish categories. As illustrated by the conceptual model (Figure D.2) high nutrient concentrations (within limits) can result in a highly productive aquatic ecosystem with high-quality sport fishery or an impaired system with lower quality sport fishery. Figure D.4 indicates that both situations may be occurring in Mississippi oxbows. Figure D.4 indicates that the medium MsFish category is associated with the lowest nutrient levels and highest clarity among oxbows while both the low and high MsFish categories are associated with high nutrient and chlorophyll and low clarity levels. This result suggests that, although they have similar levels of nutrients, chlorophyll, and clarity, oxbow lakes in the high and low MsFish categories might represent TP, TN, Chla, and SD levels associated with attaining and impaired lakes, respectively.

According to the reasoning used with reservoirs, nutrient, chlorophyll, and clarity conditions associated with the high MsFish category represent levels of those parameters that support aquatic life use as indicated by quality of the sport fishery. Therefore, the 75th percentile values of TP, TN, and Chla and the 25th value of SD could represent levels of those parameters that support aquatic life use attainment in Mississippi oxbows.

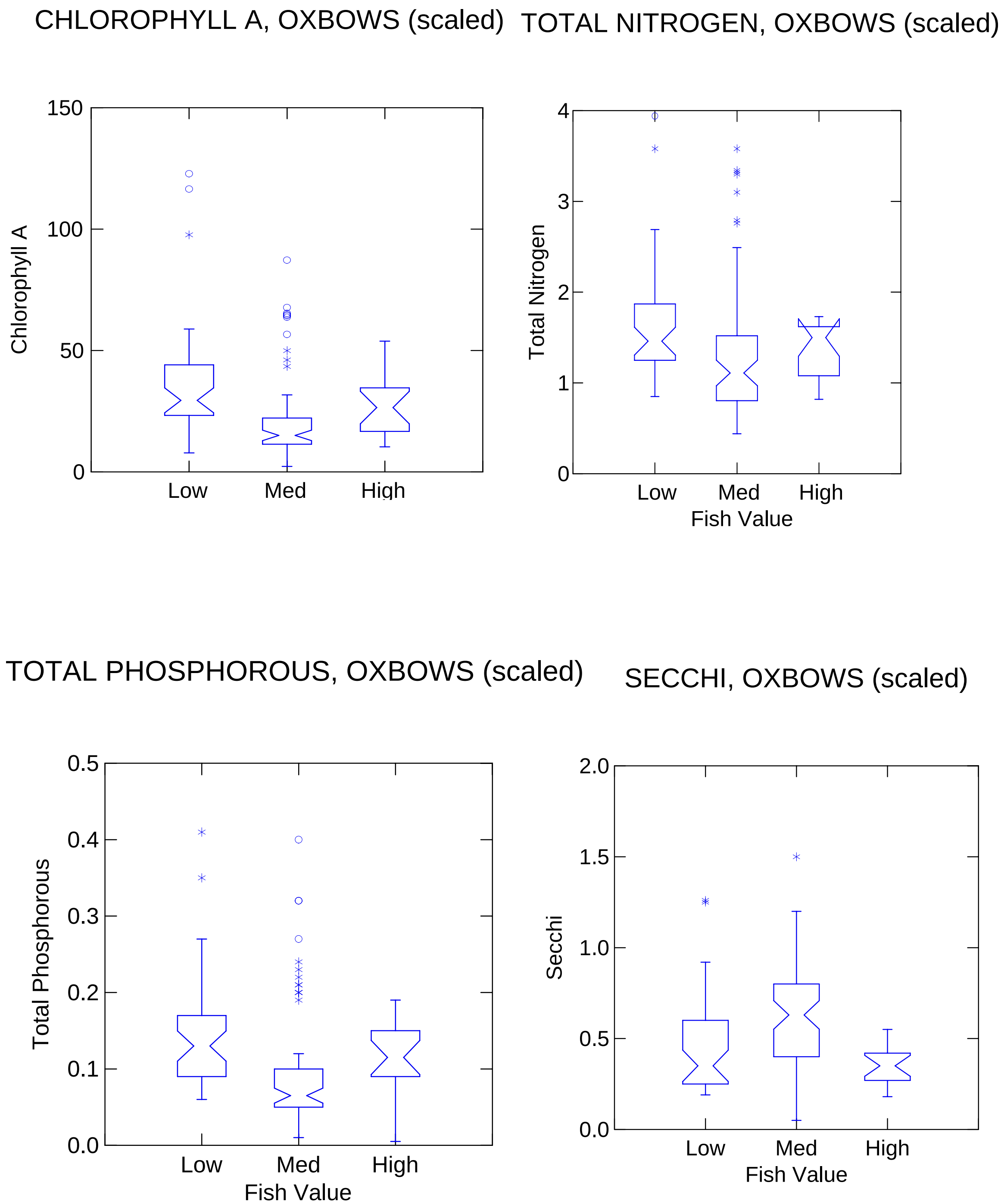

Figure D.4. Box and whisker plots comparing distributions of TP (mg/L), TN (mg/L), Chla (ug/L) and SD (m) among Low, Medium and High final MsFish index values in oxbows lakes.

Using this approach the 75th percentile values of TP, TN, and Chla and the 25th value of SD from Table D.4 are 143 ug/L, 1645 ug/L, 31.1 ug/L, and 0.30 m, respectively. The difficulty with using these values to indicate levels of nutrient, chlorophyll, and clarity that support aquatic life use attainment is that a large portion of the values in the low MsFish category are below these percentile values even though the low MsFish category represents (presumably) an impaired condition.

An alternative approach could be based upon the distribution of values, e.g. 25th percentile values for nutrients and chlorophyll and the 75th percentile value for SD in the low category. Using this approach the 25th percentile values of TP, TN, and Chla and the 75th value of SD from Table D.4 are 80 ug/L, 1208 ug/L, 20.1 ug/l and 0.64 m, respectively. This approach would identify levels of nutrients, chlorophyll, and Secchi disc that are associated with non-attainment of the aquatic life use. The difficulty with using this approach is that it would classify virtually all of the nutrient, chlorophyll, and clarity levels in the high MsFish category as not supporting the aquatic life use.

Resolving these difficulties requires a basis for distinguishing between oxbow lakes that should be compared to the low vs. high MsFish categories. This basis could be a separate line of evidence that provides some “prior expectation” as to whether the oxbow lake might be attaining its aquatic life use. For example, evidence that an oxbow lake shows high non-algal turbidity (i.e. is light limited) and/or has a low quality sport fishery provides a prior expectation that the lake is impaired and should be compared with the percentile values associated with low MsFish category. In contrast, evidence indicating that a lake supports a high quality sport fishery (e.g. based on the professional judgment of the district fishery biologist) suggests that the lake is attaining its aquatic life uses and should be compared with the percentile values associated with Mississippi lakes within the high MsFish category.

Table D.4. Selected percentile values for total phosphorus, total nitrogen, chlorophyll-a, and Secchi disc in relation to MsFish categories in oxbows. n = the number of data points on which the percentiles are based.

MsFish Category	Percentile	Parameter			
		Total Phosphorus (ug/L)	Total Nitrogen (ug/L)	Chlorophyll a (ug/L)	Secchi Disc (m)
Low	25th	80	1208	20.1	0.25
	50th	110	1445	28.0	0.40
	75th	170	1825	39.9	0.64
	n	56	56	56	56
Medium	25th	50	860	10.0	0.39
	50th	70	1130	15.0	0.61
	75th	100	1540	23.0	0.80
	n	85	85	86	88
High	25th	90	1110	15.9	0.30
	50th	115	1450	20.5	0.35
	75th	143	1645	31.1	0.42
	n	24	23	21	23

Percentile values of TP, TN, Chla, and SD associated with these alternatives are provided in Table D.5. These values represent proposed target values for purposes of TMDL development in oxbow lakes for which there is additional information to support a prior expectation of impairment vs. attainment of the aquatic life use. Target levels for TP, TN, Chla and SD in lakes for which there is a prior expectation of impairment should be based on the low MsFish category (Table D.5). The target levels shown for the high MsFish category (Table D.5) should be used for lake for which there is a prior expectation of aquatic life use attainment.

Table D.5. Proposed TMDL target values for total phosphorus, total nitrogen, chlorophyll-a, and Secchi disc in oxbow lakes.

MSFish Category	Proposed Target Level			
	Total Phosphorus (ug/L)	Total Nitrogen (ug/L)	Chlorophyll-a (ug/L)	Secchi Disc (m)
Low	80	1208	20.1	0.64
High	143	1645	31.1	0.30

It should be noted that percentile values provided in Table D.4 are based on relatively few observations. Additionally, the values for the high MsFish category come from a single lake (Bee Lake; Table D.1). Therefore there is a high degree of uncertainty associated with the proposed target levels for oxbow lakes. Accordingly, these values are proposed as target values for TMDL purposes rather than as nutrient criteria.

PHOSPHORUS TARGET LEVELS PROPOSED FOR TMDLS FOR SIX ARKANSAS LAKES AND RESERVOIRS

Target levels for TP were derived for 4 oxbow lakes and 2 reservoirs in Arkansas. Oxbows include Horseshoe Lake, Old Town Lake, First Old River Lake and Grand Lake and reservoirs are represented by Bear Creek Lake and Mallard Lake. For purposes of developing a TP target level, Mallard Lake will be classified as an oxbow lake because its location and watershed size more closely resemble those of oxbow lakes.

Using the approach provided above based on the MsFish index from reservoirs in Mississippi, a target TP level of 90 ug/L is proposed for Bear Creek Lake.

In order to use the approach described above for oxbow lakes additional information and professional judgment was obtained regarding the quality of the sport fishery in Horseshoe Lake, Old Town Lake, First Old River Lake, Grand Lake and Mallard Lake. Little quantitative data applicable to all of the lakes in this study are available. Because of this, personal interviews were conducted with AGFC district fisheries biologists. The consensus is that nutrient enrichment is generally not a major problem in regard to fisheries in these lakes. In fact, exceptional crappie fisheries are reported for Grand Lake and First Old River Lakes (telephone interviews with Diana Andrews, AGFC District 5 fisheries biologist and Drew Wilson, AGFC District 7 fisheries biologist, October 2006). The exceptions to generally healthy fisheries are Old Town Lake and Mallard Lake. Old Town Lake is reported to be “eutrophic, shallow, and soupy green” with only catfish being noted as providing good fishing during certain seasons of the year (telephone interview with Jeff Farwick, AGFC district 4 fisheries biologist, October 2006). Mallard Lake is rated “medium low” in fishery quality and has experienced a shift in species composition from desirable game fish (i.e. bass, crappie, bream) to less desirable “rough fish” such as drum and shad (telephone interview with Sam Barkley, AGFC District 3 Fisheries Biologist, October 2006).

A few small isolated fish kills over a period of 15-20 years were reported for Horseshoe Lake, Old Town Lake and First Old River Lake (telephone interviews with Jeff Farwick, AGFC District 4 fisheries biologist and Drew Wilson, AGFC District 7 fisheries biologist, October 2006). Most of the fisheries biologists interviewed suggest that fish recruitment and spawning success are likely linked to water levels during spawning, rather than nutrient impairment.

This information suggests that, because of the favorable assessment of the sport fisheries of Horseshoe Lake, First Old River Lake and Grand Lake target TP values should be obtained from the high MsFish value row of Table D.5. That is, the professional opinion of district fisheries biologists suggest that there is a prior expectation of aquatic life use attainment in Horseshoe Lake, First Old River Lake and Grand Lake. Accordingly, based on the approach described in previous sections, a TP target value of 143 ug/L (from Table D.5) is proposed for these lakes.

In contrast, the professional opinion of the sport fisheries of Mallard Lake and Old Town Lake is less favorable. That is, the professional opinion of district fisheries biologists suggests that there is a prior expectation of aquatic life use impairment in Mallard Lake and Old Town Lake. Accordingly, a TP target value of 80 ug/L (from Table D.5) is proposed for these lakes.

These proposed TP target levels are summarized in Table D.6.

Table D.6. Proposed TP target levels for TMDL development in 6 Arkansas lakes and reservoirs.

Waterbody	TP Target (ug/L)
Horseshoe Lake	143
First Old River Lake	143
Grand Lake	143
Mallard Lake	80
Old Town	80
Bear Creek Lake	90

APPENDIX D1

Mississippi Fishing Index (MSFish) Procedures

Mississippi Fishing Index (MsFish) Procedures
1/5/06

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

<u>Data Requirements</u>

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

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

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

Scoring Criteria for Parameters:

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

Acronyms:

RSDp = Relative Stock Density (preferred)
RSDm = Relative Stock Density (memorable)
RSDt = Relative Stock Density (trophy)
PSD = percent stock density
Wr = Relative weight

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

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

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

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

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

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

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

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

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

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

MsFish Calculation Procedure:

Waterbody: ___________________________ Species: ______________________

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

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

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

Mississippi Sportfishing Index (MsFish) variables. CPD = catch per day of fish $\geq$ stock size per mile of electrofishing. CPH = catch per hour.

Largemouth Bass									
Lake Name	**PSD**	**RSDp**	**RSDm**	**RSDt**	**Wr**	**CPD**	**Angler CPH**	**Size Kept**	**Target Species**
Crappie									
Bream									

APPENDIX II. Final MsFish scores ranked highest to lowest.

Largemouth Bass		**Crappie**		**Bream**	
Lake	**Score**	**Lake**	**Score**	**Lake**	**Score**

Distance Sampling

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

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

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

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

APPENDIX D2

MSFish Index Values for Mississippi Lakes and Reservoirs

Table D2.1. Unscaled average MsFish scores for each waterbody sampled by MDWFP. Waterbodies that have a "waterbody type" listed were also sampled by MDEQ. LMB = largemouth bass, CRA = crappie, and BRE = bream.

Lake Name	Waterbody Type	LMB	CRA	BRE	Lake Name	Waterbody Type	LMB	CRA	BRE
Aberdeen	Large Res	49	69	15	Paul B. Johnson		67	43	29
Aliceville	Res	34	73	20	Percy Quinn State Park		62	30	2
Arkabutla	Large Res	44	86	27	Ross Barnett Lake	Res	64	19	37
Bee	Oxbow	52	80	38	Ross Barnett Reservoir	Large Res	54	63	25
Clarkco		72	7	25	Tangipahoa	Res	66	10	18
Columbus	Large Res	46	80	18	Tippah	Res	63	53	58
Enid	Large Res	46	88	27	Washington	Oxbow	41	63	45
Geiger	Res	69	28	29	Bay Springs	Large Res	49	48	33
Lamar Bruce		71	45	59	Beulah	Oxbow	12	52	38
Lincoln	Res	68	30	38	Bogue Homa	Res	48	31	30
Lowndes		73	20	66	Charlie Capps		51	54	11
Moon	Oxbow	40	76	6	DeSoto	Oxbow	54	56	42
Sardis	Large Res	52	90	44	Eagle	Oxbow	51	48	40
Tombigbee State Park		71		58	Elvis Presley	Res		54	
Trace State Park	Res	76	13	67	Little Round		22	54	12
Tunica Cutoff	Oxbow	25	68	37	Lock A Tenn Tom	Res	35		2
Claude Bennett	Res	65	47	33	Lock C Tenn Tom	Res	36	44	4
Columbia		63	18	46	Lock D Tenn Tom	Res	53	14	12
Grenada	Large Res	33	67		Mike Conner		36	23	49
Jeff Davis		57	33	51	Okatibbee		34	56	16
Kemper	Res	63	29	16	Oktibbeha		52	48	44
Lock B Tenn Tom	Res	42	62	2	Perry		52	37	53
Mary Crawford	Res	62	38	39	Pickwick	Large Res	43	56	26
Monroe		59	51	59	Roosevelt		45	12	46
Mossy		23	60	12	Simpson		45	16	36
Natchez State Park	Res	58	20	30	Whittington	Oxbow	39	48	32

Table D2.2 Scaled average MsFish scores for each waterbody sampled by MDWFP. Waterbodies that have a "waterbody type" listed were also sampled by MDEQ. LMB = largemouth bass, CRA = crappie, and BRE = bream.

Lake Name	Waterbody Type	LMB	CRA	BRE	Lake Name	Waterbody Type	LMB	CRA	BRE
Arkabutla	Large Res	58	96	41	Mike Conner		48	25	74
Bee	Oxbow	68	89	57	Moon	Oxbow	53	84	9
Clarkco		95	8	38	Natchez State Park	Res	76	22	45
Claude Bennett		86	52	49	Percy Quinn State Park		82	33	3
Columbus	Large Res	60	89	28	Perry		68	41	79
Enid	Large Res	60	97	41	Ross Barnett Lake		84	21	55
Geiger	Res	90	31	44	Ross Barnett Reservoir	Large Res	71	70	38
Lamar Bruce		94	50	89	Tunica Cutoff	Oxbow	33	75	55
Lincoln	Res	89	33	57	Washington	Oxbow	54	70	67
Lowndes		96	22	99	Bay Springs	Large Res	64	53	49
Monroe		77	56	88	Beulah	Oxbow	16	58	57
Paul B. Johnson		88	48	44	Bogue Homa	Res	63	34	46
Sardis	Large Res	68	100	65	Charlie Capps		67	60	16
Tangipahoa	Res	87	11	27	Eagle	Oxbow	68	53	61
Tippah		83	59	88	Elvis Presley	Res	0	60	0
Tombigbee State Park		93	0	87	Little Round		29	60	18
Trace State Park	Res	100	14	100	Lock A Tenn Tom	Res	45	0	3
Aberdeen	Large Res	64	76	23	Lock B Tenn Tom	Res	55	69	3
Aliceville	Res	45	81	30	Lock C Tenn Tom	Res	47	49	6
Columbia		82	20	69	Mossy		30	67	18
DeSoto	Oxbow	71	62	63	Okatibbee		44	63	24
Grenada	Large Res	43	74	0	Oktibbeha		68	53	66
Jeff Davis		75	37	77	Pickwick	Large Res	57	62	39
Kemper	Res	83	32	25	Roosevelt		59	13	69
Lock D Tenn Tom	Res	70	16	18	Simpson		60	18	54
Mary Crawford		82	42	58	Whittington	Oxbow	52	53	48

APPENDIX E

Calculation of Inflow: In-lake TP Ratios

APPENDIX E

Calculation of Inflow to In-Lake TP Ratios

The ratio of average inflow total phosphorus (TP) concentration to average in-lake TP concentration was calculated for three oxbow lakes in the Mississippi Alluvial Plain ecoregion within the state of Mississippi. The purpose of these calculations was to estimate a ratio that could be used to account for the fact that not all of the inflow TP ends up in the water column of the lake.

These calculations used data that were reported in EPA Clean Lakes studies for each lake (FTN 1991a, b, c). These three lakes were selected for these calculations because all three lakes are in the Mississippi Alluvial Plain ecoregion and each of the lakes already had in-lake data for TP as well as annual mass balances that provided good estimates of inflow volume and inflow TP load. Flow-weighted average inflow TP concentrations were calculated as annual inflow TP loads divided by annual inflow volumes. The inflow to in-lake ratios of TP were then calculated as flow-weighted average inflow TP concentrations divided by average TP concentrations in the lake.

As shown in the table below, these calculations yielded ratios ranging from approximately 1.6 to 3.6. To provide a conservative calculation of allowable loads for Arkansas lakes, the lowest ratio (1.6) was used. The numbers used in the calculations are summarized in the table below.

Lake Name	Total Inflow 10^6 m3	Phosphorus load (Kg)	Inflow P concentration (mg/L)	Lake P concentration (mg/L)	Inflow: Lake ratio
Lake Washington	66	31620	0.48	0.13	3.69
Moon Lake	132.6	61790	0.47	0.19	2.45
Wolf Lake	64.2	22990	0.36	0.23	1.56