Fort Gibson Lake TMDL Report

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Water Quality Division

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By

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LIST OF ACRONYMS AND ABBREVIATIONS

3-D	Three-dimensional
ADCP	Acoustic Doppler Continuous Profiler
ARRA	American Recovery and Reinvestment Act of 2009
BMP	Best management practices
CBOD	Carbonaceous Biochemical oxygen demand
BUMP	Beneficial Uses Monitoring Program
CAFO	Concentrated Animal Feeding Operation
CASTNET	Clean Air Status and Trends Network
CFR	Code of Federal Regulations
cfs	cubic feet per second
Chl-a	Chlorophyll-a
COD	Chemical Oxygen Demand

COE	United States Army Corps of Engineers
COMCD	Central Oklahoma Master Conservancy District
CPP	Continuing Planning Process
CST	Central Standard Time Zone
CV	Coefficient of Variation
CWA	Clean Water Act
DEQ	Oklahoma Department of Environmental Quality
DIN	Dissolved inorganic nitrogen (DIN=nitrate + ammonia)
DMR	Discharge Monitoring Report
DO	Dissolved Oxygen
DOC	Dissolved Organic Carbon
DON	Dissolved Organic Nitrogen
DOP	Dissolved Organic Phosphorus
DSLLC	Dynamic Solutions, LLC
EFDC	Environmental Fluid Dynamics Code
EPA	Environmental Protection Agency
FWP	Fish & Wildlife Propagation
HSPF	Hydrologic Simulation Program FORTRAN
HUC	Hydrologic Unit Code
GIS	Geographic Information System
GUI	Graphical user interface
Kg	Kilograms
LA	Load Allocation
lb	pound
LTA	Long-Term average load
mg/L	milligram per liter
MDL	Maximum Daily Load
MOS	Margin of Safety
MS4	Municipal separate storm sewer system
MSGP	Multi-Sector General Permits
MSL	Mean Sea Level
NADP	National Atmospheric Deposition Program
NAD83	North American Datum of 1983
NAVD88	North American Vertical Datum of 1988
NCDC	National Climatic Data Center (NOAA)
NED	National Elevation Dataset
NGVD29	National Geodetic Vertical Datum of 1929
NH4	Ammonium-N
NHD	National Hydrography Dataset
NLCD	National Land Cover Database
NLW	Nutrient Limited Watershed
NO2	Nitrite-N
NO3	Nitrate-N
NO23	Nitrite-N + Nitrate-N
NOAA	National Oceanic Atmospheric Administration
NPDES	National Pollutant Discharge Elimination System
NPS	Nonpoint Source
N-S	Nash-Sutcliffe coefficient

NTU	Nepholometric turbidity units
O.S.	Oklahoma Statutes
OAC	Oklahoma Administrative Code
OCC	Oklahoma Conservation Commission
ODAFF	Oklahoma Department of Agriculture, Food, and Forestry
OOWA	Oklahoma Ordnance Works Authority
OKWBID	Oklahoma Waterbody Identification Number
OWRB	Oklahoma Water Resources Board
PFO	Poultry Feeding Operation
POC	Particulate Organic Carbon
PON	Particulate Organic Nitrogen
POP	Particulate Organic Phosphorus
RMS	Root Mean Square
RMSE	Root Mean Square Error
r^2	Correlation coefficient
SIC	Standard Industrial Classification
SOD	Sediment Oxygen Demand
SSO	Sanitary Sewer Overflow
SWP3	Storm Water Pollution Prevention Plan
SWS	Sensitive Water Supply
TKN	Total Kjeldahl Nitrogen
TMDL	Total Maximum Daily Load
TN	Total Nitrogen
TOC	Total Organic Carbon
TON	Total Organic Nitrogen
TOP	Total Organic Phosphorus
TP	Total Phosphorus
TPO4	Total Phosphate
TSI	Trophic State Index
TSS	Total Suspended Solids
USDA	United States Dept. Agriculture
USGS	United States Geological Survey
UTM	Universal Transverse Mercator (map projection)
WLA	Wasteload allocation
WQM	Water quality monitoring
WQMP	Water Quality Management Plan
WQS	Water Quality Standard
WWAC	Warm Water Aquatic Community
WWTP	Wastewater treatment plant

EXECUTIVE SUMMARY

Fort Gibson Lake is a 19,900-acre reservoir located in the hills of eastern Oklahoma about 5 miles northwest of Fort Gibson and 50 miles southeast of Tulsa. The lake, with 225 miles of shoreline in Wagoner, Cherokee and Mayes Counties, was constructed in 1953 by impounding the Lower Neosho River for hydropower and flood control. The lake also plays a role in ensuring adequate water for the operation of the McClellan-Kerr Arkansas River Navigation System. The reservoir, owned and operated by the USACE, Tulsa District, is located about 7.7 miles upstream of the confluence of the Lower Neosho River with the Arkansas River.

Reservoirs located upstream of Fort Gibson Lake in the Neosho River basin include Grand Lake, Lake Hudson, Spavinaw Lake, and Lake Eucha. Grand Lake (Lake o' the Cherokees) and Lake Hudson are owned and operated for hydropower by the Grand River Dam Authority. The outflow from Grand Lake is discharged into the Neosho River which in turn, flows into Lake Hudson. Flow from Lake Eucha and Spavinaw Lake is discharged into the upper end of Lake Hudson via Spavinaw Creek. In addition to inflow from the outlet of Lake Hudson on the Neosho River, tributaries to Fort Gibson Lake include Clear Creek, Spring Creek, and Fourteen Mile Creek on the eastern shore of the lake and Pryor Creek, Crutchfield Branch, and Choteau Creek on the western shore. The outflow from Lake Hudson provides the upstream boundary inflow to the lake model domain of the Lower Neosho River and Fort Gibson Lake. Drainage area of the entire watershed to Fort Gibson Lake is 12,492 square miles.

Oklahoma's 2010 Integrated Report and 303(d) list is used as the basis for identifying dissolved oxygen and turbidity as the water quality constituents responsible for impairments for Fish & Wildlife Propagation (FWP) for a Warm Water Aquatic Community (WWAC) in Fort Gibson Lake. In the 2010 Integrated Report, Fort Gibson Lake is on the 303(d) list for impaired beneficial uses of Fish and Wildlife Propagation (FWP) in a Warm Water Aquatic Community (WWAC). Appendix C of the 2010 Integrated Report shows that Fort Gibson Lake (OK121600010050_00) is identified as impaired for beneficial uses related to FWP WWAC because of dissolved oxygen. Appendix C also shows that Fort Gibson Lake, Upper (OK121600010200_00) is identified for impairment of FWP WWAC because of turbidity. In addition to the 303(d) listing in the 2010 Integrated Report, Fort Gibson Lake is one of 21 lakes in Oklahoma that have been designated as a Nutrient Limited Watershed (NLW) in the Oklahoma Water Quality Standards. Fort Gibson Lake, and the other NLW lakes, are designated as a Nutrient-Limited Watershed (NLW) in Appendix A of the OWQS because aesthetic uses of the lake are adversely affected by nutrient enrichment, as determined by Carlson's Trophic State Index (TSI, using chlorophyll-a) of 62 or greater (Carlson, 1977).

This report documents the data and assessment methods used to establish total maximum daily loads (TMDL) for Fort Gibson Lake (OK121600010050_00) and Fort Gibson Lake, Upper (OK121600010200_00). Data assessment and TMDL calculations are conducted in accordance with requirements of Section 303(d) of the federal Clean Water Act (CWA), Water Quality Planning and Management Regulations (40 CFR Part 130), United States Environmental Protection Agency (USEPA) guidance, and Oklahoma Department of Environmental Quality (DEQ) guidance and procedures. DEQ is required to submit all TMDLs to the USEPA for review and approval. Once the USEPA approves a TMDL, the waterbody may then be moved to

Category 4 of a state's Integrated Water Quality Monitoring and Assessment Report, where it remains until compliance with water quality standards (WQS) is achieved (USEPA, 2003).

The purpose of this TMDL report is to establish waste load allocations (WLA) and load allocations (LA) determined to be necessary for reducing turbidity and chlorophyll-*a* levels and maintaining sufficient dissolved oxygen levels in the lake to attain water quality targets to restore impaired FWP beneficial uses for this Nutrient Limited Watershed. TMDLs determine the pollutant loading that a waterbody, such as Fort Gibson Lake, can assimilate without exceeding water quality standards. TMDLs also establish the pollutant load allocation necessary to meet the water quality standards established for a waterbody based on the relationship between pollutant sources and water quality conditions in the waterbody. A TMDL consists of a waste load allocation (WLA), load allocation (LA), and a margin of safety (MOS). The WLA is the fraction of the total pollutant load apportioned to point sources, and includes municipal and industrial wastewater treatment facilities and urban storm water discharges regulated under the National Pollutant Discharge Elimination System (NPDES) as point sources. The LA is the fraction of the total pollutant load apportioned to nonpoint or distributed sources. The MOS is incorporated in a TMDL determination to account for the lack of knowledge associated with natural processes in aquatic systems, assumptions related to the watershed-lake model, and data limitations.

EPA guidance allows for use of either implicit or explicit expressions of the MOS, or both. When conservative assumptions are used in development of the TMDL, or conservative factors or assumptions are used in the TMDL analysis, the MOS is considered to be implicit. When a specific percentage of the TMDL is set aside to account for the lack of knowledge, then the MOS is considered explicit and the MOS quantifies an allocation amount separate from other load and wasteload allocations. The TMDLs determined for Fort Gibson Lake incorporate an implicit Margin of Safety (MOS) based on a conservative assumption for more stringent water quality targets.

This report does not identify specific control actions (regulatory controls) or management measures (voluntary best management practices) necessary to reduce pollutant loading from the watershed. Watershed-specific control actions and management measures will be identified, selected, and implemented under a separate process involving stakeholders who live and work in the watershed, along with local, state, and federal government agencies.

Problem Identification and Water Quality Targets

Designated uses of Fort Gibson Lake are hydropower production, flood control, public and private water supply, agriculture, primary body contact recreation, and fish and wildlife propagation. As of the 2010 census, the Lower Neosho River basin population is estimated at 56,846 persons. Fort Gibson Lake serves as a public water supply for several municipalities and rural towns located in the watershed. The lake is also an important recreational resource for the area with excellent fishing, swimming, camping, boating, and a public hunting area with a waterfowl refuge.

Oklahoma's 2010 Integrated Report and 303(d) list is used as the basis for identifying dissolved oxygen and turbidity as the water quality constituents responsible for impairments for Fish & Wildlife Propagation

(FWP) for a Warm Water Aquatic Community (WWAC) in Fort Gibson Lake. Fort Gibson Lake is designated as a Category 5a lake on the 2010 303(d) list with a Priority 1 ranking. Category 5 defines a waterbody where, since water quality standards are not attained, the waterbody is impaired or threatened for one or more designated uses by pollutant(s), and the water body requires a TMDL. Oklahoma DEQ has designated Fort Gibson Lake as a Nutrient Limited Watershed based on the Trophic State Index computed from chlorophyll-a data. As shown in the 2010 Integrated Report, Fort Gibson Lake is also not supporting its designated uses for Fish & Wildlife Propagation for a Warm Water Aquatic Community in two Oklahoma Waterbody Identification Numbers (OKWBID) of the lake because of dissolved oxygen (OKWBID: OK121600010050_00) and turbidity (OKWBID: OK121600010200_00). High levels of turbidity and chlorophyll-a can have deleterious effects on raw water quality, such as taste and odor complaints and treatment costs of drinking water. Low levels of dissolved oxygen below the thermocline reflect decay of organic matter in the sediment bed and restricted transfer of dissolved oxygen from the surface layer because of summer thermal stratification.

The water quality targets established for Fort Gibson Lake, based on statistics of the most recent 10 years of record used for the 2010 303(d) listing, are defined as the long-term average in-lake Trophic State Index (TSI) of 62 computed from chlorophyll-a and 25 NTU's for turbidity. The recently revised Oklahoma water quality standards for dissolved oxygen for Fort Gibson Lake are specified in relation to (a) spring and summer stratified conditions for the surface layer (epilimnion) and the anoxic volume of the lake within the hypolimnion and (b) non-stratified conditions for the surface layer (OWRB, 2013). Within the surface layer (epilimnion) during the early period of thermal stratification in spring, 10% or less of the dissolved oxygen samples shall be no less than 6 mg/L from April 1 to June 15. During the summer period of stratification from June 16-October 15, 10% or less of the dissolved oxygen samples shall be no less than 5 mg/L. During the remainder of the year (October 16 to March 31) 10% or less of the dissolved oxygen samples shall be no less than 5 mg/L for the months when the lake is non-stratified. DO criteria for a Warm Water Aquatic Community lake are also defined on the basis of the anoxic volume of the lake that is less than a target cutoff level of DO. During the period of thermal stratification, the lake is fully supporting if 50% or less of the lake volume is less than the target cutoff of 2 mg/L. Where water column DO data, rather than volumetric DO data, was used to determine impairment of the lake, the lake is considered to be fully supporting if 70% or less of the water column of sampling sites are less than the target cutoff of 2 mg/L.

Pollutant Source Assessment

Water quality constituents that relate to impairments of Fort Gibson Lake include suspended sediment, chlorophyll-a, phosphorus, nitrogen, and total organic carbon. As shown in Table ES-1, the outflow from Lake Hudson accounts for the largest existing share (63%) of nitrogen sources while watershed runoff (21%), NPDES wastewater dischargers to the lake (9%) and benthic release from the lake bed (6%) contribute smaller shares. For phosphorus loading, however, the outflow from Lake Hudson (39%) and watershed runoff (13%) accounts for more than one-half (52%) of the existing loading while NPDES wastewater dischargers to the lake (26%) and benthic release from the lake bed (22%) contribute less than one-half (48%) of the phosphorus inputs to the lake.

Waste load allocations (WLA) for NPDES municipal and industrial point sources are determined for sediment, nutrients and total organic carbon. Municipal and industrial wastewater facilities are regulated under the Clean Water Act by NPDES permits. Urban stormwater discharges are also regulated by NPDES permits as part of the MS4 Stormwater Program. The MS4 areas for Wagoner County and Tahlequah that are within the watershed boundary of this TMDL study, however, account for a very small percentage of the watershed study area. The small area accounted for by two MS4 permits within the watershed are included in the overall load allocation (LA) for runoff of sediment, nutrients and TOC to tributaries and overland flow for the watershed. For sediment loading, TSS from NPDES point sources were negligible amount based on their current loading and TSS reduction from these sources would benefit little on turbidity improvement compare to the reduction effort. Therefore, TSS WLA for NPDES point sources were set at their permit limits.

Table ES-1 Relative Contribution of Point and Nonpoint Source Loading of Pollutants to Fort Gibson Lake (Model Validation, Jan-Dec 2006)

Source	TN*	TP*	TOC*	Sediment
Lake Hudson	62.9%	38.7%	26.6%	15.7%
Watershed (HSPF)	20.9%	12.8%	68.8%	83.9%
Atmospheric Deposition	1.3%	0.05%	0.0%	0.0%
Sediment Flux	6.1%	22.2%	0.0%	0.0%
NPDES Wastewater	8.7%	26.2%	4.6%	0.4%
Total	100.0%	100.0%	100.0%	100.0%

*Total Nitrogen (TN); Total Phosphorus (TP), and Total Organic Carbon (TOC)

Watershed and Lake Model

A model framework was developed to establish the cause-effect linkage between pollutant loading from the watershed (the HSPF model) and water quality conditions in the lake (the EFDC model). Flow and pollutant loading from the watershed to the lake was simulated for a two-year calibration and validation period from January 2005 to December 2006 with the public domain HSPF watershed model. Watershed model results, other input and the results of the lake sediment flux model were used to estimate the relative contributions of point and nonpoint sources of pollutant loading presented in Table ES-1.

The EFDC model was developed to simulate water quality conditions in Fort Gibson Lake for sediments, nutrients, organic matter, dissolved oxygen and chlorophyll-*a*. EFDC is a public domain surface water model that includes hydrodynamics, sediment transport, water quality, eutrophication and sediment diagenesis. The EFDC lake model was calibrated and validated to water quality data collected at 4 station locations in the lake during the two-year period from January 2005 through December 2006. Model results were calibrated to 2005 observations for water level, water temperature, TSS, nitrogen, phosphorus, dissolved oxygen, organic carbon and algae biomass (chlorophyll-a). Model results were then validated, or confirmed, using water level, water temperature, and water quality data collected in 2006. The Relative Root Mean Square (RMS) Error performance targets are assigned as (a) 20% for water level and dissolved oxygen; (b) 50% for water temperature, nitrate and total organic phosphorus; and (c) 100% for chlorophyll-a. Composite model performance statistics averaged over the 4 stations used for comparison to model results were attained for these constituents either better than, or reasonably close to, the target criteria.

The calibrated lake model was used to evaluate the water quality response to reductions in watershed loading of sediment, total organic carbon and nutrients. Load reduction scenario model runs were performed to determine if water quality targets for turbidity and chlorophyll could be attained with point and nonpoint source load reductions based on 45% removal of loading for sediment and nutrients. Based on a long-term spin-up analysis of the watershed-lake model over a 10-year period, the model results indicated that compliance with water quality criteria for dissolved oxygen, turbidity and chlorophyll could be achieved within a reasonable time frame. The calibrated and validated model results developed for Fort Gibson Lake thus support the development of TMDLs for sediments, total organic carbon, total nitrogen, and total phosphorus to achieve compliance with water quality standards for turbidity, chlorophyll and dissolved oxygen.

TMDL, Waste Load Allocation, Load Allocation and Margin of Safety

The linked watershed (HSPF) and lake (EFDC) model framework was used to calculate average annual suspended solids, total organic carbon, nitrogen and phosphorus loads (kg/yr), that, if achieved, should meet the water quality targets established for chlorophyll-a and dissolved oxygen. For reporting purposes, the final TMDLs, according to EPA guidelines, are expressed as daily loads (kg/day). The waste load allocation (WLA) for the TMDL for Fort Gibson Lake is split among the regulated NPDES point source dischargers for municipal and industrial facilities. As the MS4 areas for Wagoner County and Tahlequah that are within the watershed boundary account for only a very small contribution (0.14%) to the total area of the watershed model domain, the MS4 permits for Wagoner County and Tahlequah are not included as WLAs determined for this TMDL study.

The small MS4 area for Wagoner County and the even smaller portion of the MS4 area for Tahlequah in the HSPF model domain are accounted for by the Load Allocation (LA) for the watershed. The LA for the TMDL is split between the inflow from Lake Hudson to the Neosho River and upper Fort Gibson Lake and watershed runoff from the HSPF model. Streamflow, nonppoint source runoff, and pollutant loading to Fort Gibson Lake are provided as time series output from the HSPF watershed model for input to the EFDC lake model. In contrast to a water quality model framework that does not incorporate linkage from a watershed model to a receiving water model, natural background conditions are not represented as an explicit component of nonpoint source loading to Fort Gibson Lake. All flow and pollutant loading data assigned for input to the EFDC lake model are derived from the HSPF watershed model.

Seasonal variation was accounted for in the TMDL determination for Fort Gibson Lake in two ways: (1) water quality standards, and (2) the time period represented by the watershed and lake models. Oklahoma's water quality standards for dissolved oxygen for lakes are developed on a seasonal basis to be protective of fish and wildlife propagation for a warm water aquatic community at all life stages, including spawning. Within the surface layer, dissolved oxygen standards specify that DO levels shall be no less than 6 mg/L from April 1 to June 15 to be protective of early life stages and no less than 5 mg/L for the remainder of the year during summer stratified conditions (June 16 to October 15) and winter well-mixed conditions (October 16 through March 31). Under summer stratified conditions in Fort Gibson Lake, determined with water temperature data to be characterized by the period from April 1 to October 1, the hypoxic volume of the lake, defined by a DO target of 2 mg/L, is not to be greater than 50% of the lake volume. Where water column DO data, rather than volumetric DO data, was used to determine impairment of the lake, the lake is considered to be fully supporting if 70% or less of the water column of sampling sites are less than the target cutoff of 2 mg/L. Seasonality was also accounted for in the TMDL analysis by developing the models using two years of streamflow and water quality data collected as part of routine water quality monitoring programs conducted by OWRB and the USACE. The watershed and lake models were developed with hourly to sub-hourly time steps over two years of simulation (2005-2006) with meteorological data representative of the dry hydrologic conditions in the watershed that characterized much of eastern Oklahoma during 2005-2006.

EPA guidance about the Margin of Safety for development of TMDLs states that: *A margin of safety expressed as unallocated assimilative capacity or conservative analytical assumptions used in establishing the TMDL; e.g., derivation of numeric targets, modeling assumptions, or effectiveness of proposed management actions which ensures attainment and maintenance of water quality standards for the allocated pollutant [40 CFR 130.33(b)(7)].*

EPA guidance allows for use of either explicit or implicit expressions of the MOS, or both, to account for any lack of knowledge concerning the relationship between load and allocations and ambient water quality conditions. When a specific percentage of the TMDL is set aside to account for the lack of knowledge, then the MOS is considered explicit and the MOS quantifies a loading rate allocation separate from other Load Allocations and Wasteload Allocations. An implicit MOS, however, is not specifically quantified as a loading rate but it does incorporate conservative assumptions or factors used for development of the TMDL. If the MOS is implicit, the conservative assumptions or factors adopted for the TMDL determination that account for the MOS must be described.

The TMDL determined for Fort Gibson Lake accounts for an implicit Margin of Safety (MOS) based on conservative assumptions for more stringent numeric water quality targets. The TMDL determinations for Fort Gibson Lake accounted for an implicit MOS with a 10% reduction in numeric water quality targets for turbidity, TSI, dissolved oxygen, and the anoxic percentage of the water column. Adoption of more stringent water quality targets as a conservative assumption will ensure an adequate implicit MOS for the determination of wasteload (WLA) and load allocations (LA) for Fort Gibson Lake. The TMDL for suspended sediment, total organic carbon, total nitrogen, and total phosphorus, determined from the lake model response to watershed load reductions, is based on 45% reduction of the existing 2006 NPDES wastewater loading, inflow from Lake Hudson to the Neosho River and watershed runoff loads estimated with the HSPF model.

Future growth in the watershed may include changes in land use from rural and agricultural uses to accommodate new residential areas and increases in municipal wastewater discharges to accommodate population growth. As pollutant loading changes due to future growth were not explicitly considered in developing the TMDLs, more efficient removal strategies may need to be adopted for NPDES permit limits to reduce point source loading from urban stormwater and municipal and industrial wastewater discharges to maintain compliance with the Waste Load Allocations. Similarly, more efficient BMPs may need to be implemented to maintain compliance with the Load Allocations determined for the Fort Gibson Lake TMDL.

The LA's and WLA's for the inflow from Lake Hudson, watershed runoff, and NPDES wastewater facilities are computed from the Total Maximum Daily Load (TMDL) that was, in turn, derived from the maximum daily load (MDL) computed from the long-term average daily reduced loads (LTA) for each group of external sources. The statistical methodology for the load distributions, documented in Appendix E of EPA (1991b), for computing the MDL limit is based on the LTA, temporal variability of the pollutant load dataset, load distribution statistical parameters expressed by the mean value and coefficient of variation (CV), and the Z-score statistic for 95% probability of occurrence. It has been demonstrated that pollutant loading from wastewater discharges and watershed runoff can be described by a lognormal distribution. It has also been demonstrated that pollutant loading from the inflow from Lake Hudson to the upstream boundary of Fort Gibson Lake can be represented by the delta lognormal distribution. The load allocation (LA) is computed from the TMDL and the percentage split of the total existing point source and nonpoint source load accounted for by the inflow from Lake Hudson and watershed runoff. WLA's are developed for each of the six NPDES wastewater sources discharging into the lake based on the TMDL and the percentage split of the total existing point and nonpoint source load accounted for by each wastewater facility. Summary calculations for the TMDL's, LA's and WLA's for Total Phosphorus, Total Nitrogen, Total Organic Carbon, and Total Suspended Solids are presented in Table ES-2 through Table ES-5. The methodology, equations, parameters, and a description of the lognormal and delta lognormal distributions used for the MDL calculations are detailed in Appendix I.

Table ES-2 Existing Long-Term Loading, Percent Share, Load Allocation and Waste Load Allocation for Total Maximum Daily Load (TMDL) for Total Phosphorus to Meet Water Quality Targets for Turbidity, TSI and Dissolved Oxygen in Fort Gibson Lake

Fort Gibson Lake Total-Phosphorus			% R= TMDL=	45% 2,087.6	kg/day	
Source	Existing E(X) Mean	Existing % Share	LA kg/day	WLA kg/day	LA+WLA kg/day	Margin of Safety
Lake Hudson Inflow	565.8	49.8%	1,039.95	0.0	1,039.9	Implicit
Watershed HSPF	187.4	16.5%	344.56	0.0	344.6	Implicit
Small WWTP	4.0	0.4%	0.00	7.4	7.4	Implicit
Large WWTP	378.5	33.3%	0.00	695.7	695.7	Implicit
Total	**1,135.7**	**100.0%**	**1,384.50**	**703.1**	**2,087.6**	Implicit
NPDES Wastewater						
OK0043907 (S)	3.5	0.31%	0	6.5	6.5	Implicit
OKG380001 (S)	0.3	0.03%	0	0.5	0.5	Implicit
OK0033791 (S)	0.2	0.02%	0	0.4	0.4	Implicit
OK34568-006 (L)	364.7	32.11%	0	670.3	670.3	Implicit
OK0000272 (L)	1.8	0.16%	0	3.3	3.3	Implicit
OK0035149 (L)	12.0	1.06%	0	22.1	22.1	Implicit
Lake Hudson Inflow	Delta lognormal distribution					
Watershed HSPF	Lognormal distribution					
Small WWTP	Lognormal distribution					
Large WWTP	Lognormal distribution					

Table ES-3 Existing Long-Term Loading, Percent Share, Load Allocation and Waste Load Allocation for Total Maximum Daily Load (TMDL) for Total Nitrogen to Meet Water Quality Targets for Turbidity, TSI and Dissolved Oxygen in Fort Gibson Lake

Fort Gibson Lake Total-Nitrogen			% R= 45% TMDL= 16,711.0 kg/day			
Source	Existing E(X) Mean	Existing % Share	LA kg/day	WLA kg/day	LA+WLA kg/day	Margin of Safety
Lake Hudson Inflow	5,012.2	68.0%	11,361.0	0.0	11,361.0	Implicit
Watershed HSPF	1,663.9	22.6%	3,771.5	0.0	3,771.5	Implicit
Small WWTP	29.0	0.4%	0.0	65.6	65.6	Implicit
Large WWTP	667.4	9.1%	0.0	1,512.9	1,512.9	Implicit
Total	**7,372.5**	**100.0%**	**15,132.5**	**1,578.5**	**16,711.0**	Implicit
NPDES Wastewater						
OK0043907 (S)	10.53	0.14%	0	23.9	23.9	Implicit
OKG380001 (S)	10.55	0.14%	0	23.9	23.9	Implicit
OK0033791 (S)	7.87	0.11%	0	17.8	17.8	Implicit
OK34568-006 (L)	570.46	7.74%	0	1,293.0	1,293.0	Implicit
OK0000272 (L)	17.12	0.23%	0	38.8	38.8	Implicit
OK0035149 (L)	80.22	1.09%	0	181.8	181.8	Implicit
Lake Hudson Inflow	Delta lognormal distribution					
Watershed HSPF	Lognormal distribution					
Small WWTP	Lognormal distribution					
Large WWTP	Lognormal distribution					

Table ES-4 Existing Long-Term Loading, Percent Share, Load Allocation and Waste Load Allocation for Total Maximum Daily Load (TMDL) for Total Organic Carbon to Meet Water Quality Targets for Turbidity, TSI and Dissolved Oxygen in Fort Gibson Lake

Fort Gibson Lake Total Organic Carbon (TOC)			% R= TMDL=	45% 63,109.4	 kg/day	
Source	Existing E(X) Mean	Existing % Share	LA kg/day	WLA kg/day	LA+WLA kg/day	Margin of Safety
Lake Hudson Lake	9,211.8	26.6%	16,800.3	0.0	16,800.3	Implicit
Watershed HSPF	23,794.4	68.8%	43,395.9	0.0	43,395.9	Implicit
Small WWTP	37.6	0.1%	0.0	68.6	68.6	Implicit
Large WWTP	1,559.8	4.5%	0.0	2,844.7	2,844.7	Implicit
Total	**34,603.6**	**100.0%**	**60,196.2**	**2,913.3**	**63,109.4**	Implicit
NPDES Wastewater						
OK0043907 (S)	30.2	0.09%	0.0	55.1	55.1	Implicit
OKG380001 (S)	4.3	0.01%	0.0	7.8	7.8	Implicit
OK0033791 (S)	3.2	0.01%	0.0	5.8	5.8	Implicit
OK34568-006 (L)	899.3	2.60%	0.0	1,640.1	1,640.1	Implicit
OK0000272 (L)	387.5	1.12%	0.0	706.8	706.8	Implicit
OK0035149 (L)	281.0	0.81%	0.0	512.5	512.5	Implicit
Lake Hudson Inflow	Delta lognormal distribution					
Watershed HSPF	Lognormal distribution					
Small WWTP	Lognormal distribution					
Large WWTP	Lognormal distribution					

Table ES-5 Existing Long-Term Loading, Percent Share, Load Allocation and Waste Load Allocation for Total Maximum Daily Load (TMDL) for Total Suspended Solids to Meet Water Quality Targets for Turbidity, TSI and Dissolved Oxygen in Fort Gibson Lake

Fort Gibson Lake Total Suspended Solids (TSS)			% R= 45% TMDL= 117,188.5 kg/day			
Source	Existing E(X) Mean	Existing % Share	LA kg/day	WLA kg/day	LA+WLA kg/day	Margin of Safety
Lake Hudson Inflow	27,556.7	15.7%	18,402.3	0.0	18,402.3	Implicit
Watershed HSPF	147,275.7	83.9%	94,242.5	0.0	94,242.5	Implicit
Small WWTP	10.5	0.0%	0.0	264.0	264.0	
Large WWTP	642.2	0.4%	0.0	4,279.7	4,279.7	
Total	**175,485.2**	**100.0%**	**112,644.8**	**4,543.7**	**117,188.5**	Implicit
NPDES Wastewater						
OK0043907 (S)	5.3	0.00%	0	227.1	227.1	
OKG380001 (S)	2.6	0.00%	0	34.1	34.1	
OK0033791 (S)	2.7	0.00%	0	2.8	2.8	
OK34568-006 (L)	438.9	0.25%	0	969.8	969.8	
OK0000272 (L)	103.0	0.06%	0	1,095.4	1,095.4	
OK0035149 (L)	103.4	0.06%	0	2,214.5	2,214.5	
Lake Hudson Inflow	Delta lognormal distribution					
Watershed HSPF	Delta lognormal distribution					
Small WWTP	Permit limit					
Large WWTP	Permit limit					

Public Participation

The public had a 45-day opportunity to review the draft TMDL report and submit written comments. One public comment was received, and the response to that public comment can be found in Appendix J. As a result of that comment, no changes were made to this final TMDL report and its 208 Factsheet. The written comment that was received during the public notice period became a part of the record of this TMDL report. The public meeting was held on Thursday, May 11, 2023 and the final TMDL was submitted to EPA for final approval.

1.0 INTRODUCTION

1.1 Clean Water Act and TMDL Program

Section 303(d) of the federal Clean Water Act (CWA) and U.S. Environmental Protection Agency (USEPA) Water Quality Planning and Management Regulations (40 Code of Federal Regulations [CFR] Part 130) require states to develop total maximum daily loads (TMDL) for waterbodies not meeting designated uses where technology-based controls are in place. TMDLs establish the allowable loadings of pollutants or other quantifiable parameters for a waterbody based on the relationship between pollution sources and in-stream water quality conditions, so States can implement water quality-based controls to reduce pollution from point and nonpoint sources and restore and maintain water quality (USEPA, 1991a).

This report documents the data and assessment used to establish TMDLs for turbidity, chlorophyll-a, and dissolved oxygen for Fort Gibson Lake reservoir in Cherokee County, Oklahoma in the Lower Neosho basin (HUC 11070209). High levels of turbidity reflect sediment loading from the watershed and elevated levels of chlorophyll-a in lakes reflect nutrient enrichment and excessive algae growth. High levels of both turbidity and chlorophyll-a can have deleterious effects on the raw water quality and treatment costs of drinking water. Excessive algae growth can also negatively affect the aquatic biological communities of lakes. Elevated chlorophyll-a concentration typically indicates eutrophication of the lake as a result of excessive loading of the primary growth-limiting algal nutrients (nitrogen or phosphorus) to the waterbody. Low levels of dissolved oxygen, particularly at depths deeper than the seasonal thermocline, reflect the effects of decomposition of organic matter below the thermocline and within the sediment bed and restricted mixing of dissolved oxygen from the surface layer of the lake to the lower layer of the lake during conditions of summer stratification.

The purpose of this TMDL report is to establish sediment, organic matter and nutrient load allocations necessary for improving turbidity, chlorophyll-a and dissolved oxygen levels in the lake as the first step toward restoring water quality in this lake. TMDLs determine the pollutant loading a waterbody can assimilate without exceeding applicable water quality standards (WQS). TMDLs also establish the allocation of pollutant loads necessary to meet the WQS established for a waterbody based on the cause-effect relationship between pollutant sources and water quality conditions in the waterbody. A TMDL consists of three components: (1) wasteload allocation (WLA), (2) load allocation (LA), and (3) margin of safety (MOS). The WLA is the fraction of the total pollutant load apportioned to point sources. Point sources include municipal and industrial wastewater facilities and urban storm water discharges regulated under the CWA National Pollutant Discharge Elimination System (NPDES). The LA is the fraction of the total pollutant load apportioned to nonpoint sources (NPS). The MOS is a percentage of the TMDL set aside to account for the lack of knowledge associated with natural process in aquatic systems, surface water model assumptions, and data limitations.

Data assessment and TMDL calculations are conducted in accordance with requirements of Section 303(d) of the CWA, Water Quality Planning and Management Regulations (40 CFR Part 130), USEPA guidance, and Oklahoma Department of Environmental Quality (DEQ) guidance and procedures. DEQ is required to submit all TMDLs to USEPA for review and approval. Once the USEPA approves a TMDL, then the waterbody may be moved to Category 4a of a State's Integrated Water Quality Monitoring and Assessment Report, where it remains until compliance with water quality standards (WQS) is achieved (USEPA 2003).

This report does not stipulate specific control actions (regulatory controls) or management measures (voluntary best management practices) necessary to reduce nutrients within the lake watershed. Watershed-specific control actions and management measures will be identified, selected, and implemented under a separate process involving stakeholders who live and work in the watersheds, along with local, state, and federal government agencies.

Fort Gibson Lake is on Oklahoma's 2010 303(d) list for impaired beneficial uses of Fish and Wildlife Propagation for Warm Water Aquatic Community life. Causes of impairment have been identified as low dissolved oxygen (OKWBID OK121600010050_00) and high turbidity in the Upper lake (OKWBID OK121600010200_00) (DEQ, 2010a). An important recreational lake for fishing and boating, Fort Gibson Lake is also designated by OWRB as a Nutrient Limited Watershed (NLW) based on Carlson's Trophic State Index and chlorophyll-a levels that impair aesthetic uses of the lake.

Figure 1-1 shows a location map of Fort Gibson Lake and the contributing sub-watersheds of the drainage basin to the lake. The map displays the locations of the upstream boundary flow station at the outlet of Lake Hudson on the Neosho River, stream water quality monitoring (WQM) stations in the watershed, and lake water quality monitoring stations used for this TMDL determination. Water quality data obtained from the lake stations over the past 10 years were used as the basis for placement of Fort Gibson Lake on the Oklahoma 303(d) list.

1.2 Watershed and Fort Gibson Lake Description

Fort Gibson Lake (OKWBID OK121600010050_00 and OK121600010200_00) is a 19,900-acre reservoir located in the hills of eastern Oklahoma in Cherokee County about 5 miles northwest of Fort Gibson and 50 miles southeast of Tulsa. The dam is located at river mile 7.7 of the Lower Neosho River at Longitude: 95° 13' 47" and Latitude: 35° 52' 11". The lake, with 225 miles of shoreline in Wagoner, Cherokee and Mayes Counties, was constructed in 1953 by impounding the Lower Neosho River for hydropower and flood control. The lake also plays a role in ensuring adequate water for the operation of the McClellan-Kerr Arkansas River Navigation System. The reservoir, owned and operated by the USACE, Tulsa District, is located 7.7 miles upstream of the confluence of the Lower Neosho River with the Arkansas River.

Reservoirs located upstream of Fort Gibson Lake in the Neosho River basin include Grand Lake, Lake Hudson, Spavinaw Lake, and Lake Eucha. Grand Lake (Lake o' the Cherokees) and Lake Hudson are owned and operated for hydropower by the Grand River Dam Authority. The outflow from Grand Lake is discharged into the Neosho River which in turn, flows into Lake Hudson. Flow and loading from Lake Eucha and Spavinaw Lake are discharged into the upper end of Lake Hudson via Spavinaw Creek. In addition to inflow from the outlet of Lake Hudson on the Neosho River, tributaries to Fort Gibson Lake include Clear Creek, Spring Creek, and Fourteen Mile Creek on the eastern shore of the lake and Pryor Creek, Crutchfield

Branch, and Choteau Creek on the western shore. The outflow from Lake Hudson provides the upstream boundary inflow to the lake model domain of the Lower Neosho River and Fort Gibson Lake. Drainage area of the entire watershed to Fort Gibson Lake is 12,492 square miles. Table 1-1 presents general physical characteristics of Fort Gibson Lake based on data obtained from OWRB and the U.S. Army Corps of Engineers, Tulsa District.

Designated uses of Fort Gibson Lake are hydropower production, flood control, public and private water supply, agriculture, primary body contact recreation, and fish and wildlife propagation. As of the 2010 census, the Lower Neosho River basin population is estimated at 56,846. Fort Gibson Lake serves as a public water supply for several municipalities (e.g., Wagoner) and rural water districts located in the watershed. The lake is also an important recreational resource for the area with excellent fishing, swimming, camping, boating, and a public hunting area with a waterfowl refuge.

Table 1-1 Physical Characteristics of Fort Gibson Lake

Drainage Area	sq-miles	12,942
Surface Area @ Normal Pool Elevation[1]	acres	19,900
Normal Conservation Pool Elevation	ft, MSL[2]	554.0
Conservation Pool Storage Volume	acre-ft	365,200
Surface Area @ Flood Pool Elevation	acres	51,000
Flood Pool Elevation	ft, MSL	582.0
Flood Control Pool Storage Volume	acre-ft	1,284,400
Average Depth	ft	18.35
Maximum Depth	ft	71.0
Shoreline	miles	225.0

1. Elevation: vertical datum, NGVD29
2. MSL: mean sea level
Data Sources: OWRB & USACE
OWRB- http://tulsaaudubon.org/guides/fort-gibson-lake-map-owrb.pdf
USACE- http://www.swt-wc.usace.army.mil/FGIB.lakepage.html

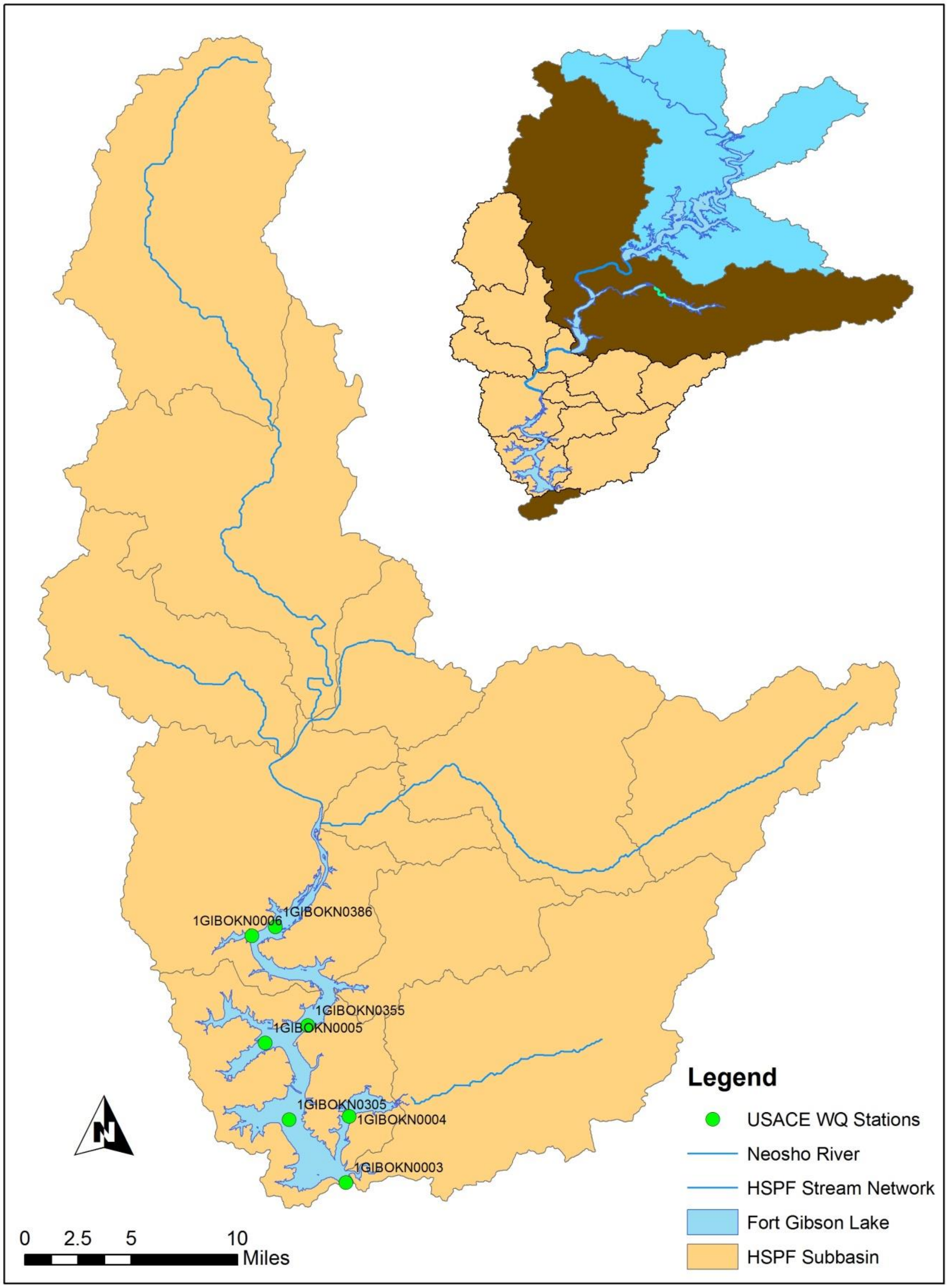

Figure 1-1 Fort Gibson Lake and Contributing Watershed

The portion of the Lower Neosho River basin that is included in the HSPF watershed model occupies 927.9 square miles of which almost one-half is primarily agricultural and pasture land. Much of the eastern portion of the basin is in the Ozark Highlands ecoregion where upland vegetation is oak-hickory and oak-hickory-pine forests. The southeast portion of the basin, characterized by oak-hickory forests and pastureland and hay fields in the flatter areas, is in the Lower Boston Mountains ecoregion. The western portion of the basin, where natural vegetation is a mix of tall grass prairie and oak-hickory forest, is in the Central Irregular Plains (Osage Cuestas) ecoregion of northeastern Oklahoma (Woods et al., 2005).

Table 1-2 summarizes the percentages and acres of land use categories for the contributing watersheds of the Lower Neosho basin used for the watershed model. Land use and land cover data were derived from the 2006 National Land Cover Database (NLCD) database (Fry et al., 2011). The most common land use category in the study area is Agricultural-Pasture with 47% of the watershed area. In addition to Grassland land use (10%), about one-third of the basin is classified as Forest with 34% of the watershed area. Urban developed land use categories account for only 7% of the watershed area and agricultural crop lands account for 2%. Land use distribution within the watershed is shown in Figure 1-2.

Table 1-2 Land Use Characteristics of the Lower Neosho River Watershed

Land Use	Area (acres)	Percentage
Agriculture - Cropland	11,911.2	2.0%
Agriculture - Pasture	278,308	46.9%
Barren or Mining	612.9	0.1%
Forest	202,130.3	34.0%
Grass Land	58,708.7	9.9%
Upland Shrub Land	785.4	0.1%
Urban	39,319.2	6.6%
Water/Wetlands	2,246.2	0.4%
Total	594,021.9	100.0%

Based on historical data for Tahlequah (2001-2012) and Muskogee (1997-2012), the Lower Neosho basin is characterized by a warm, humid, temperate climate with hot summers and no pronounced dry season. Over the course of a year, average air temperature typically ranges from ~27° F to ~95° F with the warmest months from early June to early September and the coldest months from late November through the end of February. Winds are predominantly out of the south-southeast (34%) and from the north (10%) (Weatherspark, 2015). Long-term average annual precipitation (1971-2000) in the basin ranges from 44-48 inches based on records from stations located in Pryor, Claremore and Tahlequah (NOAA NCDC, undated, Climatography of the United States, No. 81). Annual rainfall for Fort Gibson Lake measured during the model calibration and validation period from 2005-2006 was 28.6-30.4 inches for 2005 and 34.0-41.0 inches for 2006. Rainfall for both 2005 and 2006 was lower than the long term (1971-2000) average rainfall of 44-48 inches. Based on precipitation records from 1926-2006, rainfall during water year 2006 was the second driest in 82 years of record with about 65% of normal precipitation in the East Central Climate Division 6 where the southern portion of Fort Gibson Lake is located (Tortorelli, 2008).

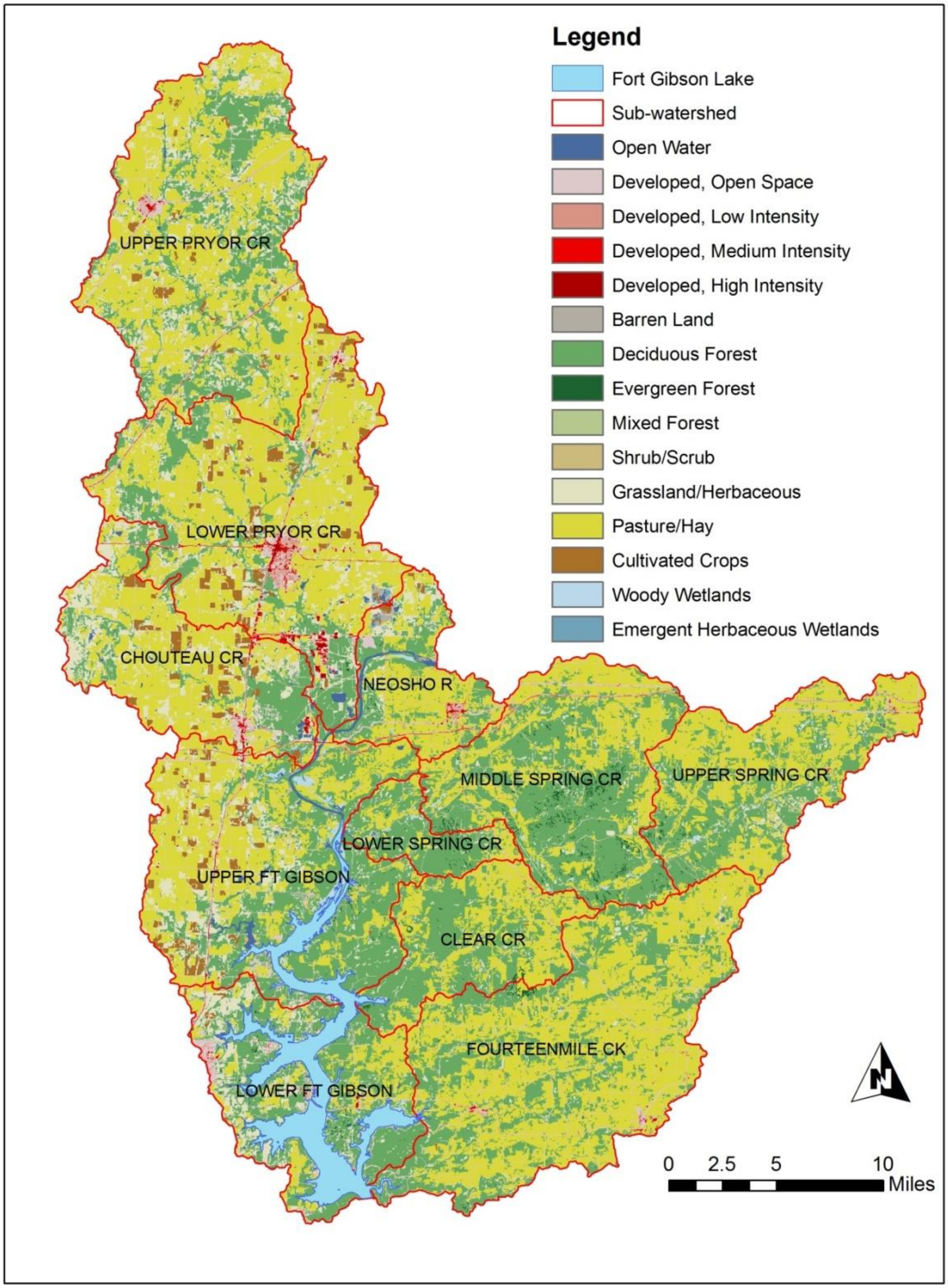

Figure 1-2 Land use in the Lower Neosho watershed of Fort Gibson Lake.

Based on 2010 census data (US Census Bureau, 2011), the population within this watershed is estimated as 56,846 based on an overlay of the watershed boundary and census tract data. Figure 1-3 presents population density of the census tract areas located within the watershed boundary. As can be seen, the highest population density of 1000-1629 persons per square mile corresponds to the City of Pryor Creek in Mayes County in the northwest sector of the watershed and Tahlequah in Cherokee County in the southeast portion of the watershed. The lowest population density (10-29 persons per square mile) is characteristic of rural areas of the watershed in the upper northwest, northeast and southwest areas. The unpopulated low-density areas correspond to the dominant land use categories of Grassland, Agriculture Pasture, and Forest shown in Figure 1-2.

Table 1-3 presents population data based on 2010 census data for Cherokee, Wagoner, Mayes and the other counties that are located within the watershed. The table presents the total population of each county and the population of each county located within the watershed based on compilation of census tract data as shown in Figure 1-3. Based on 2010 census tract data and a GIS map of municipalities in the watershed (Figure 1-4) estimates of the population served by public sewers (43%) and those with septic tanks that are not served by public sewers (57%) in 2010 are presented in Table 1-4. The US Census did not collect public sewer system data in its 2000 or 2010 census. Septic tank data were not available when the watershed model was developed. Pollutant loading from septic tanks was, therefore, not explicitly represented in the watershed model. The water quality impact of septic tanks on stream water quality has been, however, implicitly accounted for in calibration of the watershed model.

Table 1-3 County Population within the Lower Neosho River Watershed

County	Population Total	Population in Watershed
Wagoner	73,085	9,592
Mayes	41,259	27,193
Rogers	86,905	5,471
Cherokee	46,987	13,169
Delaware	41,487	1,178
Craig	15,029	244
Total	304,752	56,846
Data Source: 2010 US Census		

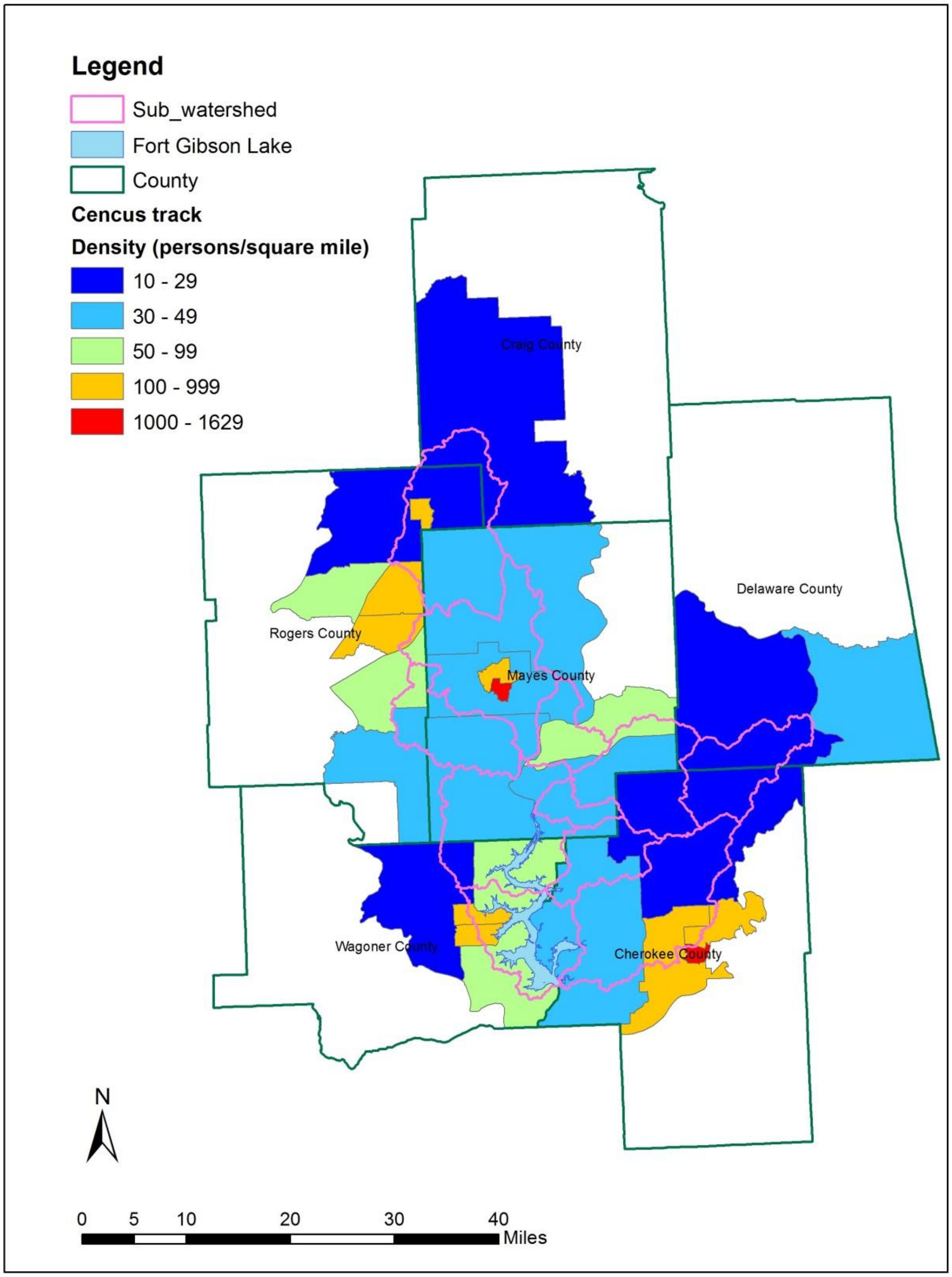

Figure 1-3 Population Density (persons per square mile) based on 2010 Census Tracts within the counties of the Lower Neosho Watershed

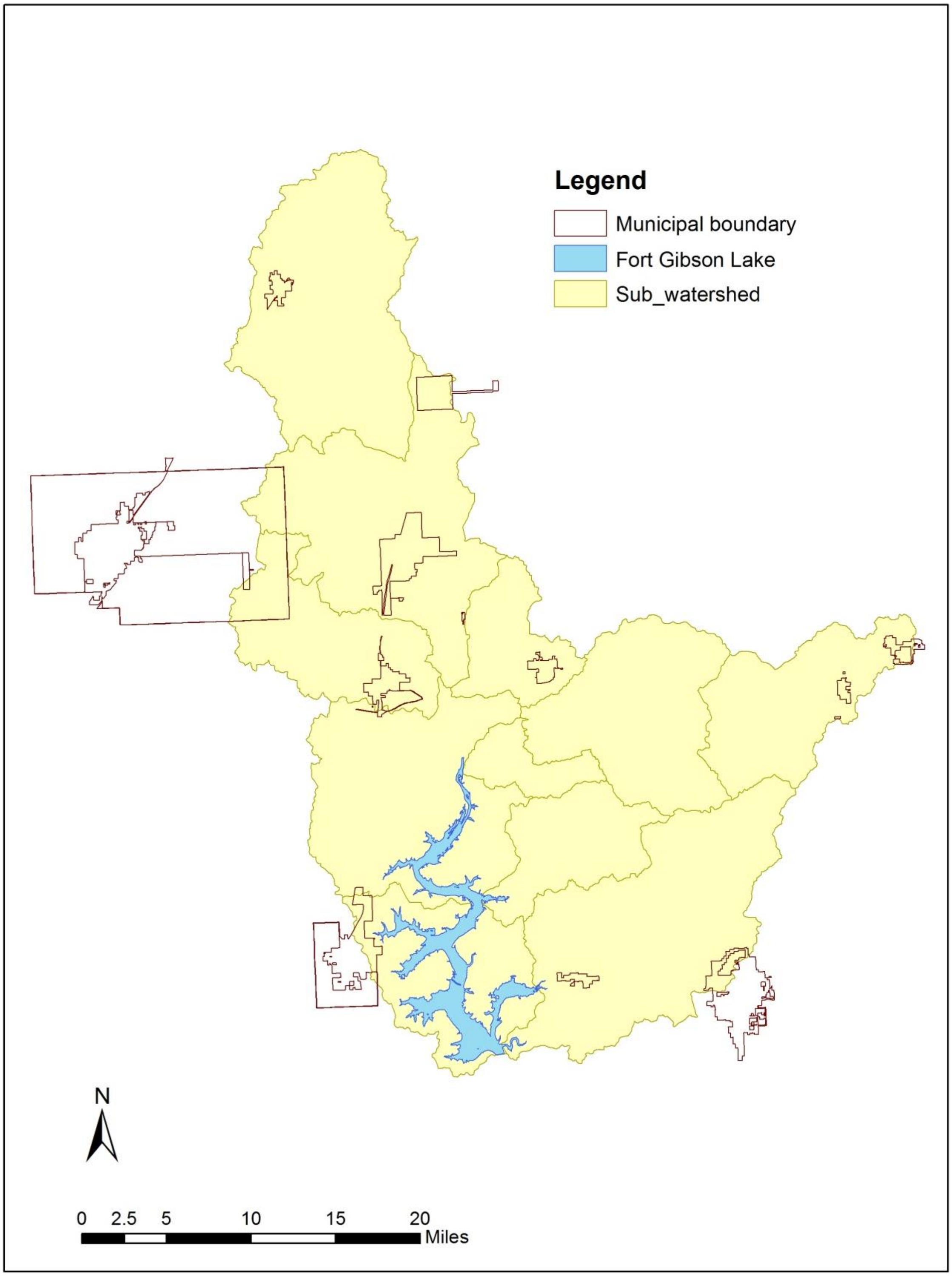

Figure 1-4 Municipal Boundaries within the Lower Neosho Watershed

Table 1-4 2010 Population Served by Public Sewer Systems in the Lower Neosho Watershed

2010	Population Total	Percent of Total
Public Sewer	8,266	43%
Septic Tank, Unsewered	10,909	57%
Total	19,175	100%
Data Sources: 2010 US Census; GIS maps of public sewer systems; 19,346 housing units		

1.3 Streamflow Characteristics

The magnitudes of annual, seasonal and daily variability of streamflow in the watershed provide essential data to characterize water and pollutant load inflows to a receiving waterbody for a water quality management study such as this TMDL assessment of Fort Gibson Lake. The upstream boundary inflow for the lake model is defined by flow measured at the USGS Gage 07191500 on the Neosho River just downstream of the Lake Hudson dam. Flow on the Neosho River into Fort Gibson Lake is regulated by the Grand River Dam Authority with releases managed for hydroelectric projects on the Grand Lake o' the Cherokees and Lake Hudson. Based on 51 years of daily flow records from 1963-2014, long-term average annual flow is 8,837 cfs. During this period of record, minimum annual flow recorded was 1,579 cfs in 2006 and maximum annual flow was 21,770 cfs in 1973. Monthly average flow ranges from a high of 13,400 - 13,800 cfs during April through June and a low of 4,810 - 5,530 cfs from August through October. During the year selected for model calibration (2005), annual flow of 8,819 cfs was essentially the same as the long-term annual average flow of 8,837 cfs. In 2006, however, the year chosen for model validation, annual average flow of 1,579 cfs, only 18% of the long-term average annual flow, was the lowest annual flow recorded from 1963-2014. The low flow recorded at the outflow from Lake Hudson in 2006 is consistent with the regional pattern of drought conditions recorded in northeastern Oklahoma during Water Year 2006 (Tortorelli, 2008). Evaluation of annual rainfall data and annual streamflow data indicates that the 2006 data set used for development of the watershed-lake model and analysis of pollutant loads for the TMDL determination represent "dry" hydrologic conditions for the watershed.

In the absence of streamflow measurements within the watershed study area (other than limited USACE flow data for Pryor Creek), flow estimates for streams entering the lake were developed with the HSPF watershed model. Crutchfield Branch, Spring Creek, Clear Creek, and Fourteen Mile Creek discharge to the eastern shore of the lake. Pryor Creek, Choteau Creek, and distributed runoff from the Upper and Lower sub-basins discharge to the western shore of the lake. The watershed model developed for the Fort Gibson Lake study is summarized in Section 3.2 of this report. A technical report for the watershed model is presented in Appendix A of this report.

2.0 PROBLEM IDENTIFICATION AND WATER QUALITY TARGETS

2.1 Oklahoma Water Quality Standards/Criteria

Chapters 45 and 46 of Title 785 of the Oklahoma Administrative Code (OAC) contain Oklahoma's WQS and implementation procedures, respectively. The Oklahoma Water Resources Board (OWRB) has statutory authority and responsibility concerning establishment of state water quality standards, as provided under 82 Oklahoma Statute [O.S.], §1085.30. This statute authorizes the OWRB to promulgate rules …*which establish classifications of uses of waters of the state, criteria to maintain and protect such classifications, and other standards or policies pertaining to the quality of such waters*. [O.S. 82:1085:30(A)]. Beneficial uses are designated for all waters of the state. Such uses are protected through restrictions imposed by the anti-degradation policy statement, narrative water quality criteria, and numerical criteria (OWRB, 2016). An excerpt of the Oklahoma WQS (Chapter 45, Title 785) summarizing the State of Oklahoma Anti-degradation Policy is provided in Appendix C. Table 2-1, excerpted from the 2010 Integrated Report, lists the supporting status of beneficial uses designated for Fort Gibson Lake (DEQ, 2010). Beneficial uses include:

- AES – Aesthetics
- AG – Agriculture
- WWAC – Warm Water Aquatic Community, Fish and Wildlife Propagation
- FISH – Fish Consumption
- PBCR – Primary Body Contact Recreation
- PPWS – Public & Private Water Supply

Table 2-1 2010 Integrated Report – Oklahoma §303(d) List of Impaired Waters (Category 5a) for Fort Gibson Lake

Waterbody Name	Waterbody ID	AES	AG	WWAC	FISH	PBCR	PPWS
Fort Gibson Lake, Upper	OK121600010200_00	I	F	N	X	I	I
Fort Gibson Lake	OK121600010050_00	I	F	N	X	I	I

F – Fully supporting; N – Not supporting; I – Insufficient information; X – Not assessed
Source: 2010 Integrated Report, DEQ 2010

Nutrient Limited Watersheds (NLW) are defined in the 2016 Oklahoma Water Quality Standards (WQS) *in the Oklahoma Administrative Code, Title 785, Chapter 45 (OAC 785:45).* **"Nutrient-limited watershed"** means a watershed of a waterbody with a designated beneficial use which is adversely affected by excess nutrients as determined by Carlson's Trophic State Index (TSI) of 62 or greater, or is otherwise listed as NLW in Appendix A of Chapter 45 (OWRB, 2017). The "Trophic State Index" is a numerical quantification of nutrient enrichment and lake productivity based on planktonic chlorophyll-a biomass measured in the surface layer. The TSI, developed by Carlson (1977) from paired lake measurements of phosphorus, secchi depth and chlorophyll-a, is determined from planktonic chlorophyll-a (as μg/l) as: TSI = 9.81 x Ln (chlorophyll-a) + 30.6. The State of Oklahoma has designated Fort Gibson Lake as one of 21 NLW waterbodies in Chapter 45 of Oklahoma Water Quality Standards (OWRB, 2017).

Based on Carlson's (1977) relationship of TSI and chlorophyll-a, a TSI index of 62 is equivalent to a chlorophyll-a concentration of 24.5 μg/L. A lake is designated as NLW in Oklahoma if annual average chlorophyll-a measurements at stations in a waterbody segment are greater than or equal to 24.5 μg/L. Although high levels of chlorophyll-a in the lake are often related to taste and odor complaints for a water supply system, the 2010 Integrated Report and 303(d) list shows that Private and Public Water Supply (PPWS) and Primary Body Contact Recreation (PBCR) uses in both segments of Fort Gibson Lake are characterized as "I" (Insufficient Information) rather than "F" (Fully Supporting) for beneficial uses. Adequate data or other information was not available to support an assessment of "Fully Supporting" status for these beneficial uses.

The TMDL determination for Fort Gibson Lake uses the 2010 Integrated Report and 303(d) list as the basis for identifying dissolved oxygen and turbidity as the water quality constituents responsible for impairments for Fish & Wildlife Propagation (FWP) for a Warm Water Aquatic Community (WWAC) in Fort Gibson Lake. Table 2-2 summarizes the impairment status from the 2010 Integrated Report for the two Waterbody Segment IDs of Fort Gibson Lake. Inspection of the Integrated Reports for 2012, 2014, and 2016 shows that both segments of Fort Gibson Lake were designated as impaired because of Dissolved Oxygen (DO) and TSI and corresponding chlorophyll-a levels.

Fort Gibson Lake is designated as a Category 5a lake. Category 5 defines a waterbody where, since the water quality standard is not attained, the waterbody is impaired or threatened for one or more designated uses by a pollutant(s), and the water body requires a TMDL. This category constitutes the Section 303(d) list of waters impaired or threatened by a pollutant(s) for which one or more TMDL(s) are needed. Sub-Category 5a means that a TMDL is underway or will be scheduled. The TMDLs established in this report, which are a necessary step in the process of restoring water quality, address water quality issues related to nonattainment of the public and private water supply and warm water aquatic community beneficial uses.

Table 2-2 2010 Integrated Report – Oklahoma 303(d) List for Fort Gibson Lake

Waterbody Name	Waterbody ID	Size (acres)	TMDL Date	Priority	Turbidity	DO	Chl-a
Fort Gibson Lake, Upper	OK1216000100200_00	7,450	2012	1	●		●
Fort Gibson Lake	OK121600010050_00	7,450	2012	1		●	●

Turbidity Standards for Lakes

The following excerpt from the Oklahoma WQS [OAC 785:45-5-12(f)(7)] stipulates the turbidity numeric criterion to maintain and protect "Warm Water Aquatic Community" beneficial uses (OWRB, 2017).

(A) Turbidity from other than natural sources shall be restricted to not exceed the following numerical limits:

i. Cool Water Aquatic Community/Trout Fisheries: 10 NTUs;

ii. Lakes: 25 NTU; and

iii. Other surface waters: 50 NTUs.

(B) In waters where background turbidity exceeds these values, turbidity from point sources will be restricted to not exceed ambient levels.

(C) Numerical criteria listed in (A) of this paragraph apply only to seasonal base flow conditions.

(D) Elevated turbidity levels may be expected during, and for several days after, a runoff event

The abbreviated excerpt below from Chapter 46: 785:46-15-5, stipulates how water quality data will be assessed to determine support of fish and wildlife propagation as well as how the water quality target for TMDLs will be defined for turbidity.

Assessment of Fish and Wildlife Propagation support

(a) Scope. The provisions of this Section shall be used to determine whether the beneficial use of Fish and Wildlife Propagation or any subcategory thereof designated in OAC 785:45 for a waterbody is supported.

(e) Turbidity. The criteria for turbidity stated in 785:45-5-12(f)(7) shall constitute the screening levels for turbidity. The tests for use support shall follow the default protocol in 785:46-15-4(b).

785:46-15-4. Default protocols

(b) Short term average numerical parameters.

(1) Short term average numerical parameters are based upon exposure periods of less than seven days. Short term average parameters to which this Section applies include, but are not limited to, sample standards and turbidity.

(2) A beneficial use shall be deemed to be fully supported for a given parameter whose criterion is based upon a short-term average if 10% or less of the samples for that parameter exceed the applicable screening level prescribed in this Subchapter.

Turbidity is a measure of water clarity and is caused by suspended particles in the water column. Turbidity, however, cannot be expressed as a mass load. Total suspended solids (TSS) are therefore modeled and evaluated as a surrogate for turbidity using a site-specific relationship derived from TSS and turbidity measurements.

Dissolved Oxygen Standards for Lakes

Oklahoma water quality standards for dissolved oxygen have been proposed for revision by OWRB (2014). Compliance with the revised standards for dissolved oxygen is specified in relation to: (a) spring and summer stratified conditions for the surface layer (epilimnion) and the anoxic volume and water column of the lake within the hypolimnion; and (b) non-stratified conditions for the surface layer. Within the surface layer (epilimnion) during the early period of thermal stratification in spring, 10% or less of the dissolved oxygen samples shall be no less than 6 mg/L from April 1 to June 15. During the summer period of stratification from June 16-October 15, 10% or less of the dissolved oxygen samples shall be no less than 5 mg/L. During the remainder of the year (October 16 to March 31) 10% or less of the dissolved oxygen samples shall be no less than 5 mg/L for the months when the lake is non-stratified.

Table 2-3 summarizes the proposed revision of water quality standards for dissolved oxygen within the surface layer of a waterbody.

Table 2-3 Dissolved Oxygen Criteria to Protect Fish and Wildlife Propagation and All Subcategories Thereof. Source: OWRB (2014)

Dissolved Oxygen Criteria to Protect Fish and Wildlife Propagation and All Subcategories Thereof [1]

SUBCATEGORY OF FISH AND WILDLIFE PROPAGATION (FISHERY CLASS)	DATES APPLICABLE	D.O. CRITERIA [4] (MINIMUM) (mg/L)	SEASONAL TEMPERATURE (ºC)
Habitat Limited Aquatic Community			
Early Life Stages	4/1 - 6/15	4.0	25[3]
Other Life Stages			
Summer Conditions	6/16 - 10/15	3.0	32
Winter Conditions	10/16 - 3/31	3.0	18
Warm Water Aquatic Community [5]			
Early Life Stages	4/1 - 6/15	6.0[2]	25[3]
Other Life Stages			
Summer Conditions	6/16 - 10/15	5.0[2]	32
Winter Conditions	10/16 - 3/31	5.0	18
Cool Water Aquatic Community & Trout			
Early Life Stages	3/1 - 5/31	7.0[2]	22
Other Life Stages			
Summer Conditions	6/1 - 10/15	6.0[2]	29

1 For use in calculation of the allowable load.

2 Because of natural diurnal dissolved oxygen fluctuation, a 1.0 mg/l dissolved oxygen concentration deficit shall be allowed for not more than eight (8) hours during any twenty-four (24) hour period.

3 Discharge limits necessary to meet summer conditions will apply from June 1 of each year. However, where discharge limits based on Early Life Stage (spring) conditions are more restrictive, those limits may be extended to July 1.

4 DO shall not exhibit concentrations less than the criteria magnitudes expressed above in greater than 10% of the samples as assessed across all life stages and seasons.

5 For Lakes, the warm water aquatic community dissolved oxygen criteria expressed above are applicable to the surface waters.

In addition to water quality standards for dissolved oxygen within the surface layer, the proposed revisions to Oklahoma water quality standards for dissolved oxygen also specify criteria based on the percent volume of the lake or percent of the water column (OWRB, 2014).

For lakes, no more than 50% of the water volume shall exhibit a DO concentration less than 2.0 mg/L. If no volumetric data is available, then no more than 70% of the water column at any given sample site shall exhibit a DO concentration less than 2.0 mg/L. If a lake specific study including historical analysis demonstrates that a different percent volume or percent water column than described above is protective of the WWAC use, then that lake specific result takes precedence

Trophic State Index Standards for Nutrient Limited Watershed Lakes

Fort Gibson Lake is designated as a Nutrient Limited Watershed (NLW) (http://www.owrb.ok.gov/maps/pdf_map/nutrient_limited_watersheds.pdf). The definition of NLW is summarized in the following excerpt from OAC 785:45-1-2 of the Oklahoma WQS (OWRB 2017):

Nutrient-Limited Watershed (NLW) means a watershed of a waterbody with a designated beneficial use that is adversely affected by excess nutrients as determined by a Carlson's Trophic State Index (using chlorophyll-a) of 62 or greater, or is otherwise listed as "NLW" in Appendix A of the OWQS. https://www.owrb.ok.gov/rules/pdf/current/Ch45.pdf

An analysis of water quality data collected at 3 sites in Fort Gibson Lake from 1998-2007 indicated a mean TSI value of 61.4 for the upper WBID (OK121600010200_00) with a range of 46-69 for the upper lake. Based on data collected at 5 sites in the lower WBID (OK121600010050_00), mean TSI was 62.0 with a range of 32-70. The mean TSI values for the two WBIDs correspond to a chlorophyll-a level of 23 µg/L for the upper WBID and 24 µg/L for the lower WBID. Based on this data and the TSI criteria of 62, Fort Gibson Lake was designated as a Nutrient Limited Watershed (ORWB, 2006).

2.2 Overview of Water Quality Problems and Issues

Fort Gibson Lake, located in the hills of northeastern Oklahoma about 50 miles southeast of Tulsa in Cherokee, Wagoner, and Mayes Counties is a popular recreational lake with excellent fishing, swimming, camping, boating, and a public hunting area with a waterfowl refuge. Originally constructed in 1953 by the USACE to provide hydropower and flood control, the reservoir serves as the water supply source for local municipalities (e.g., Wagoner) and rural water districts. Designated uses of the lake are public and private water supply, agriculture, primary body contact recreation, fish and wildlife propagation, and aesthetics. As of the 2010 census, the Lower Neosho River basin population is estimated as 56,846 persons.

Based on an assessment of water quality monitoring data for the 2010 Integrated Report, Oklahoma DEQ has determined that Fort Gibson Lake is not supporting its designated uses for Fish and Wildlife Propagation for a Warm Water Aquatic Community because of high levels of turbidity (OK121600010200_00) and low dissolved oxygen (OK121600010050_00). Fort Gibson Lake is also designated as one of 21 Nutrient Limited Watersheds in Oklahoma because of nutrient enrichment and excessive levels of chlorophyll-a that impair aesthetic uses of the lake. Within the 12,492 square mile drainage basin, external sources of nutrient loading related to nutrient enrichment and eutrophication in Fort Gibson Lake include loading from the Headwaters, Upper and Middle Neosho River basins and the Elk and Spring River basins via outflow from Grand The outflow from Grand Lake is discharged into the Neosho River which in turn, flows into Lake Hudson. Flow from Lake Eucha and Spavinaw Lake is discharged into the upper end of Lake Hudson via Spavinaw Creek. In addition to inflow from the outlet of Lake Hudson on the Neosho River, nutrient loading to Fort Gibson Lake is contributed by municipal and industrial wastewater discharges, urban stormwater and local land use driven loading from tributaries (e.g., Clear Creek, Pryor Creek) and overland runoff. A TMDL assessment for Fort Gibson Lake is required by the CWA to determine appropriate load reductions for these external sources that could be implemented to achieve compliance with water quality standards for the lake.

Table 2-4 summarizes the site designation names, station numbers and geographic locations of the water quality monitoring stations maintained by OWRB and the USACE Tulsa District in Fort Gibson Lake. Oklahoma WBID numbers are listed to identify the stations located in each of the two WBID segments of the lake. Figure 2-1 shows the locations of the OWRB and USACE stations in the lake.

Table 2-4 OWRB and USACE Water Quality Monitoring Stations for Fort Gibson Lake, Upper (WBID 121600010200_00) and Fort Gibson Lake (WBID 121600010050_00)

Station_ID		Agency	OKWBID	Lon (W)	Lat (N)
1GIBOKN0003		USACE	121600010050_00	-95.230278	35.870278
1GIBOKN0004		USACE	121600010050_00	-95.228611	35.915278
1GIBOKN0005		USACE	121600010050_00	-95.300556	35.964167
1GIBOKN0305		USACE	121600010050_00	-95.278889	35.912222
1GIBOKN0355		USACE	121600010050_00	-95.265278	35.976667
1GIBOKN0006		USACE	121600010200_00	-95.313889	36.036667
1GIBOKN0386		USACE	121600010200_00	-95.294444	36.043333
121600010050-01S	Site 1	OWRB	121600010050_00	-95.233056	35.871667
121600010050-01B	Site 1	OWRB	121600010050_00	-95.233056	35.871667
121600010050-02	Site 2	OWRB	121600010050_00	-95.305556	35.911944
121600010050-03	Site 3	OWRB	121600010050_00	-95.271389	35.933889
121600010050-04	Site 4	OWRB	121600010050_00	-95.281111	35.961667
121600010200-05	Site 5	OWRB	121600010050_00	-95.315833	35.944440
121600010200-06	Site 6	OWRB	121600010200_00	-95.245000	36.001667
121600010200-07	Site 7	OWRB	121600010200_00	-95.311389	36.031111
121600010200-08	Site 8	OWRB	121600010200_00	-95.285833	36.049167

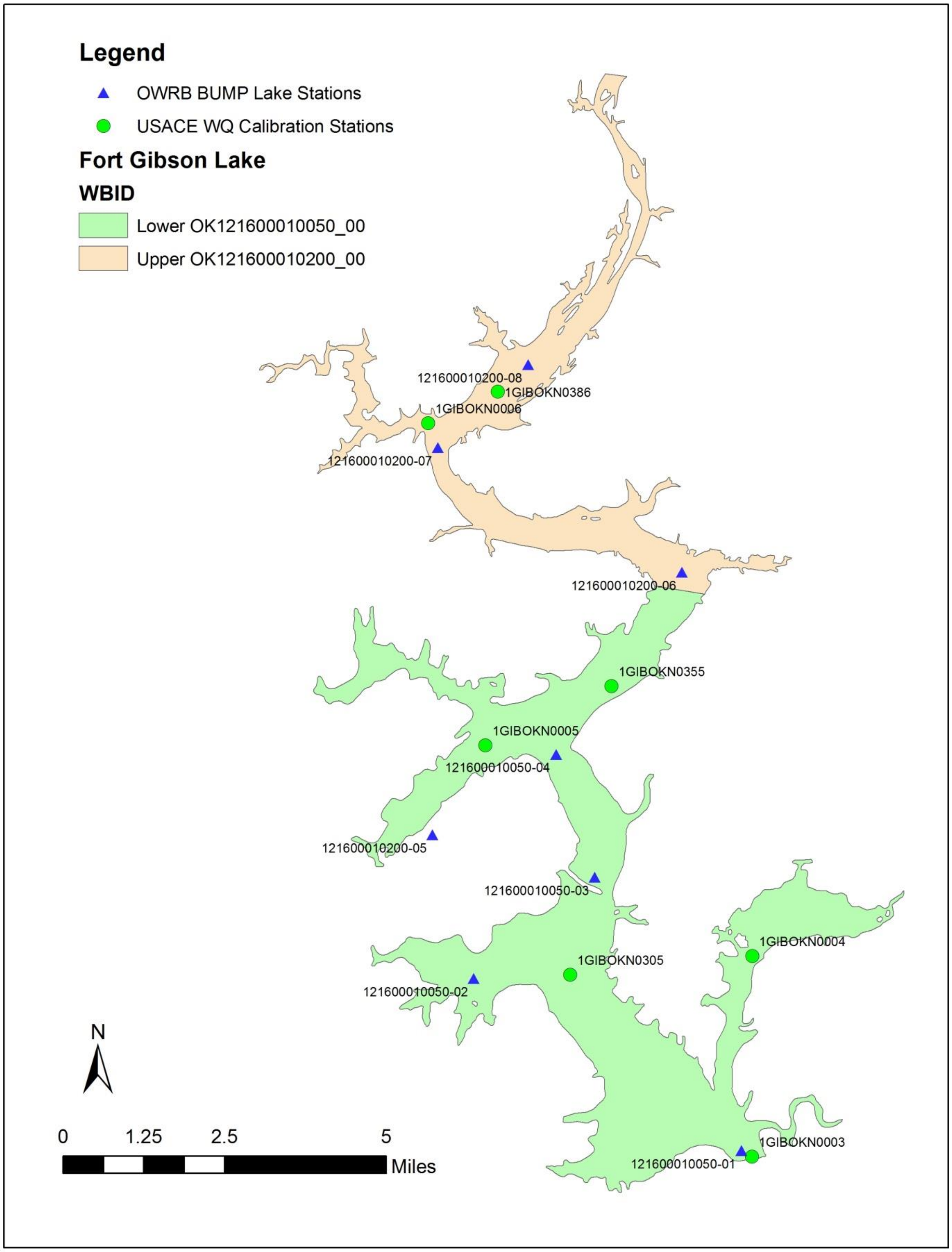

Figure 2-1 OWRB BUMP and USACE Water Quality Monitoring Stations for Fort Gibson Lake

2.3 Water Quality Observations and Targets for Turbidity, Trophic State index and Dissolved Oxygen

Water quality targets adopted for the Fort Gibson Lake TMDL study for turbidity, Trophic State Index (TSI), and dissolved oxygen are as follows:

- Turbidity: no more than 10% of turbidity samples greater than 25 NTU based on long-term record of most recent 10 years
- Trophic State Index (TSI): Average value of TSI no greater than 62 based on long-term record of chlorophyll-a measurements of most recent 10 years.
- Dissolved Oxygen, Stratified Conditions (April 1 to June 15): Within the surface/epilimnion layer for protection of fish and wildlife propagation in warm water aquatic community DO no less than 6 mg/L.
- Dissolved Oxygen, Stratified Conditions (June 16 to October 15): Within the surface/epilimnion layer for protection of fish and wildlife propagation in warm water aquatic community DO no less than 5 mg/L.
- Dissolved Oxygen, Non-Stratified Conditions (October 16 to March 31): Within the surface/epilimnion layer for protection of fish and wildlife propagation in warm water aquatic community DO no less than 5 mg/L.
- Dissolved Oxygen, Stratified Conditions (April 1 to October 1): Anoxic volume of the lake, defined by a DO target level of 2 mg/L, shall not exceed 50% of the lake volume based on volumetric data or 70% of the water column based on sampling sites during the summer stratified season.

As stipulated in the Implementation Procedures for Oklahoma Water Quality Standards [785:46-15-3c], the most recent 10 years of water quality data are to be used as the basis for assessment of the water quality conditions and beneficial use support for a waterbody (OWRB, 2016). Fort Gibson Lake is listed as impaired in the 2010 Integrated Report based on an analysis of 10 years of records for turbidity, TSI, chlorophyll-a, and DO data collected by OWRB from May 1999 through April 30, 2009.

OWRB provided data files used for analysis of the lake water quality data to support impairment determinations for the 2010 Integrated Report and 303(d) list. Inspection of the data sets showed that data was available from the Lake Ft. Gibson OWRB BUMP surveys only for the period from June 1998 through June 2007. Data was also available from the USACE Tulsa District for June 2003 through September 2006. Data was not available for the lake from July 2007 through October 2012 when OWRB conducted the next series of BUMP surveys of Lake Ft. Gibson from November 2012 through April 2013. The dates presented in Table 2-5, Table 2-6 and Table 2-7 show the date ranges of the available water quality data used by OWRB for the 2010 Integrated Report and 303(d) list.

Summary statistics presented in Table 2-5 through Table 2-8 are based on data collected by OWRB from 1998 through 2007. This data was used by OWRB for evaluation of the impairments of Fort Gibson Lake. Time series of turbidity (Figure 2-2), TSI (Figure 2-3) and chlorophyll-a (Figure 2-4) present data collected at the USACE and OWRB monitoring sites listed in Table 2-4. Figure 2-5 presents surface to bottom water column data for dissolved oxygen for the OWRB and USACE monitoring sites located near the dam (Figure 2-5). The data tables present summary statistics for the OWRB data used to determine impairments for the 2010 Integrated Report and 303(d) list. Data plotted in Figure 2-2 through Figure 2-5, however, show both OWRB and USACE data. Data other than that available from OWRB BUMP surveys is presented to provide DEQ, EPA Region 6, and Stakeholders with more information about observed turbidity, TSI, chlorophyll, and dissolved oxygen over the 10-year period. A listing of the water quality data sets collected by the USACE Tulsa District in 2005-2006 that was used to support development of the watershed and lake models for this TMDL are presented in Appendix D.

The number of data points shown in Table 2-5 (N=36) for the Upper Lake is only for the OWRB data set because determination of 2010 303(d) impairments for turbidity and TSI was based only on the OWRB data. Figure 2-2, however, shows both OWRB and USACE turbidity data to provide Stakeholders with more information about observed turbidity over the 10-year period.

Table 2-5 Summary Statistics for OWRB Observed Turbidity in Fort Gibson Lake, WBID: OK121600010200_00 and OK121600010050_00

WBID	OK121600010200_00	
SUMMARY STATISTIC	Turbidity NTU	WQ Target NTU
N_Records	36	
Start Date	6/24/1998	
End Date	6/5/2007	
Min	4.0	
10th %ile	7.5	
25th %ile	8.8	
Mean	15.8	
50th %ile	11.0	
75th %ile	21.0	
90th %ile	31.0	25
Max	52.0	

WBID	OK121600010050_00	
SUMMARY STATISTIC	Turbidity NTU	WQ Target NTU
N_Records	62	
Start Date	6/24/1998	
End Date	6/5/2007	
Min	4.0	
10th %ile	5.0	
25th %ile	7.0	
Mean	9.6	
50th %ile	8.0	
75th %ile	12.3	
90th %ile	16.0	25
Max	27.0	

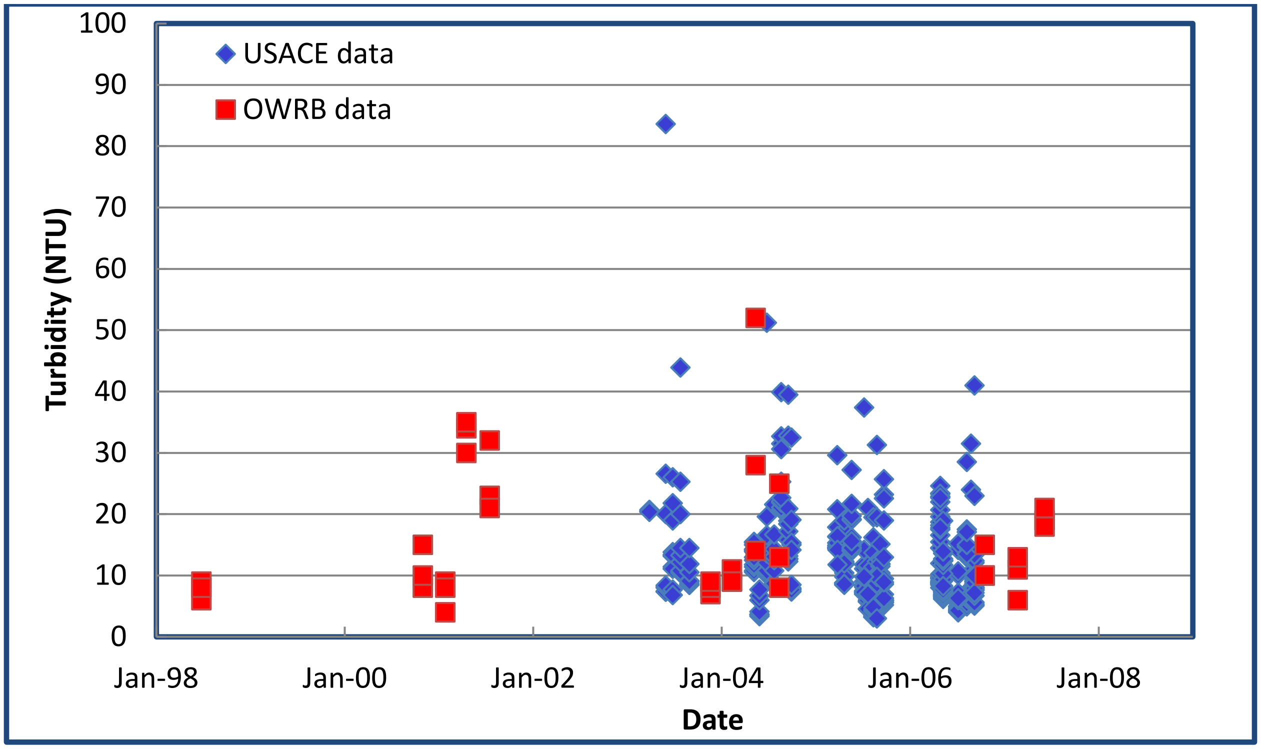

Figure 2-2 Observed Turbidity in Fort Gibson Lake, Upper WBID OK121600010200_00

Table 2-6 Summary Statistics for OWRB Observed TSI in Fort Gibson Lake, WBID: OK121600010200_00 and OK121600010050_00

WBID	OK121600010200_00	
SUMMARY STATISTIC	TSI	WQ Target TSI
N_Records	36	
Start Date	6/24/1998	
End Date	6/5/2007	
Min	46.6	
10th %ile	50.0	
25th %ile	55.4	
Mean	61.4	62
50th %ile	60.9	
75th %ile	64.2	
90th %ile	67.5	
Max	69.0	

WBID	OK121600010050_00	
SUMMARY STATISTIC	TSI	WQ Target TSI
N_Records	62	
Start Date	6/24/1998	
End Date	6/5/2007	
Min	32.4	
10th %ile	50.3	
25th %ile	57.0	
Mean	62.0	62
50th %ile	60.5	
75th %ile	64.7	
90th %ile	68.8	
Max	70.1	

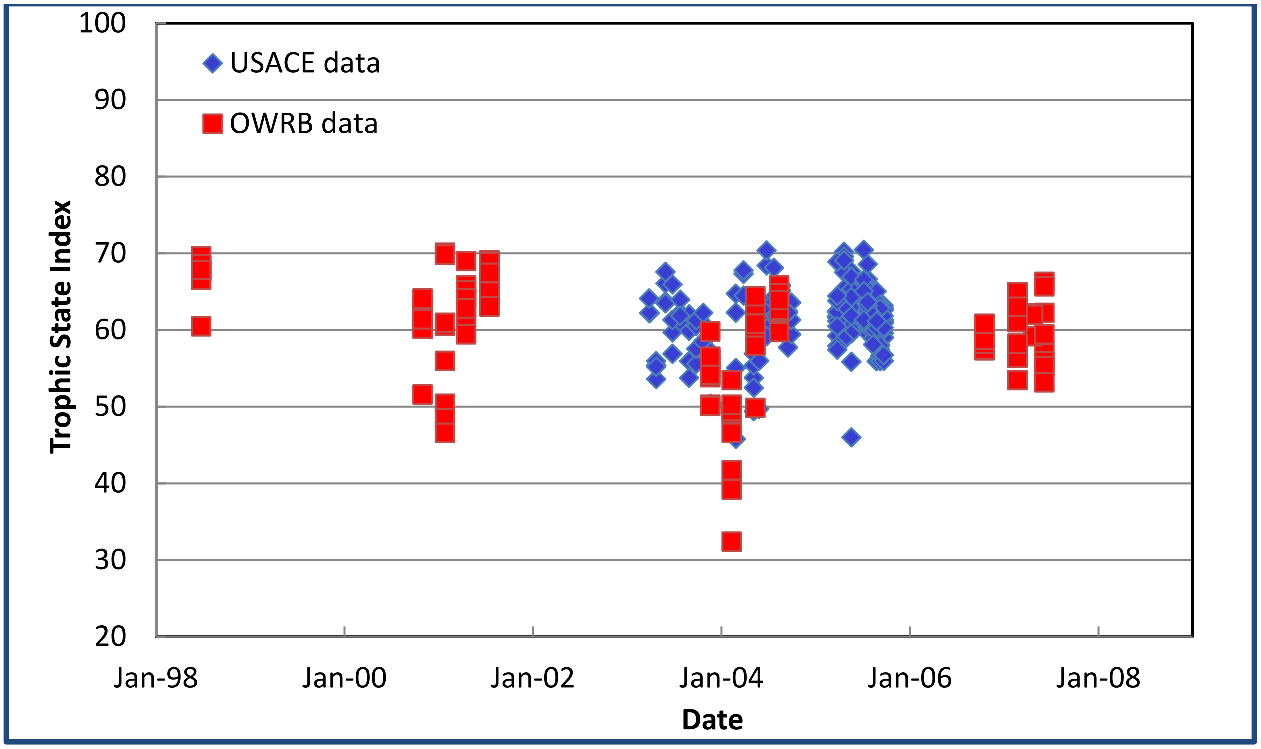

Figure 2-3 Observed TSI in Fort Gibson Lake WBIDs: OK121600010200_00 and OK121600010050_00

Table 2-7 Summary Statistics for OWRB Observed Chlorophyll-a in Fort Gibson Lake, WBID: OK121600010200_00 and OK121600010050_00

WBID	OK121600010200_00	
SUMMARY STATISTIC	Chlorophyll µg/L	WQ Target
N_Records	36	
Start Date	6/24/1998	
End Date	6/5/2007	
Min	5.1	
10th %ile	7.3	
25th %ile	12.6	
Mean	23.2	
50th %ile	21.9	
75th %ile	30.7	
90th %ile	43.2	
Max	50.2	

WBID	OK121600010050_00	
SUMMARY STATISTIC	Chlorophyll µg/L	WQ Target
N_Records	62	
Start Date	6/24/1998	
End Date	6/5/2007	
Min	1.2	
10th %ile	7.4	
25th %ile	14.8	
Mean	24.4	
50th %ile	21.1	
75th %ile	32.3	
90th %ile	49.0	
Max	55.9	

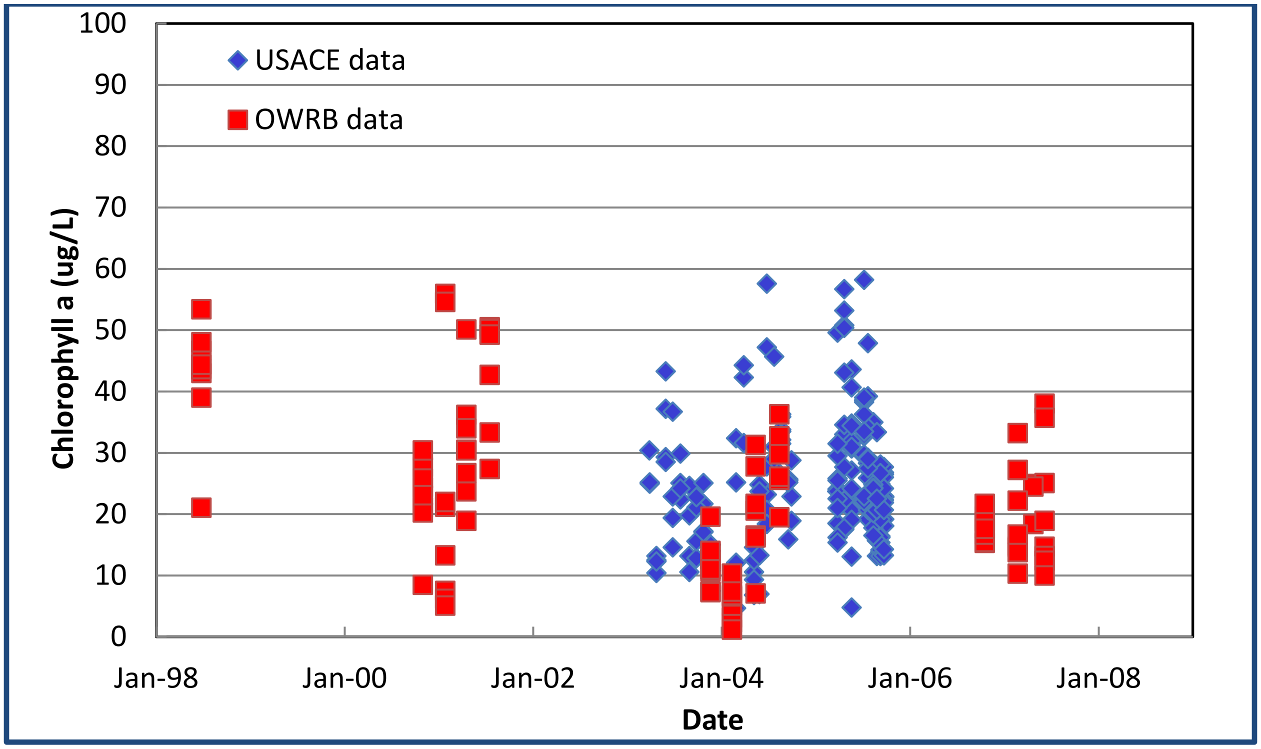

Figure 2-4 Observed Chlorophyll in Fort Gibson Lake WBIDs: OK121600010200_00 and OK121600010050_00

As can be seen in the data presented in Table 2-5, the 90th percentile for observed turbidity (31 NTU) in Fort Gibson Lake, Upper (OK121600010200_00) exceeds the water quality criteria target of 25 NTU. In the lower segment of the lake, the 90th percentile (16 NTU) for WBID OK121600010050_00 does not exceed the 25 NTU target and is seen to be in compliance. The observed data used by OWRB for the 2010 303(d) list documents that water quality conditions in Upper Fort Gibson Lake (WBID OK121600010200_00) did not support the Warm Water Aquatic Community use for Fish and Wildlife Propagation because of impairments by turbidity.

As shown in Table 2-6 and Table 2-7, the mean TSI values of 61.4 and 62.0 computed from the mean chlorophyll (23.2-24.4 µg/L) for both WBID segments of the lake match, or are very close to, the NLW water quality criteria of 62. Observed TSI data documents that water quality conditions did not support the beneficial use of both WBID segments of the lake for aesthetics as a designated NLW waterbody.

Based on an assessment of water column dissolved oxygen data for the 2010 303(d) list, OWRB has determined that Fort Gibson Lake WBID OK121600010050_00 is not fully supporting its beneficial uses for Fish and Wildlife Propagation because of the anoxic percentage of the water column of dissolved oxygen during summer stratified conditions. As shown in Table 2-8, vertical profiles of dissolved oxygen collected at the OWRB and USACE stations near the dam (Site 1 and 1GIBOKN0003) showed that more than 70% of the water column was less than the 2 mg/L target for anoxia within the hypolimnion for 4 of the sampling surveys from 2001-2007. Data for the sites near the dam also showed that the 5 mg/L surface layer (z=0.1 m) criteria for dissolved oxygen was not in compliance for 5 sampling surveys. The observed data used by OWRB for the 2010 303(d) assessment documents that water quality conditions in Fort Gibson Lake WBID OK121600010050_00 did not support the Warm Water Aquatic Community use for Fish and Wildlife Propagation because of dissolved oxygen. Worst case conditions for dissolved oxygen in this WBID were recorded at the two sampling sites located near the dam.

The Code of Federal Regulations [40 CFR §130.7(c)(1)] states that, "*TMDLs shall be established at levels necessary to attain and maintain the applicable narrative and numerical water quality standards*." The water quality targets established for Fort Gibson Lake must demonstrate compliance with the numeric criteria prescribed for Fish and Wildlife Propagation, Warm Water Aquatic Community and NLW lakes in the Oklahoma WQS.

Water quality variables that relate to impairments of Fort Gibson Lake for turbidity (water clarity) include suspended sediment and algae biomass as chlorophyll-a. Water quality constituents that relate to impairments for TSI include algae biomass as chlorophyll-a, total nitrogen, total phosphorus, and suspended solids. Water quality constituents that relate to impairments for dissolved oxygen include algae biomass, TOC, CBOD, and ammonia nitrogen.

Although the water quality criteria for water clarity is based on turbidity, total suspended solids (TSS) is commonly used as a surrogate indicator of water clarity for development of the mass balance-based loading analysis required for the TMDL determination. A site-specific relationship must be developed therefore to transform TSS data to turbidity to be able to compare the effect of sediment loading of TSS from the watershed on compliance with the water quality criteria for turbidity in the lake. The methodology used to develop the TSS-turbidity relationship is summarized in Section 4 of this report.

Table 2-8 Water Column Observations of Dissolved Oxygen at OWRB and USACE Stations Near the Dam in Fort Gibson Lake, WBID: OK121600010050_00

DATE	Water Column < 2 mg/L	DO (mg/L) z=0.1 m
Target==>	<70%	>5
OWRB	Site-01	
7/16/2001	79.0%	3.27
8/16/2004	36.8%	3.71
6/5/2007	11.0%	8.66
7/23/2007	71.0%	7.17
USACE	1GIBOKN0003	
6/25/2003	73.7%	5.34
7/24/2003	53.0%	8.59
8/28/2003	88.9%	2.49
6/24/2004	10.5%	8.97
5/18/2005	0.0%	9.18

7/6/2005	20.0%	10.71
7/20/2005	52.6%	6.83
8/10/2005	63.2%	10.53
8/24/2005	47.4%	6.00
9/7/2005	0.0%	5.08
9/21/2005	5.6%	12.70
6/8/2006	45.0%	9.10
7/5/2005	35.3%	9.18
8/8/2006	50.0%	5.97
8/24/2006	55.6%	2.32
9/6/2006	27.8%	4.34

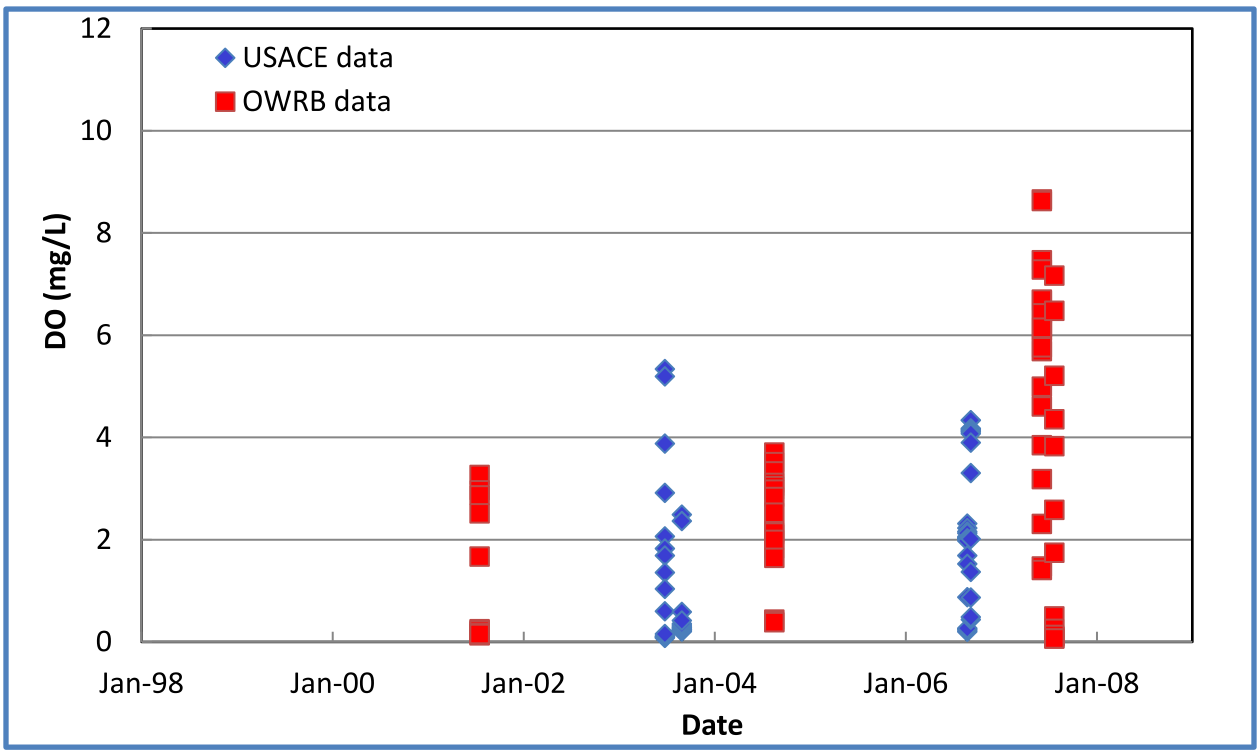

Figure 2-5 Water Column Observations of Dissolved Oxygen at OWRB and USACE Stations Near the Dam in Fort Gibson Lake, WBID: OK121600010050_00

3.0 POLLUTANT SOURCE ASSESSMENT

This section includes an assessment of the known and suspected sources of nutrients, organic matter and sediments contributing to the eutrophication and water quality impairments of Fort Gibson Lake. Pollutant sources identified are categorized and quantified to the extent that reliable information is available. Generally, sediment and nutrient loadings causing impairment of lakes originate from point or nonpoint sources of pollution. Point source discharges are regulated under permits through the NPDES program. Nonpoint sources are diffuse sources that typically cannot be identified as entering a waterbody through a discrete conveyance, such as a pipe, at a single location. Nonpoint sources may originate from rainfall runoff and landscape dependent characteristics and processes that contribute sediment, organic matter and nutrient loads to surface waters. For the TMDLs presented in this report, all sources of pollutant loading not regulated under the NPDES permit system are considered nonpoint sources.

Under 40 CFR, §122.2, a point source is described as an identifiable, confined, and discrete conveyance from which pollutants are, or may be, discharged to surface waters. NPDES- permitted facilities classified as point sources that may contribute sediment, organic matter and nutrient loading include:

- NPDES Municipal wastewater treatment plant (WWTP) discharges;
- NPDES Industrial WWTP discharges;
- Municipal no-discharge WWTPs;
- NPDES Municipal separate storm sewer system (MS4) discharges;
- NPDES Construction Site stormwater discharges;
- NPDES Multi-Sector General Permits (MSGP) stormwater discharges; and
- NPDES Concentrated animal feeding operations (CAFO)
- NPDES Poultry feeding operations (PFO)

All of the above listed types of permitted facilities are present in the Fort Gibson Lake study area. Urban stormwater runoff from MS4 areas, which is now regulated under the EPA NPDES Program, can contribute significant loading of sediments, organic matter and nutrients to Fort Gibson Lake. In the study area for this TMDL determination, MS4 permits have been issued for Wagoner County and Tahlequah. Stormwater runoff from MS4 areas, facilities under multi-sector general permits (MSGP), and NPDES permitted construction sites, which are regulated under the EPA NPDES Program, can all contribute sediment loading to the lake. Within the Fort Gibson Lake watershed there are a number of construction site permits and multi-sector general permits that have been issued and will be addressed in Section 3.1.4 and 3.1.5 of this report. 40 CFR §130.2(h) requires that NPDES-regulated stormwater discharges must be addressed by the wasteload allocation (WLA) component of a TMDL assessment.

3.1 Assessment of Point Sources

3.1.1 NPDES Municipal and Industrial Wastewater Dischargers

Municipal and industrial wastewater discharge facilities included in the watershed and lake model are listed in Table 3-1. All facilities identified as either major or minor NPDES permitted dischargers within the watershed are listed in Appendix H. NPDES facilities listed in Table 3-1 were selected for input to the watershed and lake models if the effluent flow rate was larger than 0.1 MGD. Figure 3-1 shows the locations of the NPDES wastewater sources included in the models. Effluent flow rate and effluent concentration data used to assign input data for these wastewater point sources to the watershed and lake model are presented in Appendix H of this report.

Table 3-1 NPDES Wastewater Treatment Dischargers to Fort Gibson Lake and Watershed

NPDES_ID	Facility Name	Receiving Water	Latitude	Longitude	Design flow (MGD)
OK0022781	CHELSEA ECONOMIC DEV ATHRTY WWTP	Pryor Creek	36.52	-95.42	0.5
OK0022764	CHOUTEAU WWTP	Chouteau Creek	36.19	-95.32	0.32
OK0040258	CALPINE PRYOR	Pryor Creek	36.24	-95.28	Inactive, permit closed in 2013
OK0022772	LOCUST GROVE WWTP	Crutchfield Branch	36.21	-95.17	0.75
OK0000272	PRYOR IND CONSERVE PICC	Neosho River	36.19	-95.25	3.7
OK0043907	ASSOCIATED ELEC COOP AECI CHOUTEAU PWR PLT	Neosho River	36.218	-95.247	0.6
OK0033791	WAGONER CNTY RWD NUMBER 2	Ft Gibson Lake	35.956	-95.28	Report, water treatment plant, no BOD limits
OK0034568	OKLA ORDNANCE WORKS ATHRTY OOWA PRYOR	Neosho River	36.21	-95.25	4.6
OK0035149	GRAND RIVER DAM ATHRTY CHOUTEAU COAL FIRED COMPLEX	Grand Neosho River	36.18	-95.28	Report, no BOD limits
OK0040479	PRYOR CREEK WWTP	Mid America Creek Pryor Creek Neosho R	36.27	-95.34	1.67
OKG380001 (changed to OK0046035 in 2012)	WAGONER WTP	Ft Gibson Lake	36.02	-95.30	Report, water treatment plant, no BOD limits

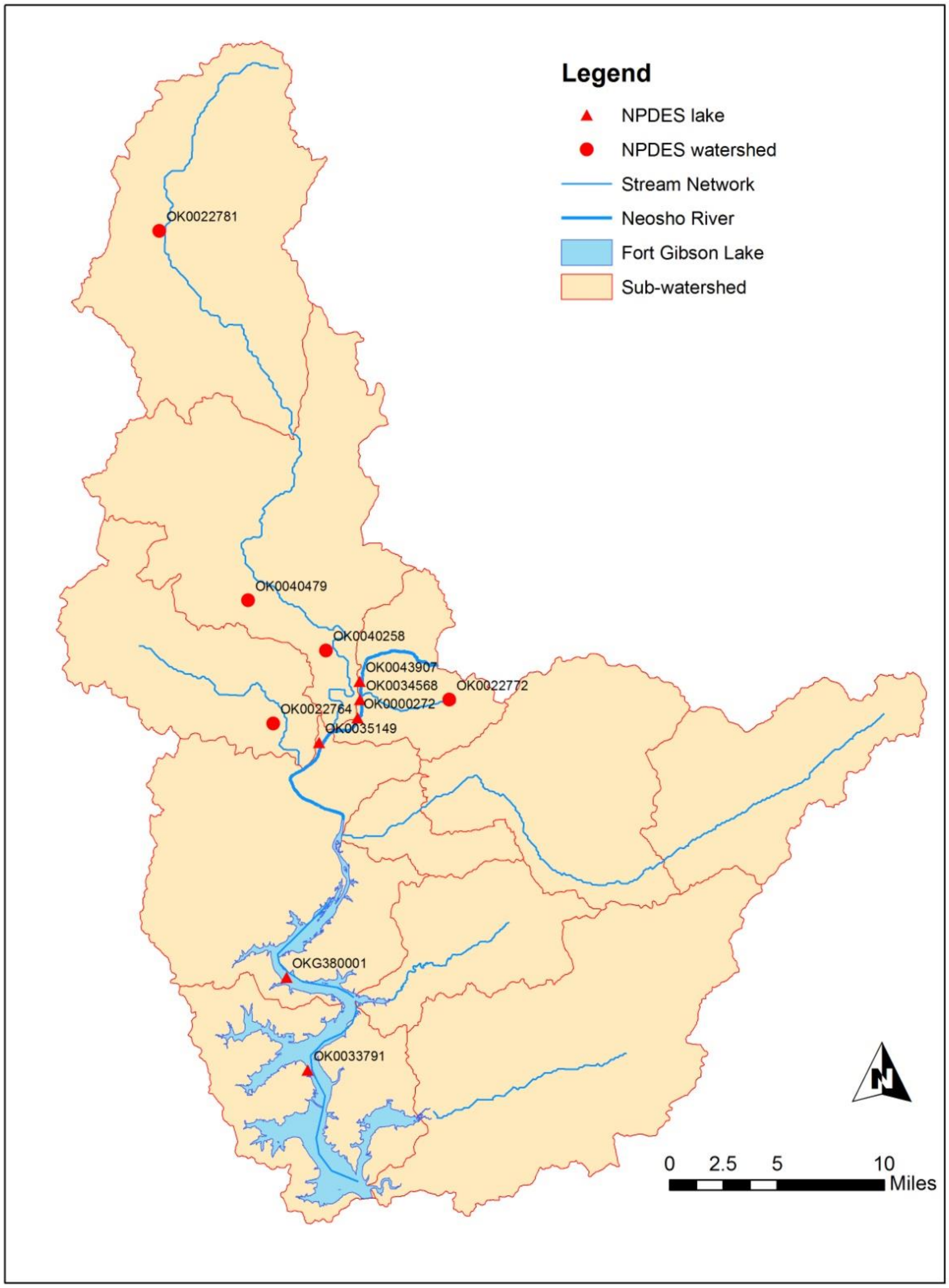

Figure 3-1 NPDES Wastewater Dischargers to Fort Gibson Lake and Watershed

3.1.2 No-Discharge Wastewater Treatment Plants

No-discharge WWTP facilities do not discharge wastewater effluent to either streams of the watershed or directly to Fort Gibson Lake. As shown in Figure 3-2 and Table 3-2, there are four no-discharge facilities located within the watershed study area. For the purposes of this TMDL study, no-discharge facilities are not considered a source of sediment, organic matter or nutrient loading to Fort Gibson Lake.

It is possible, however, that the wastewater collection system associated with no-discharge facilities could be a source of pollutant loading to streams, or that discharges from the WWTP may occur during large rainfall events that exceed the storage capacity of the wastewater system. These types of unauthorized wastewater discharges are typically reported as sanitary sewer overflows (SSO's) or bypass overflows.

Sanitary sewer overflows (SSO) from wastewater collection systems of discharging WWTP facilities, although infrequent, can also be a major source of pollutant loading to streams. SSOs have existed since the introduction of separate sanitary sewers, and most are caused by blockage of sewer pipes by grease, tree roots, and other debris that clog sewer lines, by sewer line breaks and leaks, cross connections with storm sewers, and inflow and infiltration of groundwater into sanitary sewers. SSOs are NPDES permit violations that must be addressed by the responsible NPDES permit holder. The reporting of SSOs has been strongly encouraged by EPA, primarily through enforcement and monetary fines. While not all sewer overflows are reported, DEQ maintains a database on reported SSOs. Within the Pryor Creek sub-watershed, there were 62 overflow events reported during the years from 1999 to February 2015 that spilled more than 1000 gallons with a maximum bypass volume of 40,000 gallons. In the Choteau Creek sub-watershed, there were 55 overflows reported during the years from 2000 to 2001 that spilled more than1000 gallons with a maximum bypass volume of >3 million gallons. Table 3-3 summarizes the SSO bypass occurrences in the Pryor Creek and Choteau Creek sub-watersheds. A list of SSO bypass events for Pryor Creek and Choteau Creek is presented in Appendix F.

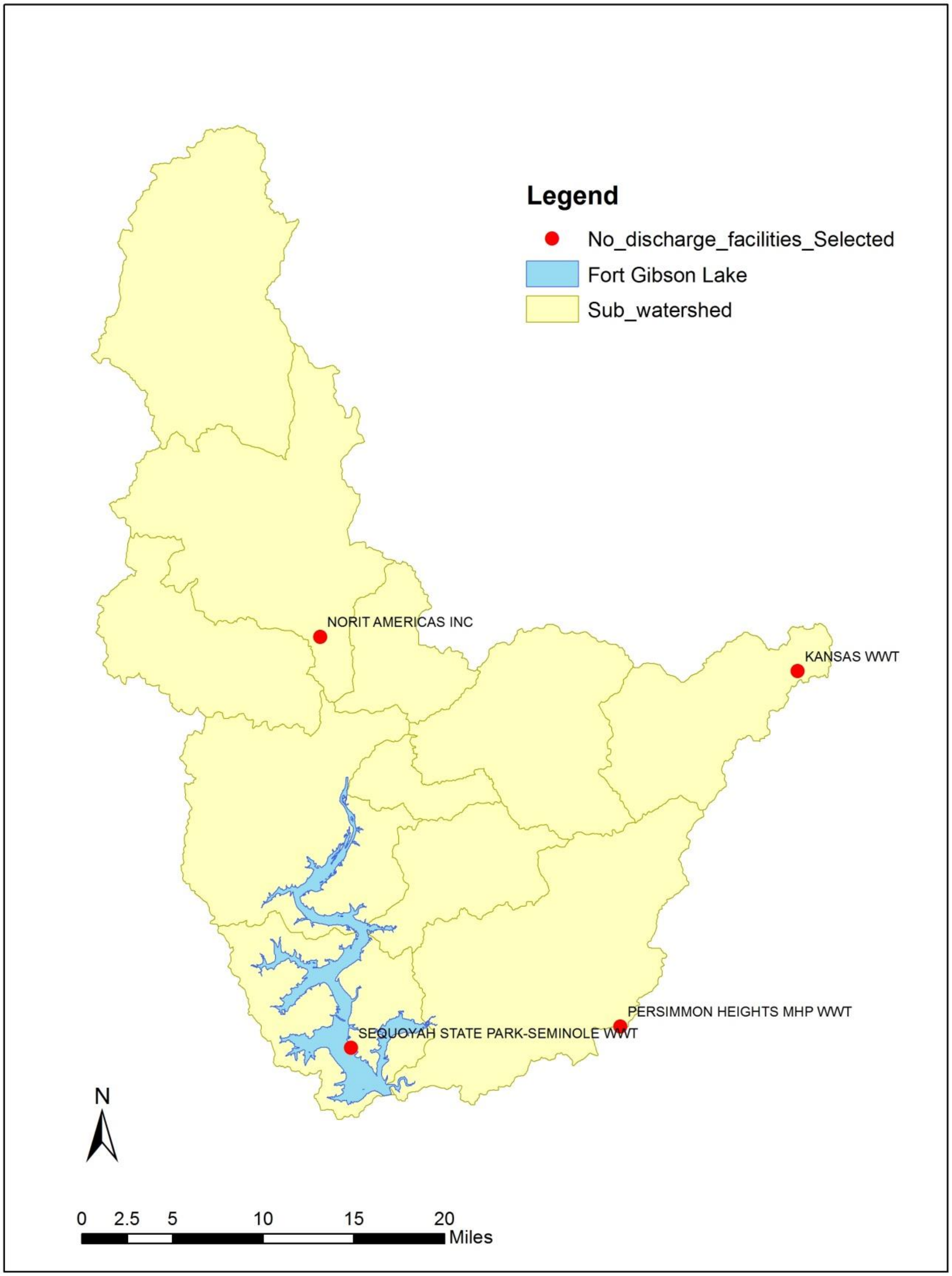

Figure 3-2 Location of NPDES No-Discharge WWTP Facilities in Fort Gibson Lake Watershed

Table 3-2 NPDES No-Discharge Facilities in Fort Gibson Lake Watershed

FACILITY	FACILITY ID	OWRB	COUNTY	FACILITY_TYPE
KANSAS WWT	S21675		DELAWARE	LAGOON (TOTAL RETENTION)
NORIT AMERICAS INC		WD90-017	MAYES	TOTAL RETENTION
PERSIMMON HEIGHTS MHP WWT	S21723		CHEROKEE	LAGOON (TOTAL RETENTION)
SEQUOYAH STATE PARK-SEMINOLE WWT	S21641		CHEROKEE	LAGOON (TOTAL RETENTION)

Table 3-3 Summary of Sanitary Sewer Overflow (SSO) Bypass (> 1000 gallons) Occurrences in the Fort Gibson Lake Watershed

City Name	Bypass Volume (gallons)	Number Events	Date Range		Max. Bypass Volume (gallons)
			From	To	
Pryor Creek, S21623	73,594	62	10/03/1999	2/13/2015	40,000
Choteau, S21624	12,319,772	55	1/05/2000	4/25/2001	> 3 Million Gallons

3.1.3 NPDES Municipal Separate Storm Sewer System (MS4)

In 1990 the EPA developed rules establishing Phase I of the NPDES Stormwater Program, designed to prevent pollutants from being washed off by stormwater runoff into municipal separate storm sewer systems (MS4s) or from being dumped directly into the stormwater system and then discharged into local receiving water bodies (EPA, 2005). Phase I of the program required operators of medium and large MS4s, defined as facilities serving populations of 100,000 or greater, to implement a stormwater management program as a means to control polluted urban runoff discharges to surface waters. Approved stormwater management programs for medium and large MS4s are required to address a variety of water quality-related issues, including roadway runoff management, municipal-owned operations, and hazardous waste treatment. Within the watershed area for Fort Gibson Lake there are no Phase I MS4 permits.

Phase II of the rule extends coverage of the NPDES stormwater program to certain smaller urban areas with stormwater systems. Small MS4s are defined as any MS4 that is not defined as a medium or large MS4 covered by Phase I of the NPDES Stormwater Program. Phase II requires operators of regulated small MS4s to obtain NPDES permits and develop a stormwater management program. Programs are designed to reduce discharges of pollutants to the “maximum extent practicable,” protect water quality, and satisfy appropriate water quality requirements of the CWA. Small MS4 stormwater programs must address the following minimum control measures:

- Public Education and Outreach;

- Public Participation/Involvement;
- Illicit Discharge Detection and Elimination;
- Construction Site Runoff Control;
- Post- Construction Runoff Control; and
- Pollution Prevention and Good Housekeeping.

The small MS4 General Permit for communities in Oklahoma became effective on February 8, 2005. DEQ provides information on the current status of the MS4 program on the agency website (http://www.deq.state.ok.us/WQDnew/stormwater/ms4/). Within the domain of the Fort Gibson Lake watershed model, Wagoner County and Tahlequah have been issued Phase II MS4 permits for stormwater discharges and stormwater management (Figure 3-3). Fort Gibson has also been issued a MS4 Phase II stormwater permit. The boundaries for the Fort Gibson MS4 permit are, however, outside the delineated boundary for the Fort Gibson Lake watershed model. Table 3-4 lists the Phase II MS4 permits within the Fort Gibson Lake watershed domain.

There are no numeric load limits associated with MS4 permits. Pollutant loading from the small portions of the Wagoner County MS4 and the Tahlequah MS4 that are within the watershed domain is estimated from the sub-watershed loads in proportion to the small areas of Wagoner County and Tahlequah that are within the larger areas of the Lower Fort Gibson and Fourteen Mile Creek sub-watersheds defined for the HSPF watershed model. The incremental areas of Wagoner County and Tahlequah within the watershed domain used for the HSPF model account for only 1.5% of the Lower Fort Gibson sub-watershed and 0.26% of the Fourteen Mile Creek sub-watershed areas. Since Wagoner County and Tahlequah combined account for only a very small contribution (0.14%) to the total area of the watershed model domain, the MS4 permits for Wagoner County and Tahlequah will, therefore, not be included as WLAs determined for this TMDL study. The small MS4 area for Wagoner County and the even smaller portion of the MS4 area for Tahlequah in the HSPF model domain will be accounted for by the Load Allocation (LA) estimated for the watershed.

Table 3-4 Urban Areas with MS4 Permits in the Fort Gibson Lake Watershed

City Name	Permit-ID	MS4 Phase	Date Issued
Wagoner County	OKR040020	Phase II	10/31/2005
Tahlequah	OKR040035	Phase II	07/24/2006

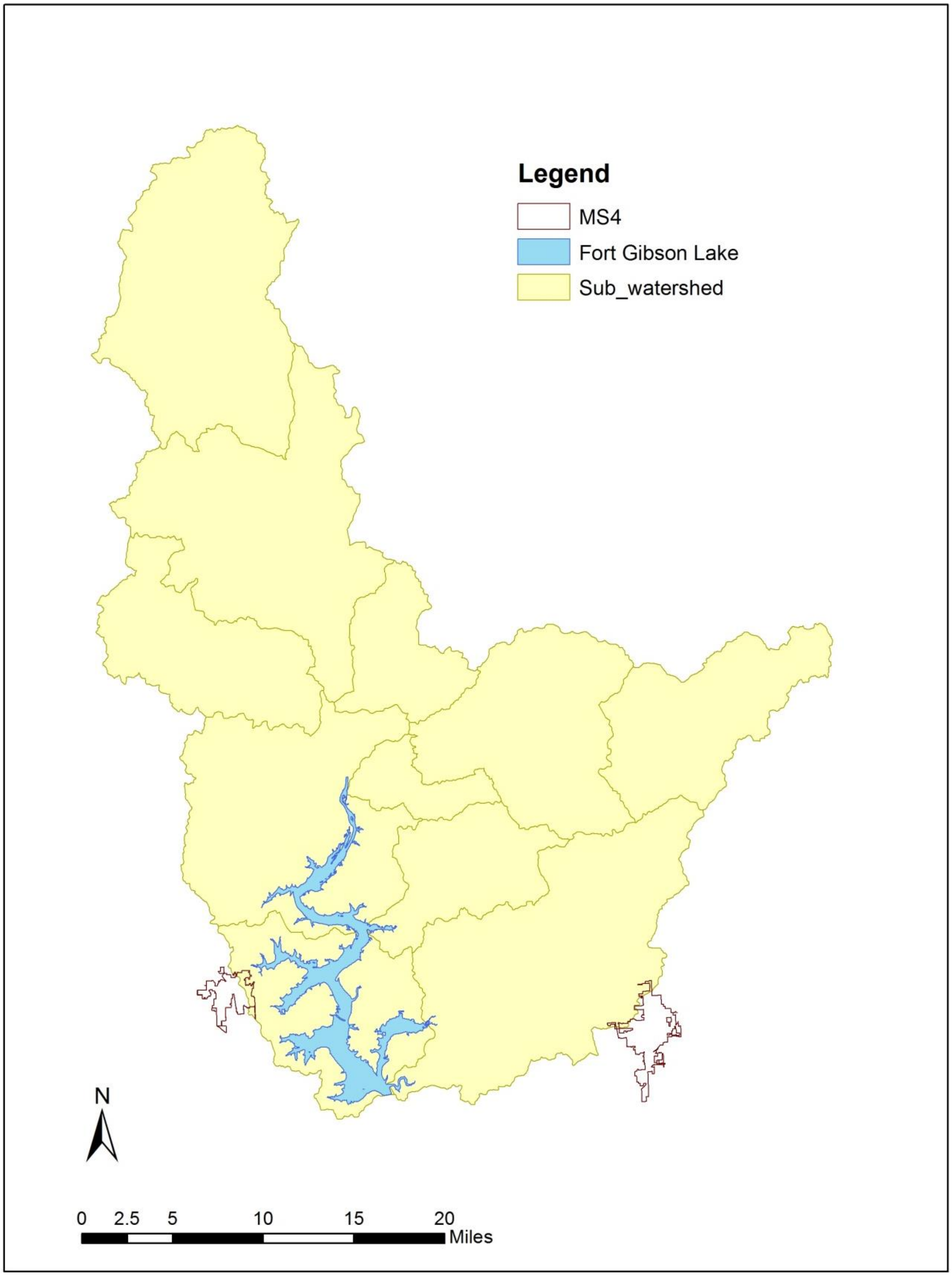

Figure 3-3 MS4 Stormwater Permit Boundary for Wagoner County and Tahlequah in the Fort Gibson Lake Watershed

3.1.4 NPDES Construction Site Permits

The Oklahoma Department of Environmental Quality (DEQ) has issued the "General Permit OKR10 for Stormwater Discharges from Construction Activities within the State of Oklahoma". Permits are issued for a period of 5 years for the period from 2007-2012. Permit authorizations are required for construction activities that disturb more than one acre or less than one acre if the construction activity is part of a larger common plan of development that totals at least one acre. This includes the installation, or relocation, of water or sewer lines that have the potential to disturb more than one acre. Construction activities that are on Indian Country Lands or are at oil and gas exploration and production related industry and pipeline operations that are under the jurisdiction of the Oklahoma Corporation Commission are regulated by the US Environmental Protection Agency.

A permit authorization to discharge storm water from activity at a construction site must be obtained prior to the commencement of any soil disturbing activities. The owner/operator must also develop and implement a Storm Water Pollution Prevention Plan (SWP3) for the construction site. The SWP3 shall provide information that pertains to the site description, storm water controls, maintenance, inspections and non-storm water discharges. Permit authorizations are terminated at the completion of the project or when there is a change of owner/operator for the entire project. Permit termination means that all of the temporary sediment control measures have been removed and that the site has had 70 percent vegetative cover established. The locations, and year, of the 13 construction site permits issued from 2007-2012 within the Fort Gibson Lake watershed are shown in Figure 3-4. Table 3-5 summarizes the information available for the construction site permits issued from 2007 (n=3), 2008 (n=7), and 2012 (n=3) where the issue date of the permit was available.

Table 3-5 Construction Site Permits Issued in the Fort Gibson Lake Watershed

Facility Name	PERMIT ID	COUNTY	DATE ISSUED	RECWATER	EST. ACRES
LIMESTONE CREEK	OKR108281	MAYES	10/24/2007	SULPHUR CREEK	5
MIDAMERICA INDUSTRIAL PARK P	OKR108471	MAYES	10/30/2007	CHOUTEAU CREEK	33
NORTHWEST MAID SUBSTATION	OKR107989	MAYES	12/18/2007	PRYOR CREEK	4
WEST MAINSTREET SUBSTATION	OKR108098	MAYES	1/10/2008	UNNAMED INTERMITTENT T	2
ODOT JP#20893(04)	OKR108720	MAYES	1/11/2008	CHOUTEAU CREEK	2
NEW RAILSPUR/ IMPOUNDMENT RE	OKR107237	MAYES	1/18/2008	PRYOR CREEK	2.1
HULBERT QUARRY	OKR106793	CHEROKEE	3/5/2008	DOUBLE SPRING CREEK	15
SUMMERFIELD PLACE IV	OKR108864	MAYES	3/14/2008	MIDAMERICA CREEK	12
ODOT JP#22153(04)	OKR108849	CHEROKEE	3/14/2008	RATTLESNAKE CREEK	3
PECAN VALLEY	OKR106809	ROGERS	3/24/2008	UNNAMED TRIBUTARY OF C	30
Cookson Hills Christian School- Phase 1 Infrastructure	OKR1021013	Delaware	9/28/2012	SPRING CREEK	5.5
Salina Water System Improvements	OKR1021589	Mayes	10/16/2012	SULPHUR CREEK	25
Track 138 Rehabilitation	OKR1021692	Mayes	11/9/2012	UNNAMED TRIB TO PRYOR CREEK	2

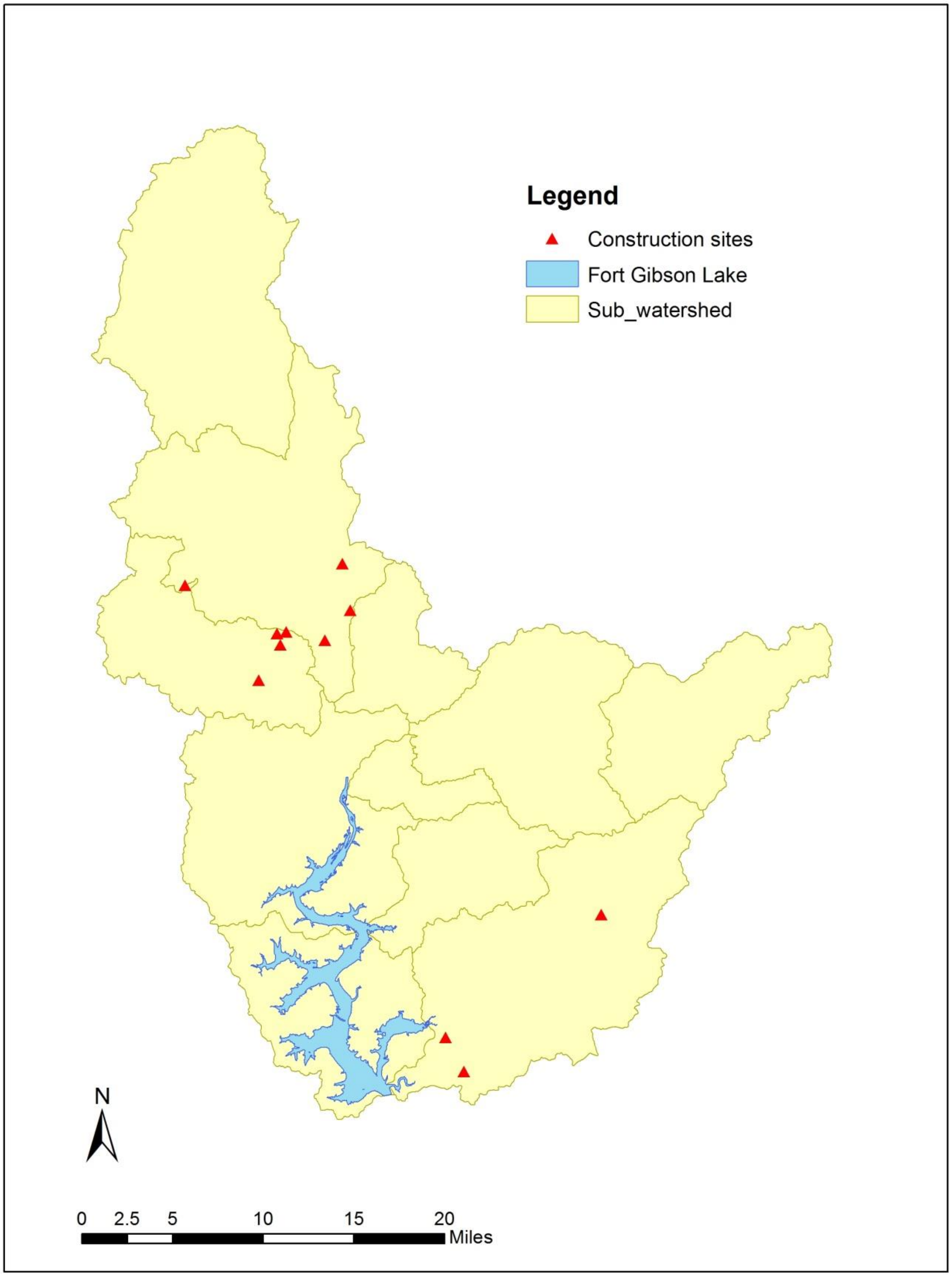

Figure 3-4 Construction Site Permits in Fort Gibson Lake Watershed

3.1.5 NPDES Multi-Sector General Permits (MSGP) for Industrial Sites

NPDES permit authorizations are required for stormwater discharges from 29 sectors of SIC-coded industrial activities listed in the OKR05 Multi-Sector General Permit (DEQ, 2011). Industrial activities that are on Indian Country Lands or are at oil and gas exploration and production related industry and pipeline operations that are under the jurisdiction of the Oklahoma Corporation Commission are regulated by the US Environmental Protection Agency.

An NPDES permit authorization to discharge storm water from an industrial activity must be obtained prior to the start of any operations. The owner/operator permit holder must also develop and implement a Storm Water Pollution Prevention Plan (SWP3) for the industrial facility maintained at the site. The SWP3 provides information that pertains to the site description, storm water controls, maintenance, inspections and non-storm water discharges. Permit authorizations are terminated when operations have ceased and there no longer are discharges of storm water associated with industrial activity from the facility. Table 3-6, organized by facility name and the permit identification numbers, lists the MSGP industrial site permits issued in the Fort Gibson Lake watershed. The locations of the industrial site MSGP permits are shown in Figure 3-5.

Table 3-6 Industrial Site MSGP Permits Issued in Fort Gibson Lake Watershed

Permittee	Facility Name	PERMIT ID	COUNTY	DATE ISSUED
Walkers Auto Salvage	WALKERS AUTO SALVAGE	OKR050039	Mayes	9/16/2011
ORCHIDS PAPER PRODUCTS	ORCHIDS PAPER PRODUCTS MILL PLANT	OKR050054	Mayes	11/29/2011
A P GREEN INDUSTRIES INC	A P GREEN INDUSTRIES INC PRYOR OK PLANT	OKR050059	Mayes	9/26/2011
OKLAHOMA ORDNANCE WORKS AUTHORITY	MIDAMERICA INDUSTRIAL PARK AIRPORT	OKR050125	Mayes	12/5/2011
SOLAE CO LLC	SOLAE CO LLC	OKR050141	Mayes	10/17/2011
EXPRESS METAL FABRICATORS	EXPRESS METAL FABRICATORS	OKR050146	Mayes	10/7/2011
Grand River Dam Authority	GRDA COAL FIRED COMPLEX	OKR050226	Mayes	11/10/2011
Tahlequah Auto Salvage LLC	TAHLEQUAH AUTO SALVAGE	OKR050238	Cherokee	11/21/2011
OKLAHOMA ORDNANCE WORKS AUTHORITY	EAST WASTEWATER TREATMENT PLANT	OKR050248	Mayes	12/5/2011
Frailey's Salvage	FRAILEYS SALVAGE	OKR050340	Mayes	9/15/2011
RAE Corporation	RAE CORP	OKR050423	Mayes	10/5/2011
JER CO INDUSTRIES	JER CO INDUSTRIES	OKR050448	Mayes	12/9/2011
Gap Roofing Inc	GAP ROOFING INC	OKR050449	Mayes	11/15/2011
The Nordam Group	NORDAM JET ENGINE TESTSITE	OKR050550	Mayes	10/12/2011
Industrial Vehicles International Inc	INDUSTRIAL VEHICLES INTERNATIONAL INC	OKR050667	Tulsa	9/27/2011
Performance Pipe Pryor Plt A Div of Chevron Phillips Chem Co	PREFORMANCE PIPE PRYOR PLT DIV OF CHEVRON CHEM CO	OKR050783	Mayes	12/14/2011

Permittee	Facility Name	PERMIT ID	COUNTY	DATE ISSUED
LSB Industries Inc	PRYOR PLT CHEMICAL CO	OKR050830	Mayes	11/28/2011
Air Products & Chemicals Inc	AIR PRODUCTS & CHEMICALS INC	OKR050885	Mayes	9/26/2011
Heater Specialists LLC - Mazie	Heater Specialists LLC - Mazie	OKR050889	Mayes	10/17/2011
APAC-CENTRAL, INC	PRYOR QUARRY	OKR050925	Mayes	12/15/2011
Amax Sign Company	A MAX SIGN	OKR051010	Tulsa	9/15/2011
Red Devil Inc	RED DEVIL, INC	OKR051142	Mayes	10/31/2011
Old Hwy 33 Salvage	OLD 33 SALVAGE	OKR051216	Mayes	10/25/2011
VERNON SALVAGE	VERNON SALVAGE	OKR051250	Mayes	3/22/2012
American Castings LLC	AMERICAN CASTINGS LLC	OKR051260	Mayes	9/20/2011
Sowers Auto Salvage & Recycling	SOWERS AUTO SALVAGE & RECYCLING	OKR051271	Mayes	11/21/2011
Martins Salvage	MARTIN'S SALVAGE	OKR051316	Delaware	9/23/2011
GEORGIA-PACIFIC GYPSUM LLC	GEORGIA-PACIFIC GYPSUM LLC PRYOR OKLAHOMA PAPER	OKR051397	Mayes	11/29/2011
LONE STAR INDUSTRIES DBA BUZZI UNICEM USA	PRYOR CEMENT PLANT	OKR051614	Mayes	10/7/2011
Central Carbide LLC	CENTRAL CARBIDE LLC	OKR051716	Mayes	11/10/2011
M5 Enterprises	M5 ENTERPRISES ROCK AND GRAVEL	OKR052024	Cherokee	9/23/2011
TD Williamson Inc	TD Williamson Inc - Remote W	OKR052105	Tulsa	9/23/2011
A&C Recycling	A&C Recycling	OKR052300	Cherokee	2/2/2012
NGC INDUSTRIES LLC	NGC INDUSTRIES LLC	OKR052468	Mayes	11/9/2012
USA Metal Recyclers	USA Metal Recyclers	OKR052554	Mayes	5/3/2013
Pryor Stone Inc	Parker Ranch Quarry	OKR052593	Mayes	8/21/2013
American Castings LLC	American Castings Quarry	OKR052697	Mayes	2/6/2014

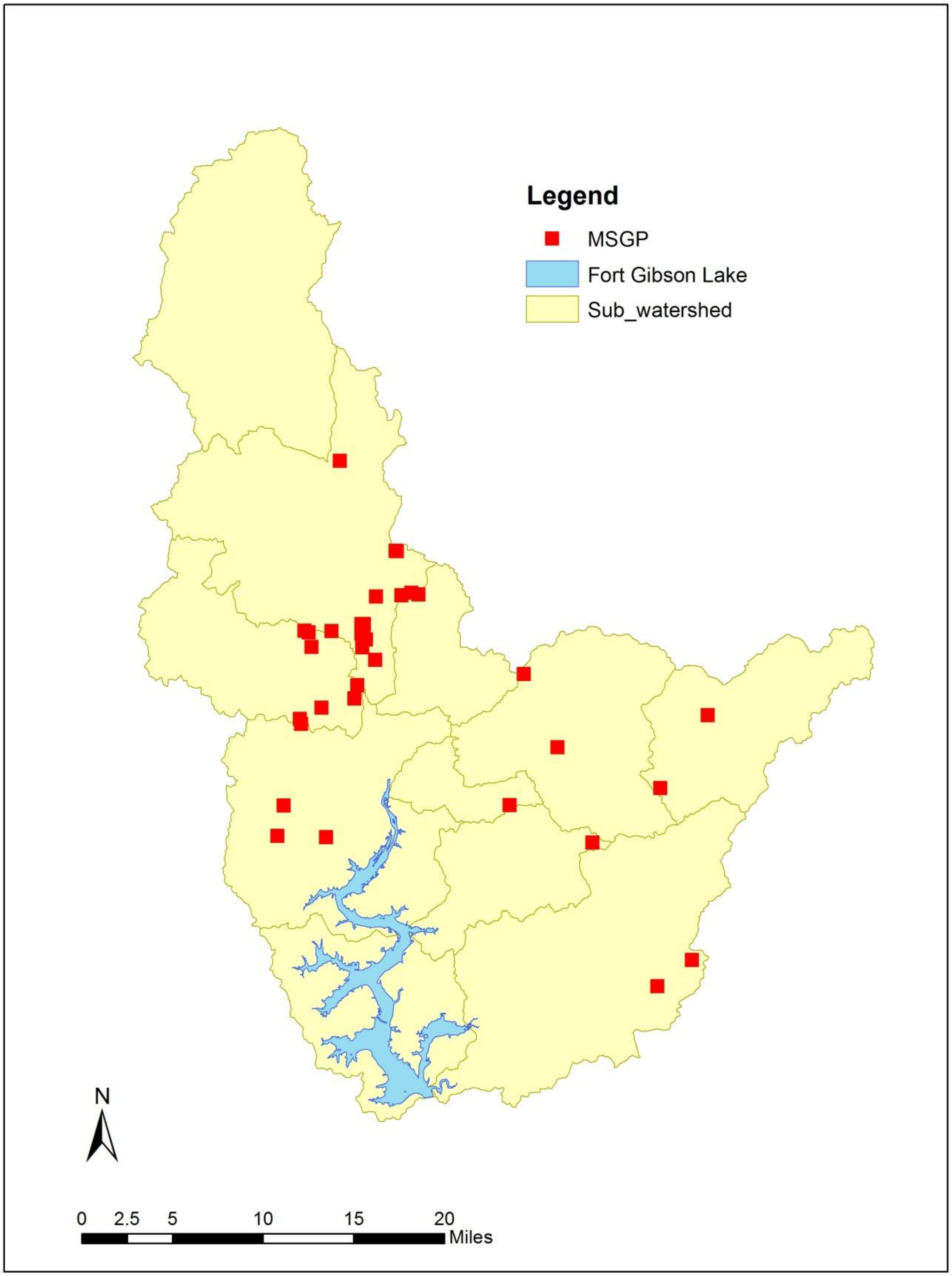

Figure 3-5 Multi-Sector General Permits (MSGP) Issued in the Fort Gibson Lake Watershed for Industrial Sites

3.1.6 NPDES Confined Animal Feedlot Operations (CAFO) and Poultry Feeding Operations (PFO)

There are no Confined Animal Feeding Operations (CAFO) in the Fort Gibson Lake watershed. Poultry Feeding Operations (PFO's), located in the Spring Creek and Pryor Creek sub-watersheds, are listed in

Table 3-7 and mapped in Figure 3-6. The Agricultural Environmental Management Services (AEMS) of the Oklahoma Department of Agriculture, Food and Forestry (ODAFF) was created to help develop, coordinate, and oversee environmental policies and programs aimed at protecting the environment from pollutants associated with waste from agricultural animals. ODAFF estimates that only 20% of the chicken litter from producers in the Fort Gibson Lake watershed is land applied in the watershed. The remainder of chicken litter is trucked outside of the watershed for disposal. Chicken litter data was not explicitly included in the watershed model. The impact of chicken litter on water quality, however, has been implicitly accounted for by agricultural land use in calibration of the watershed model.

Table 3-7 Poultry Feeding Operations in Fort Gibson Lake watershed

POULTRY ID	INTEGRATOR	TYPE	TOTAL # OF BIRDS	COUNTY
64	TYSON FOODS	Broilers	30,000	CHEROKEE
177	SIMMONS FOODS	Broilers	80,000	DELAWARE
178	SIMMONS FOODS	Broilers	40,000	DELAWARE
179	SIMMONS FOODS	Broilers	37,000	DELAWARE
626	SIMMONS FOODS	Broilers	120,000	MAYES
730	TYSON FOODS	Broilers	80,000	MAYES
1016	SIMMONS FOODS	Broilers	108,000	MAYES
1140	COBB-VANTRESS	Layers	16,000	DELAWARE
1157	TYSON FOODS	Broilers	300,000	ROGERS
1203	COBB-VANTRESS	Layers	30,000	DELAWARE
1263	COBB-VANTRESS	Pullets	36,000	CHEROKEE
1348	SIMMONS FOODS	Broilers	208,000	MAYES
1408	TYSON FOODS	Broilers	30,000	CHEROKEE
1416	TYSON FOODS	Broilers	304,000	DELAWARE
1417	SIMMONS FOODS	Broilers	160,000	MAYES
1448	SIMMONS FOODS	Pullets	72,000	MAYES
1459	TYSON FOODS	Breeders	21,000	MAYES
1476	TYSON FOODS	Broilers	70,000	MAYES
1485	COBB-VANTRESS	Pullets	40,000	DELAWARE
1560	COBB-VANTRESS	Breeders	20,000	DELAWARE
1576	SIMMONS FOODS	Layers	19,000	DELAWARE
1588	SIMMONS FOODS	Broilers	240,000	ROGERS
1599	SIMMONS FOODS	Broilers	108,000	MAYES
1613	SIMMONS FOODS	Broilers	327,000	DELAWARE
1614	SIMMONS FOODS	Broilers	168,000	DELAWARE
1615	SIMMONS FOODS	Broilers	82,000	DELAWARE
1630	INDEPENDENT	Broilers	60,000	CHEROKEE
1659	SIMMONS FOODS	Broilers	348,000	CHEROKEE
1714	SIMMONS FOODS	Broilers	342,000	DELAWARE
1746	TYSON FOODS	Broilers	92,000	MAYES

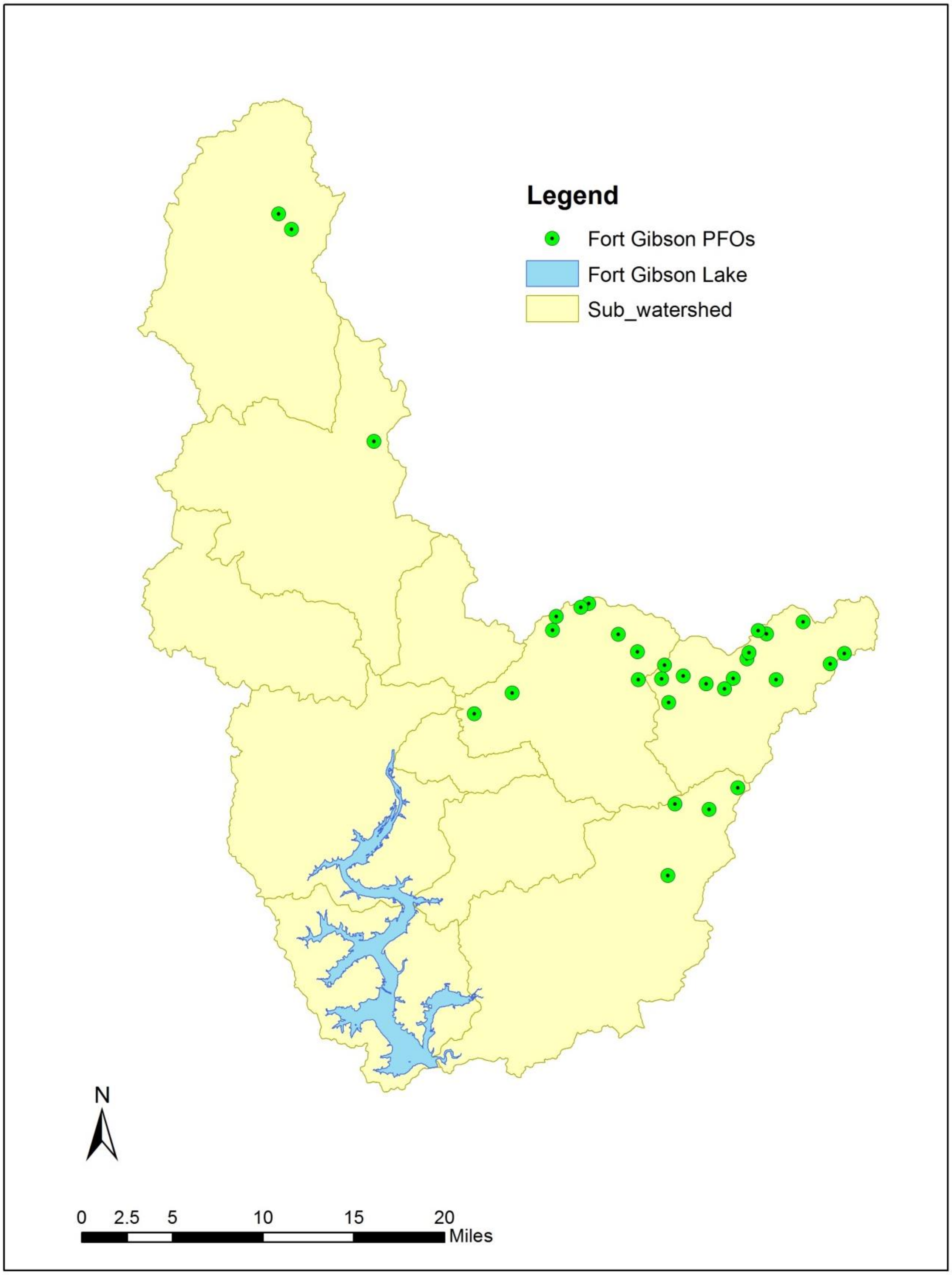

Figure 3-6 Poultry Feeding Operations (PFO's) in the Fort Gibson Lake Watershed

3.1.7 Atmospheric Deposition of Nutrients

In many coastal and inland watersheds, atmospheric deposition of nitrogen, derived primarily from burning fossil fuels, can account for a significant fraction of the total nitrogen loading to a waterbody. Atmospheric deposition, for example, accounts for 10-40% of nitrogen loading to estuaries along the East coast of the USA and eastern Gulf of Mexico (Paerl et al., 2002) and 25-28% in Chesapeake Bay (EPA, 2010). Atmospheric deposition of nitrogen is therefore a potentially significant component of nutrient loading to a waterbody.

Atmospheric deposition is considered to be an uncontrollable source term for the Fort Gibson Lake TMDL determination. Nevertheless, lake water quality models that simulate the nutrient balance of the lake must account for all sources of both nitrogen and phosphorus. Atmospheric deposition of nitrogen and phosphorus to a waterbody is contributed by both dry and wet deposition. Dry deposition is defined as a mass flux rate (as g/m^2-day) for a constituent that settles as dust or is deposited on a dry surface during a period of no precipitation. The mass flux of a constituent from wet deposition is defined by the concentration of the constituent in rainfall and the rate of precipitation. For Fort Gibson Lake, wet and dry deposition data was estimated as the average of annual data from 2005-2006 for ammonia and nitrate from the National Atmospheric Deposition Program (NADP) for Station AR27 (Fayetteville, AR) and the Clean Air Status and Trends Network (CASTNET) Station CHE185 (Cherokee Nation). Data was not available from the CASTNET or NADP sites for deposition of phosphorus. Dry deposition for phosphorus was estimated using the CASTNET and NADP data for nitrogen with annual average N/P ratios for atmospheric deposition of N and P reported for 6 sites located in Iowa (Anderson and Downing, 2006). Annual average wet phosphorus concentration was estimated in proportion to the Dry/Wet ratio for phosphate deposition fluxes reported by Anderson and Downing (2006). Appendix B details the data sources and parameter values used to assign atmospheric deposition of nitrogen and phosphorus for the lake model.

3.1.8 Upstream River and Watershed Loading of Nutrients and Sediment

External loading of nutrients and sediments to Fort Gibson Lake is contributed by the outflow from Lake Hudson to the Neosho River and runoff over the watershed drainage area to Fort Gibson Lake from Lake Hudson to the dam in Fort Gibson Lake. Loading from Lake Hudson, defined for this TMDL study as a specified upstream boundary input to the lake model, is driven by (a) outflow from Spavinaw Lake and Eucha Lake to the Spavinaw River, and (b) outflow from Grand Lake to the Neosho River. Outflows from these reservoirs, in turn, are controlled by upstream watershed loading and physical transport and biochemical processes in the reservoirs.

Watershed loading results from precipitation and hydrologic runoff processes over drainage area catchments that are dependent on characteristic properties of the landscape such as topography, land use, soil types and physical processes such as infiltration and erosion. Flow and pollutants, derived from watershed runoff, are transported through a network of streams and rivers with discharge into the lake at downstream outlets of the streams. Since watershed loading of nutrients usually is a significant component of the overall nutrient loading to a waterbody, loading from the watershed to the lake is considered as a controllable source term for a TMDL determination.

Streamflow, runoff and pollutant loading of nutrients and sediments from the Lower Neosho drainage basin into Fort Gibson Lake is estimated using a public domain and peer reviewed watershed model, Hydrologic Simulation Program-FORTRAN (HSPF). An overview description of the application of the HSPF watershed model for the Fort Gibson Lake project is presented in Section 3.3 of this report. A more complete description of the watershed model is given in Appendix A of this report.

3.1.9 Internal Lake Loading from Benthic Nutrient Release

In addition to the external loading of nutrients from watershed runoff and atmospheric deposition into the lake, decomposition processes in the sediment bed can also contribute a significant internal load of nutrients to the overall nutrient loading to the lake and contribute to eutrophication of the lake. Particulate organic matter in the water column and sediment bed of Fort Gibson Lake is derived from both external wastewater sources and watershed runoff and internal biological production of organic matter. Particulate organic matter settles out of the water column, accumulates within the sediment bed, and undergoes decomposition processes. During the summer months of stratification from April through October, decay processes within the sediment bed deplete dissolved oxygen below the thermocline and release inorganic nutrients from the sediment bed back into the water column. The release of ammonia and phosphate from the bed to the water column, in particular, is controlled, in part, by bottom water dissolved oxygen levels with the largest internal release rates occurring during summer anoxic conditions. This internal source of nutrients is considered to be an uncontrollable source term for the TMDL determination in this study. Nevertheless, just like atmospheric deposition of nutrients, lake water quality models that simulate the nutrient balance of the lake must account for this internal source of nutrients as a contributing factor for eutrophication and the mass balance of nutrients.

Site-specific measurements of nutrient release from the sediment bed under aerobic and anoxic conditions in Fort Gibson Lake are not available. Benthic nutrient release data is available, however, from some lakes and reservoirs in the region such as Lake Wister (Haggard and Scott, 2011); Lake Frances (Haggard and Soerens, 2006); Lake Eucha (Haggard et al., 2005) in Oklahoma; Beaver Lake in Arkansas (Sen et al., 2007; Hamdan et al., 2010), Acton Lake in Ohio (Nowlin et al., 2005) and a group of 17 lakes and reservoirs in the Central Plains (Dzialowski and Carter, 2011). Benthic phosphate release rates, characteristic of mesotrophic lakes and reservoirs, can also be estimated by for Fort Gibson Lake using an empirical methodology developed by Nurnberg (1984). Data from Dzialowski and Carter (2011) was used to confirm model results simulated by the internally coupled sediment diagenesis sub-model of the EFDC lake model that was developed for Fort Gibson Lake.

3.2 HSPF Watershed Model

3.2.1 Overview of HSPF model

The Hydrological Simulation Program FORTRAN (HSPF), supported by EPA and the USGS as a public domain model, is a lumped parameter watershed runoff model that simulates watershed hydrology and non-point source pollutant loadings for organic matter, nutrients, sediments, bacteria and toxic chemicals within a watershed network of delineated sub-basins. The internal stream model routes flow and water quality constituents through a network of river reaches for each sub-basin of the watershed. The HSPF hydrologic sub-model provides for simulation of water balances in each sub-basin based on precipitation, evaporation, water withdrawals, irrigation, diversions, wastewater discharges, infiltration, and active and deep groundwater reservoirs. Empirical model parameters are assigned for each sub-basin land use through model calibration to simulate the water balance and pollutant loading from a sub-basin. HSPF is designed as a time variable model with results generated on an hourly or daily basis. Hundreds of applications of HSPF over the past two decades have included short-term storm events and/or continuous simulations over annual and decadal cycles. BMP alternatives designed to reduce pollutant loads to receiving waters can be represented in HSPF by adjustments of land use-based yield coefficients for a pollutant. Windows-based user-friendly GUI software tools such as WinHSPF (Duda et al., 2001), GenScn (Kittle et al., 1998) and HSPFParm (Donigian et al., 1999) have been developed to facilitate pre- and post-processing tasks for HSPF. Time series results for streamflow and pollutant loads generated by HSPF have been linked for input to hydrodynamic (e.g., EFDC) and water quality models (e.g., EFDC, WASP7) in numerous applications over the past decade. HSPF, considered a Level 3 Complex or Advanced Model, is available for download from EPA's BASINS website https://www.epa.gov/ceam/basins-user-information-and-guidance.

3.2.2 Model Setup and Data Sources

The HSPF model was initially setup using EPA's BASINS (Version 4.1) watershed modeling platform. The sub-watershed boundaries were delineated based on USGS's National Elevation Dataset and EPA's River Reach File Version 1 (RF1) stream network. The 10 sub-watersheds delineated for the watershed model are shown in Figure 3-7. Data sets collected in 2005-2006 were identified for calibration of the watershed-lake model. Although the most recent data available for land use is the 2011 NLCD database, the 2011 data set is not consistent with the choice of 2005-2006 as the time period for development and calibration of the watershed model. The 2006 NLCD data is used for watershed model setup because it provides the best representation of the effect of watershed runoff on land uses and land cover that, in turn, impacted water quality conditions in watershed streams during 2005-2006. Flow data were monitored by USACE Tulsa District at a station on Upper Pryor Creek (PYR02) as shown in Figure 3-7. The Fort Gibson watershed hydrologic model was calibrated at the USACE station on Pryor Creek where the drainage area was approximately 137.0 square miles. Flow generated for each of the 10 sub-watersheds delineated for the HSPF model was estimated with the hydrologic modules of the watershed model. Monthly water quality data were available for comparison to the watershed model results at the OWRB station on Spring Creek (Figure 3-7).

Five-minute meteorological data from three MESONET stations (Figure 3-8) are used in the watershed model to represent spatial variability of precipitation. Cloud cover data, not available at the MESONET stations, was obtained from the NOAA NCDC stations at Tahlequah Municipal Airport and Claremore Regional Airport. Information for the meteorological stations is given in Table 3-8.

EPA's National Pollutant Discharge Elimination System (NPDES) identifies 10 major and minor wastewater facilities (point sources) that discharge into the Lower Neosho River. Five facilities, as shown in Figure 3-10 and Table 3-9, with a monthly average discharge greater than 0.1 MGD (0.15 cfs) were considered as point source discharges of wastewater for the watershed model. The stream reach receiving effluent from each point source facility was identified using either EPA's Permit Compliance System (PCS) or GIS-based geographic locations.

EPA TMDL guidance on natural background is given as follows: "*The TMDL submittal must include a description of the point and nonpoint sources of the pollutant of concern, including the magnitude and location of the sources. Where it is possible to separate natural background from nonpoint sources, a description of the natural background must be provided, including the magnitude and location of the source(s). Such information is necessary for EPA's review of the load and wasteload allocations that are required by regulation.*"

Streamflow and pollutant loading to Fort Gibson Lake are provided as time series output from the HSPF hydrologic runoff model to the EFDC lake model. Simulated flow and watershed loading are dependent on land use characteristics, soils, topography and hydrologic inputs. Natural background conditions are not represented as an explicit component of nonpoint source loading generated by the HSPF watershed model.

EPA regulations require that a TMDL include LAs, which identify the portion of the loading capacity attributed to existing and future nonpoint sources and to natural background. Load allocations may range from reasonably accurate estimates to gross allotments (40 C.F.R.§130.2(g)). Where possible, load allocations should be described separately for natural background and nonpoint sources.

Table 3-8 Meteorological Stations Used in the HSPF Model of the Lower Neosho Basin

Station ID	Data Frequency	Station Name	Latitude	Longitude
PYRO	5-minute*	Pryor	36.36914	-95.27138
INOL	5-minute*	Inola	36.14246	-95.45067
TAHL	5-minute*	Tahlequah	35.97235	-94.98671
Tahlequah	Hourly	Tahlequah Municipal Airport	35.92900	-95.00400
Claremore	Hourly	Claremore Regional Airport	36.29400	-95.47900

* 5-minute frequency meteorological data is averaged to 1-hour intervals for model setup

Table 3-9 Wastewater Treatment Facilities Included in Watershed Model

NPDES_ID	Facility Name	Receiving Water	Latitude	Longitude	Design flow (MGD)
OK0022781	CHELSEA ECONOMIC DEV ATHRTY WWTP	Pryor Creek	36.52	-95.42	0.5
OK0022764	CHOUTEAU WWTP	Chouteau Creek	36.19	-95.32	0.32
OK0040258	CALPINE PRYOR	Pryor Creek	36.24	-95.28	Inactive, permit closed in 2013
OK0022772	LOCUST GROVE WWTP	Crutchfield Branch	36.21	-95.17	0.75
OK0040479	PRYOR CREEK WWTP	Pryor Creek	36.27	-95.34	1.67

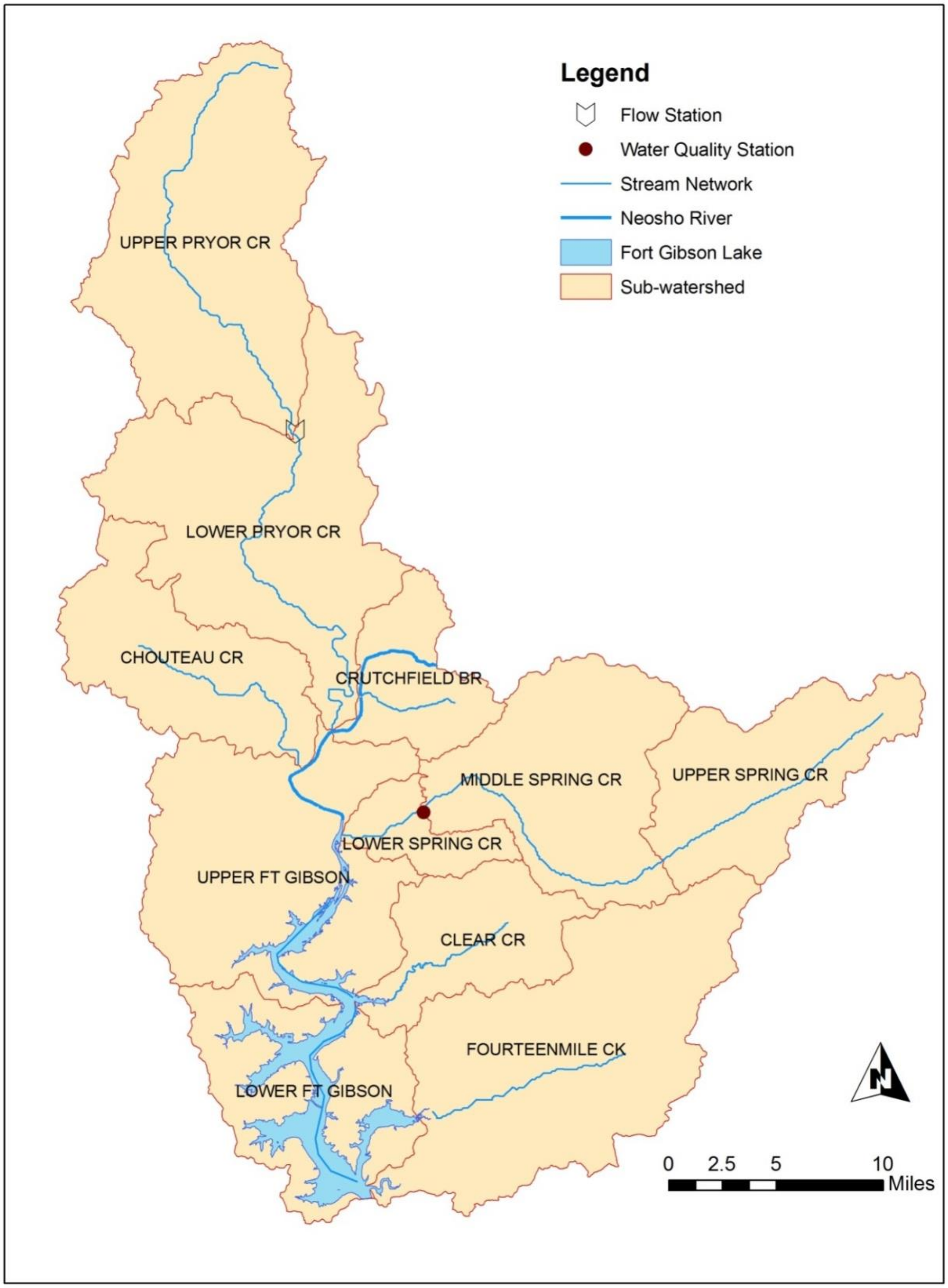

Figure 3-7 HSPF Model Discretization of the Fort Gibson Lake Watershed

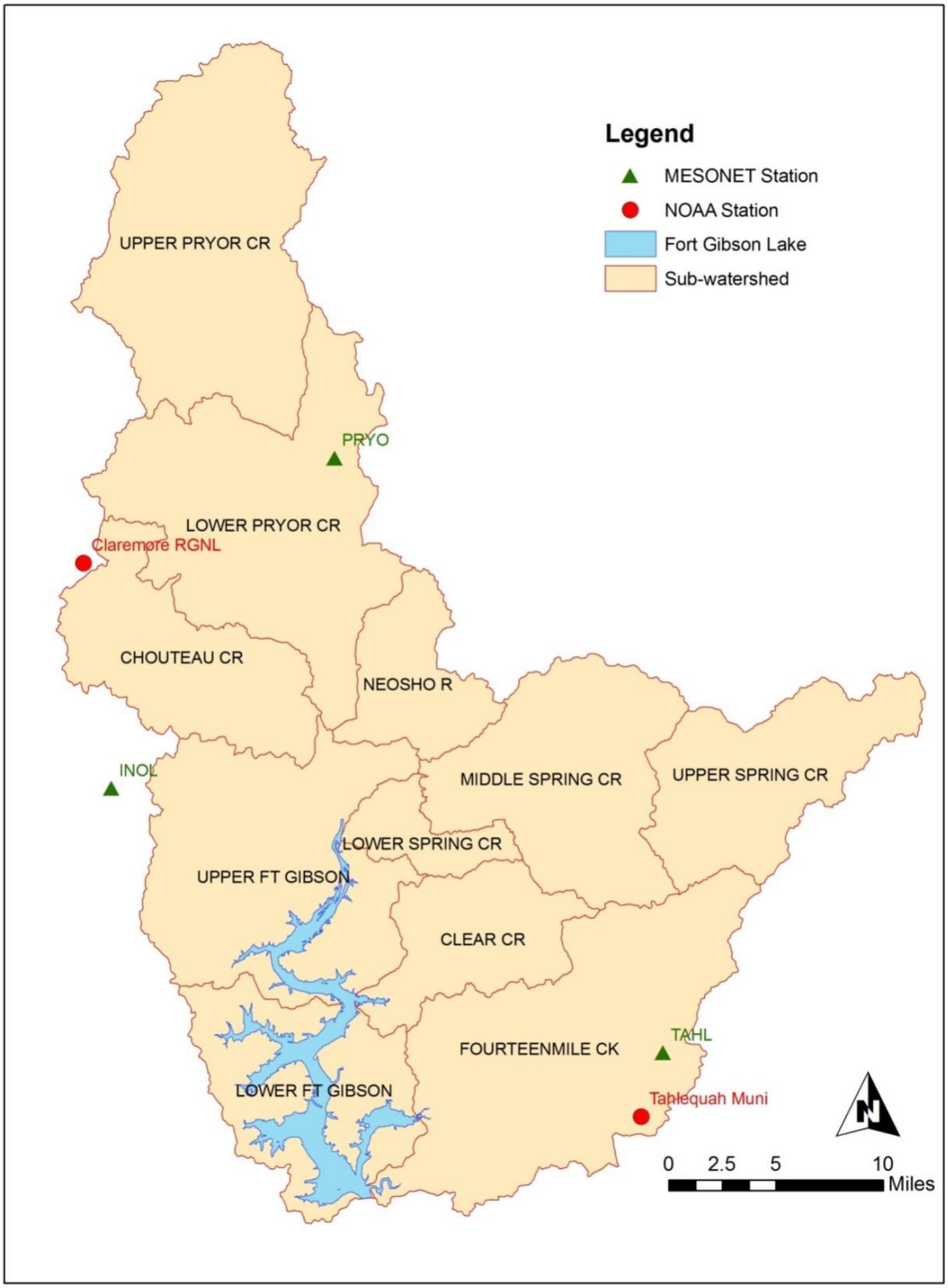

Figure 3-8 Locations of MESONET and NOAA Meteorological Stations

3.2.3 Model domain and discretization for sub-watershed representation

The Fort Gibson Lake watershed was delineated into 10 sub-watersheds (see Figure 3-7) based on the USGS National Elevation Dataset. Table 3-10 provides data for the reach characteristics developed by BASINS for the HSPF model.

Table 3-10 REACH Characteristics Developed by BASINS for Lower Neosho Watershed Model

Reach ID	REACH Name	Length (mile)	ΔElevation* (feet)	Longitudinal Slope
1	CHOUTEAU CR	12.42	49	0.00075
2	CLEAR CR	8.7	213	0.00464
3	FOURTEENMILE CK	10.68	266	0.00472
5	LOWER PRYOR CR	22.67	75	0.00063
6	LOWER SPRING CR	4.37	164	0.00711
7	MIDDLE SPRING CR	15.78	167	0.00200
9	UPPER PRYOR CR	25.16	279	0.00210
10	UPPER SPRING CR	13.36	223	0.00316
11	CRUTCHFIELD BR	8.03	79	0.00186

* ΔElevation is the drop in stream bed elevation from the upstream to downstream end of a reach

3.2.4 Observed Flow and Water Quality Data for Model Calibration

For the Fort Gibson Lake watershed model, flow was calibrated to a station located on Upper Pryor Creek (Figure 3-7). Observed flow data for Pryor Creek for 2007-2008 and station location information were obtained by request from the USACE Tulsa District. Streamflow for the watershed model was calibrated to data collected from January 1, 2008 through December 31, 2008.

USGS gage station 07191500 on the Neosho River is located at the downstream end of Lake Hudson at the dam. The flow at USGS 07191500 accounts for the discharge at the dam from Lake Hudson. In configuring the riverine portion of the EFDC model grid, the model domain was extended upstream on the Neosho River to the dam at Lake Hudson (Figure 3-9). Streamflow data available from USGS gage station 07191500 was used to define the upstream flow boundary condition for input to the lake model.

Observed water temperature, DO, nitrate, ammonia, total nitrogen, orthophosphate and total phosphorus data are only available at a station on Spring Creek with data collected monthly by OWRB (Figure 3-7). The water quality model was calibrated to data collected from January 1, 2005 through December 31, 2008.

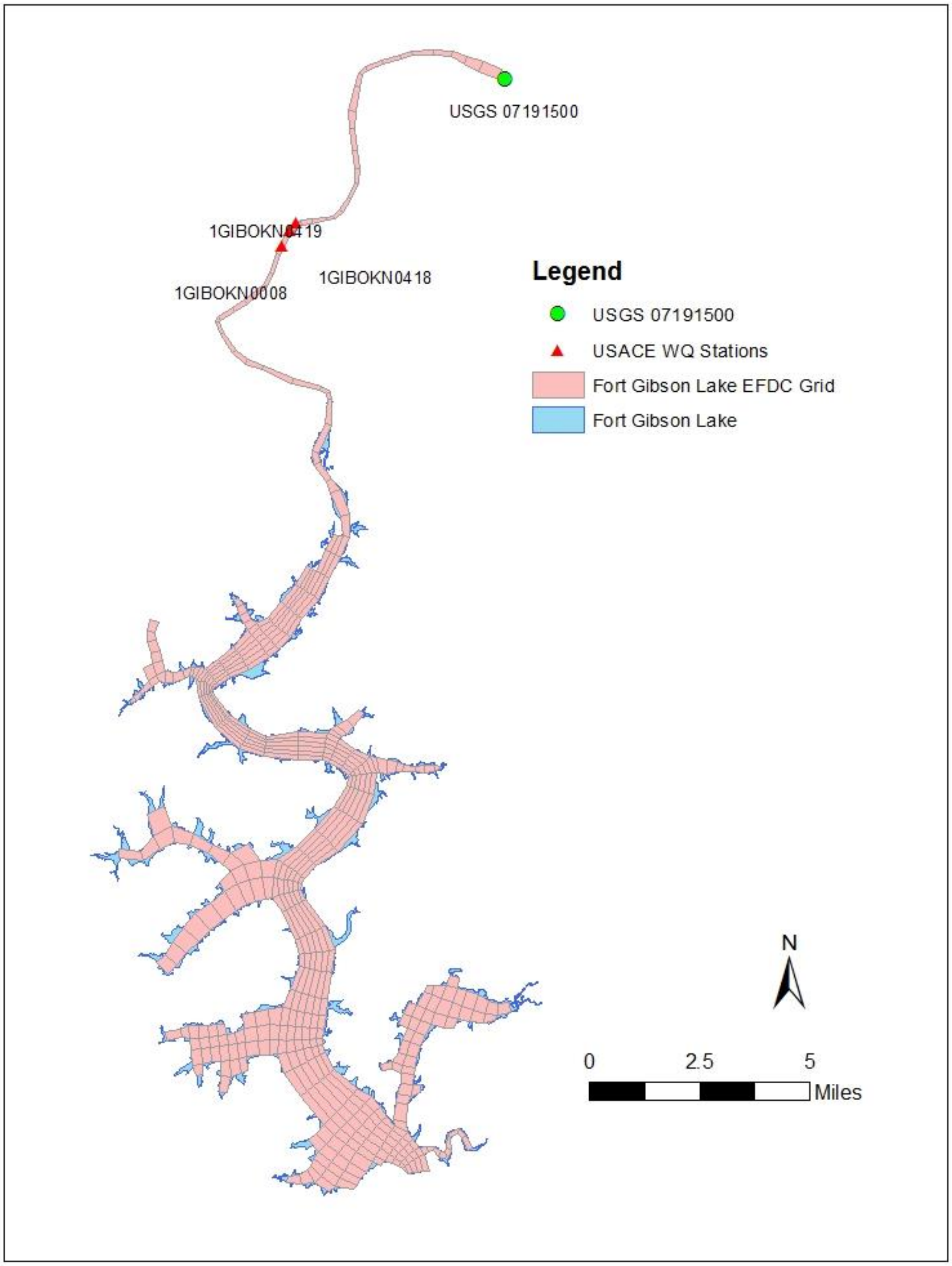

Figure 3-9 Location of USGS and USACE Stations in Upstream Neosho River

3.2.5 HSPF Model Calibration

Computer water quality models are simplified representation of the physical world. In addition, observed data from monitoring have inherent errors from the sample collection process, equipment used, and lab analysis procedures. As a result, models, even after calibration, do not produce results that match exactly with observed data. To judge if a model performs as designed and simulates pollutant loads with a reasonable accuracy, graphic comparison and statistical analyses are conducted to evaluate model performance.

In this study, observed stream discharge and water quality parameters for water temperature, DO and nutrients were plotted on the same graphs with simulated time series. Visual inspections were made to compare the observed and simulated data. Three statistics, percent difference of average values (% error), correlation coefficient (r^2), and Nash-Sutcliffe coefficient (N-S), were calculated to quantify how well the model simulation matched the observed data. Statistics for comparison of observed data and the model simulation were calculated as shown in Table 3-11. Time series comparison plots for water temperature and water quality variables are presented in Figure 3-10 through Figure 3-16.

Table 3-11 Model Performance Statistics for Calibrated Water Quality Parameters

Parameter	Mean observed	Mean simulated	MPE	R	NS
Water temperature (° F)	61.89	60.82	1.7	0.92	0.70
DO (mg/L)	9.29	9.58	-3.2	0.49	0.08
NO3 (mg/L)	0.406	0.239	41.2	-0.61	-0.52
TN (mg/L)	0.519	0.322	37.8	0.21	-0.35
PO4 (mg/L)	0.008	0.006	26.0	-0.09	-2.52
TP (mg/L)	0.015	0.013	-13.9	-0.19	-0.36

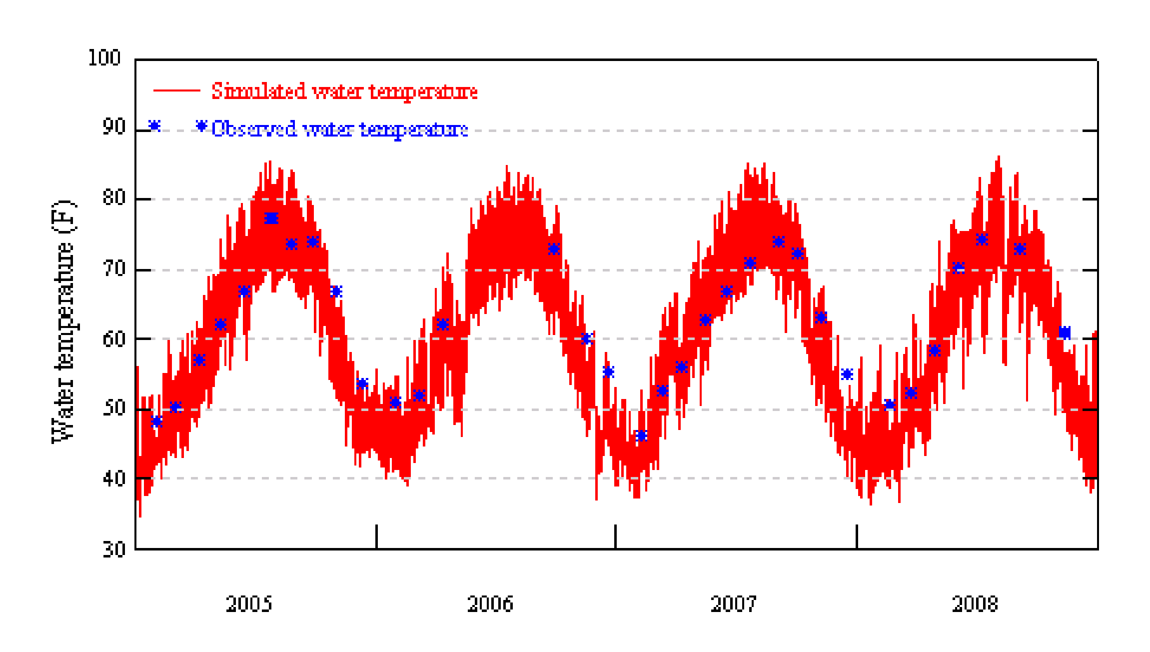

Figure 3-10 Water Temperature Calibration at Spring Creek, 2005-2006

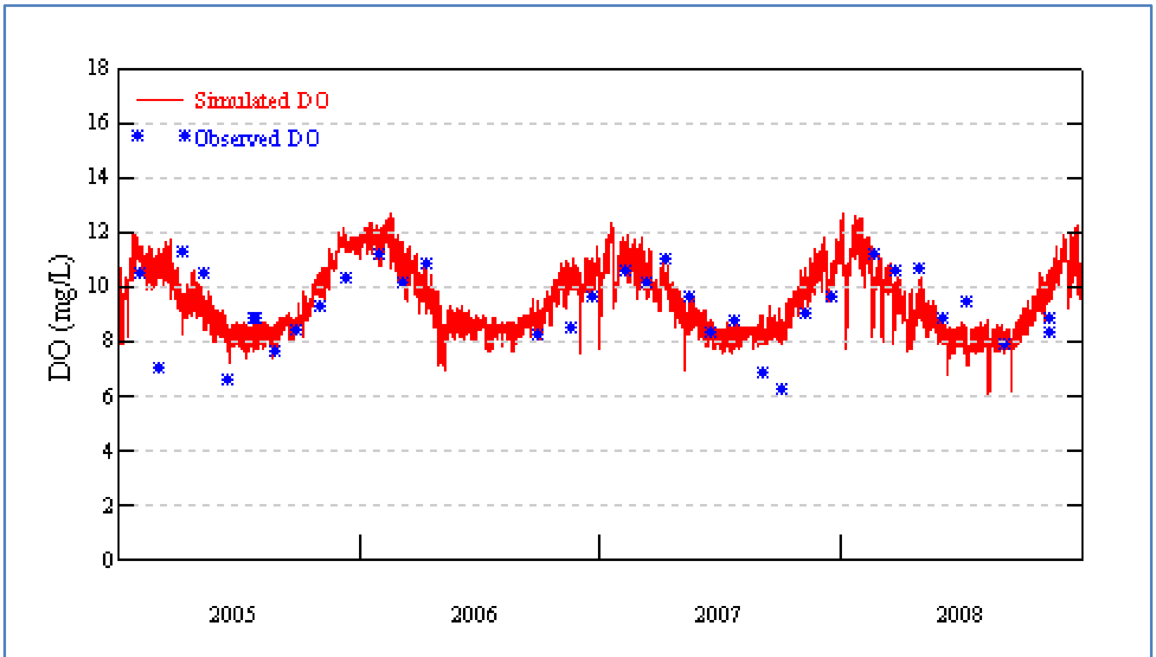

Figure 3-11 DO Calibration at Spring Creek, 2005-2006

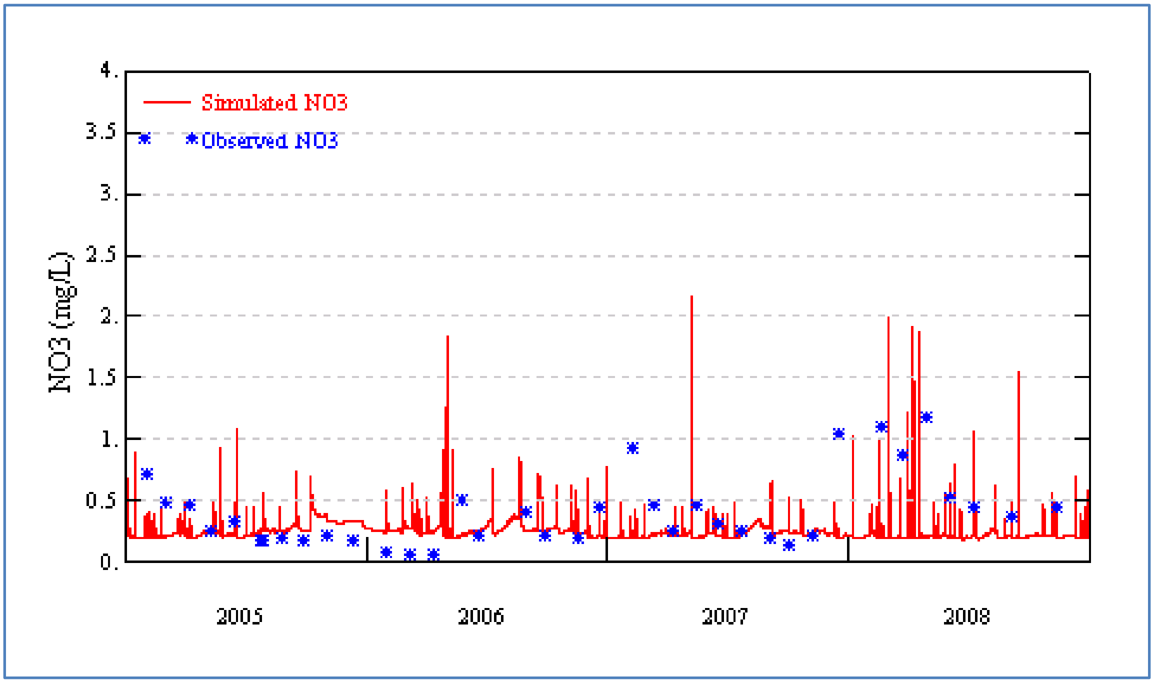

Figure 3-12 Nitrate Calibration at Spring Creek, 2005-2006

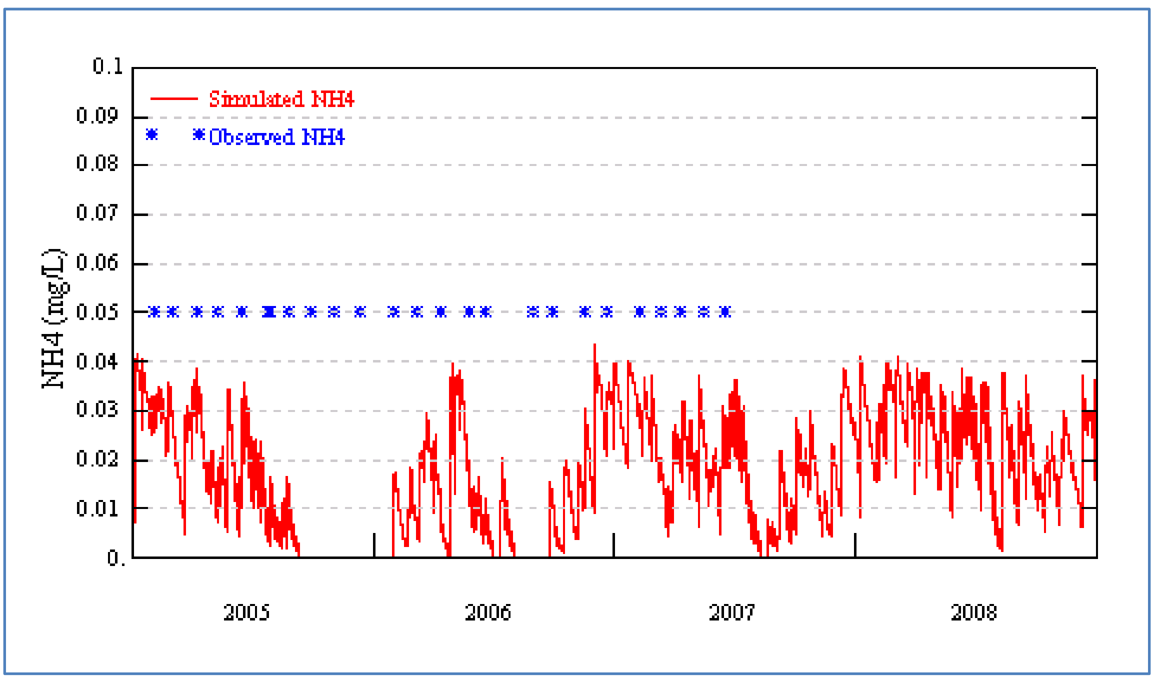

Figure 3-13 Ammonia Calibration at Spring Creek, 2005-2006.
Observed ammonia data is all at detection limit of 0.05 mg/L.

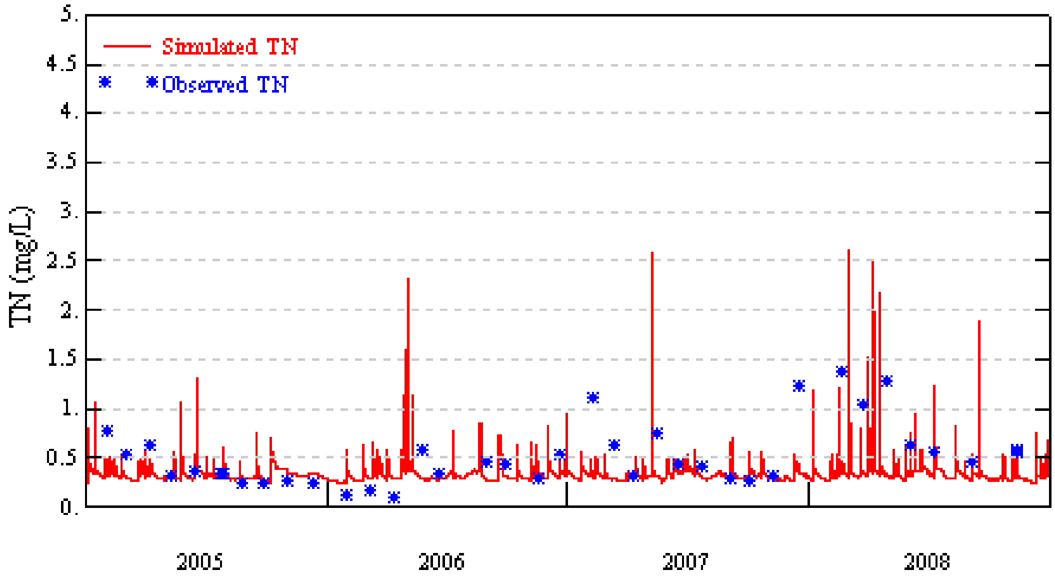

Figure 3-14 Total Nitrogen Calibration at Spring Creek, 2005-2006

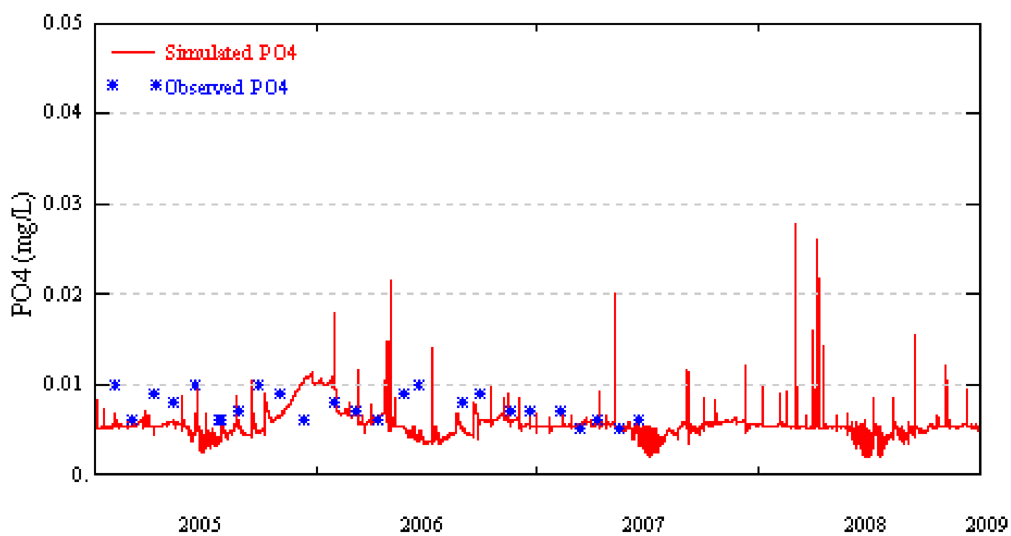

Figure 3-15 Orthophosphate Calibration at Spring Creek, 2005-2006

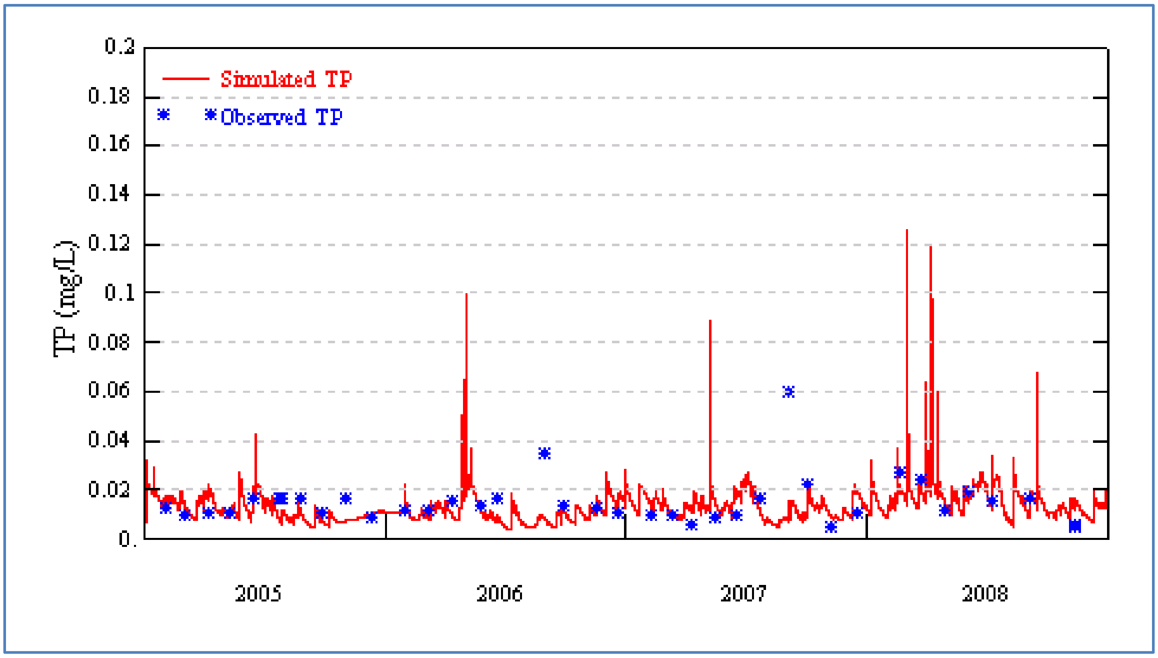

Figure 3-16 Total Phosphorus Calibration at Spring Creek, 2005-2006

3.2.6 HSPF Loads for TSS, TN, TP and CBOD for Existing Calibration Conditions

The HSPF model framework consists of a network of sub-watersheds that generate flow and pollutant loading from streamflow and runoff over the land uses of sub-watersheds defined within a larger watershed domain for a project. Some, but not all, sub-watersheds are defined by an in-stream reach where flow and pollutant loads simulated as land use dependent runoff are input and routed through a stream reach defined by length, volume, surface area, depth and hydraulic residence time. A sub-watershed that is defined by an in-stream reach generates flow (cubic ft/sec) and water quality concentrations (mg/L) at a specific downstream outlet location of each sub-watershed. A sub-watershed that does not include an in-stream reach generates water volume (cubic ft/hr) and pollutant loads (lbs/hr) as distributed, or overland, runoff over the entire sub-watershed.

Time series results generated by the watershed model for in-stream reach sub-watersheds and overland distributed runoff sub-watersheds are time-averaged, and converted as needed, to derive daily time series for flow (cubic ft/sec), pollutant load (lbs/day) and pollutant concentration (mg/L) for each sub-watershed. Pollutant loads and pollutant concentration generated by the HSPF model are related to flow by the following relationship: Load (lbs/day) = Flow (cfs) x Concentration (mg/L) x 5.39.

Daily time series data sets of flow and pollutant loads generated for each sub-watershed are used to link the flow and pollutant loading output of the HSPF watershed model as input to the EFDC lake model (see

Section 4.2). In contrast to a water quality model framework that does not incorporate linkage from a watershed model to a receiving water model, natural background conditions are not represented as an explicit component of nonpoint source loading generated by the HSPF watershed model. All flow and pollutant loading data assigned for input to the EFDC lake model are derived from the HSPF watershed model.

By aggregating modeled time series of pollutant loading simulated for all in-stream reach tributaries and all NPS overland sub-watersheds, an annual pollutant load budget for the HSPF watershed model is derived for sediment, CBOD, TN, and TP (Table 3-12).

Table 3-12 HSPF Model Watershed Load Budget for Lower Neosho Watershed (lbs/year)

Source	Sediment	CBOD	TN	TP
Loading from tributary	1.92E+07	2.39E+06	7.75E+05	4.16E+04
Loading from NPS distributed runoff	4.97E+06	4.42E+05	1.58E+05	8.10E+03
Total (Tributary + NPS runoff)	2.42E+07	2.84E+06	9.33E+05	4.97E+04

The HSPF watershed model simulates the unit area loading (lbs/acre) of water quality constituents for each of the eight land use categories defined for the watershed model: (1) wetland, (2) urban, (3) mining, (4) forest, (5) cropland, (6) grassland, (7) pasture, and (8) upland shrub. The sequence of steps used for calculation of water quality consituent loadings (as lbs/acre-year) for each sub-watershed of the model domain are as follows: (1) calculate areas of the 8 land uses for each sub-watershed; (2) use HSPF to simulate the annual unit loading for each water quality constituent from all 8 land uses for 2006; (3) calculate loading for each land use as the product of land use area and unit loading rate for all sub-watersheds; (4) calculate the total loadings (lbs/year) from the sum of the 8 land uses for each sub-watershed; and (5) calculate the composite aggregated unit loading rate (lbs/acre-year) by dividing the total loading by the drainage area of each sub-watershed. PPollutant loads for each sub-watershed are time averaged and summed to derive spatial maps of pollutant loadings on an annual basis (lbs/acre-yr) as shown in Figure 3-17 through Figure 3-20 for sediment, CBOD, TN, and TP.

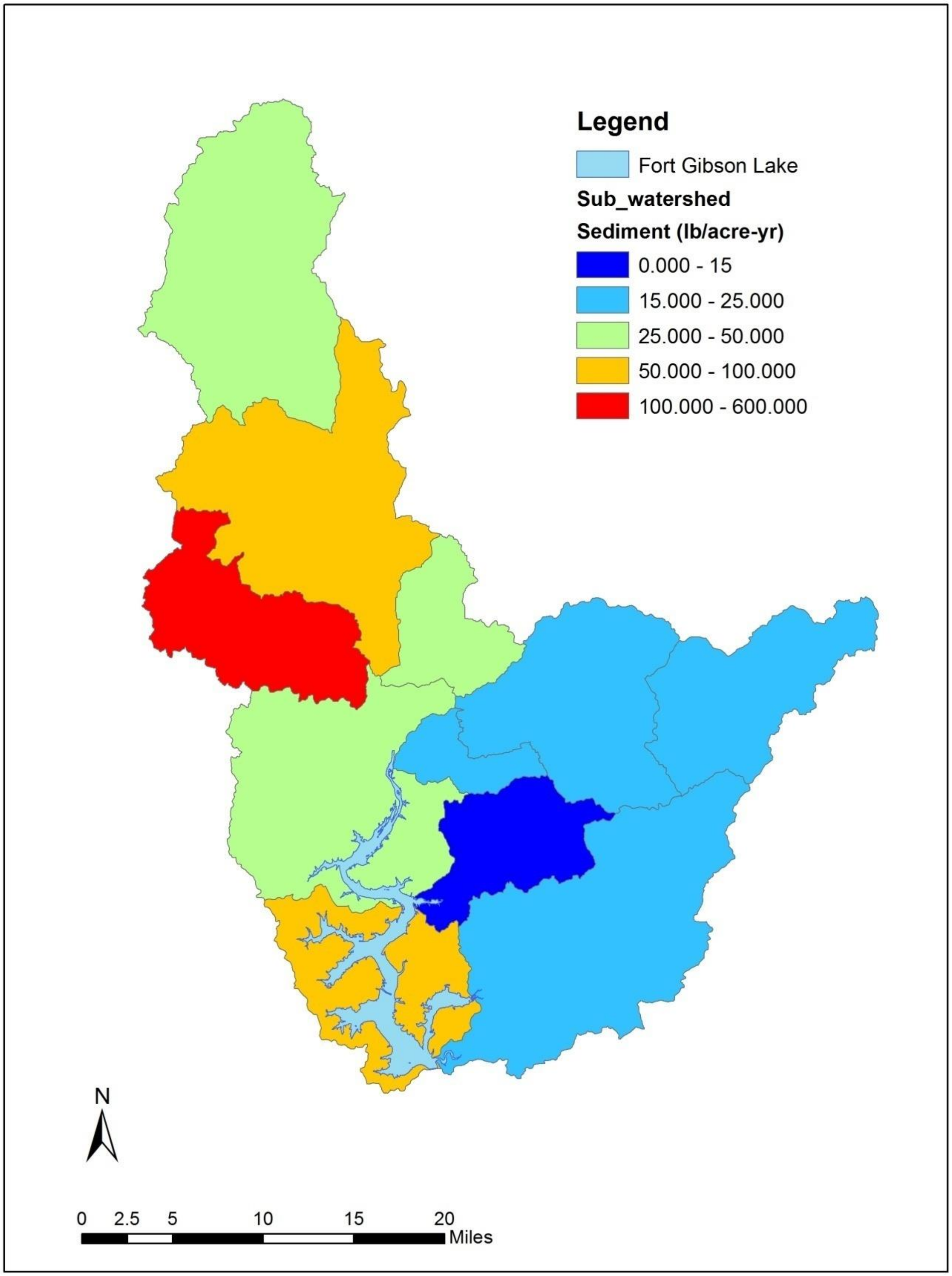

Figure 3-17 Sub-watershed sediment loadings by HSPF Model (lbs/acre-yr)

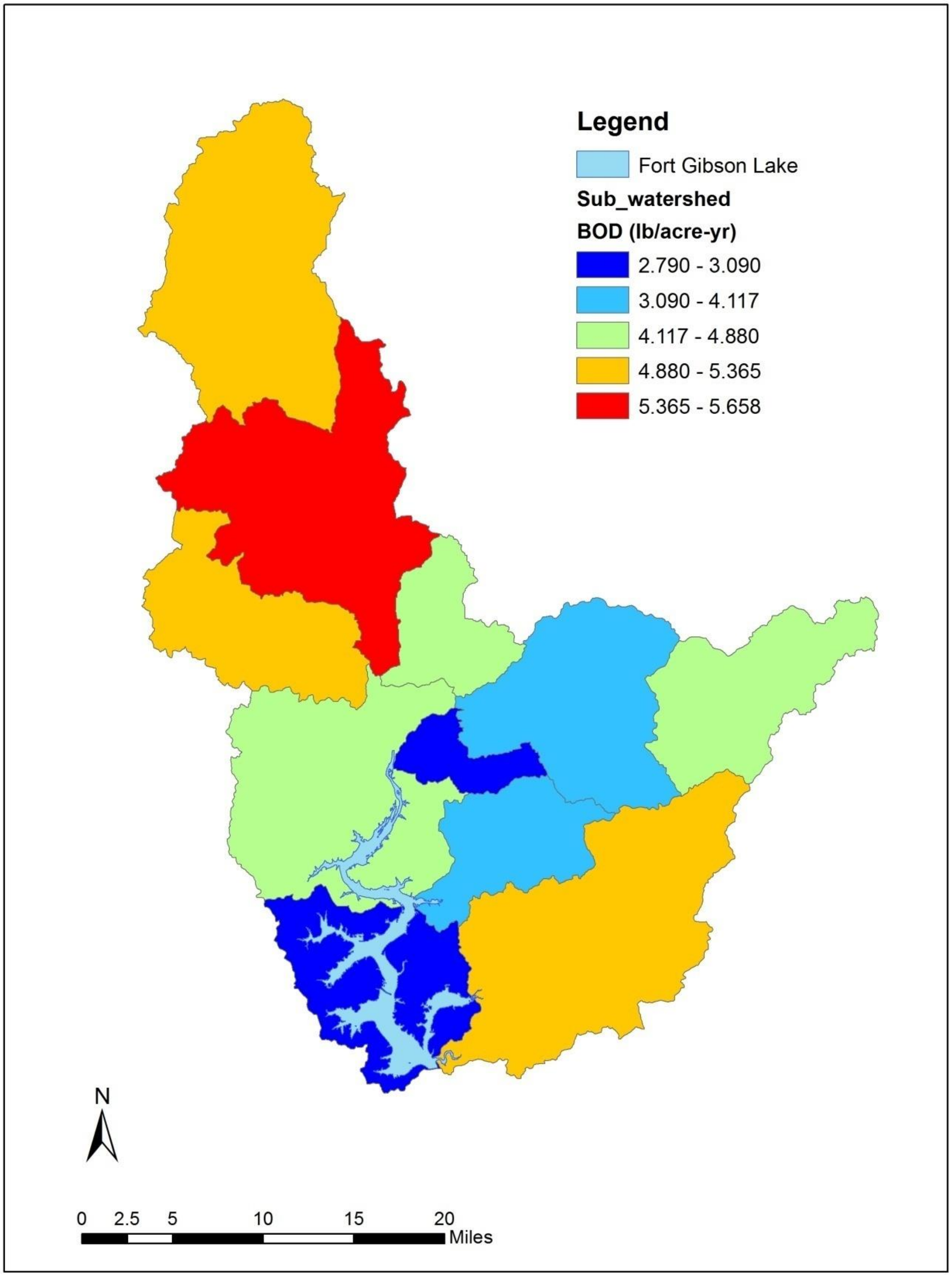

Figure 3-18 Sub-watershed CBOD loadings by HSPF Model (lbs/acre-yr)

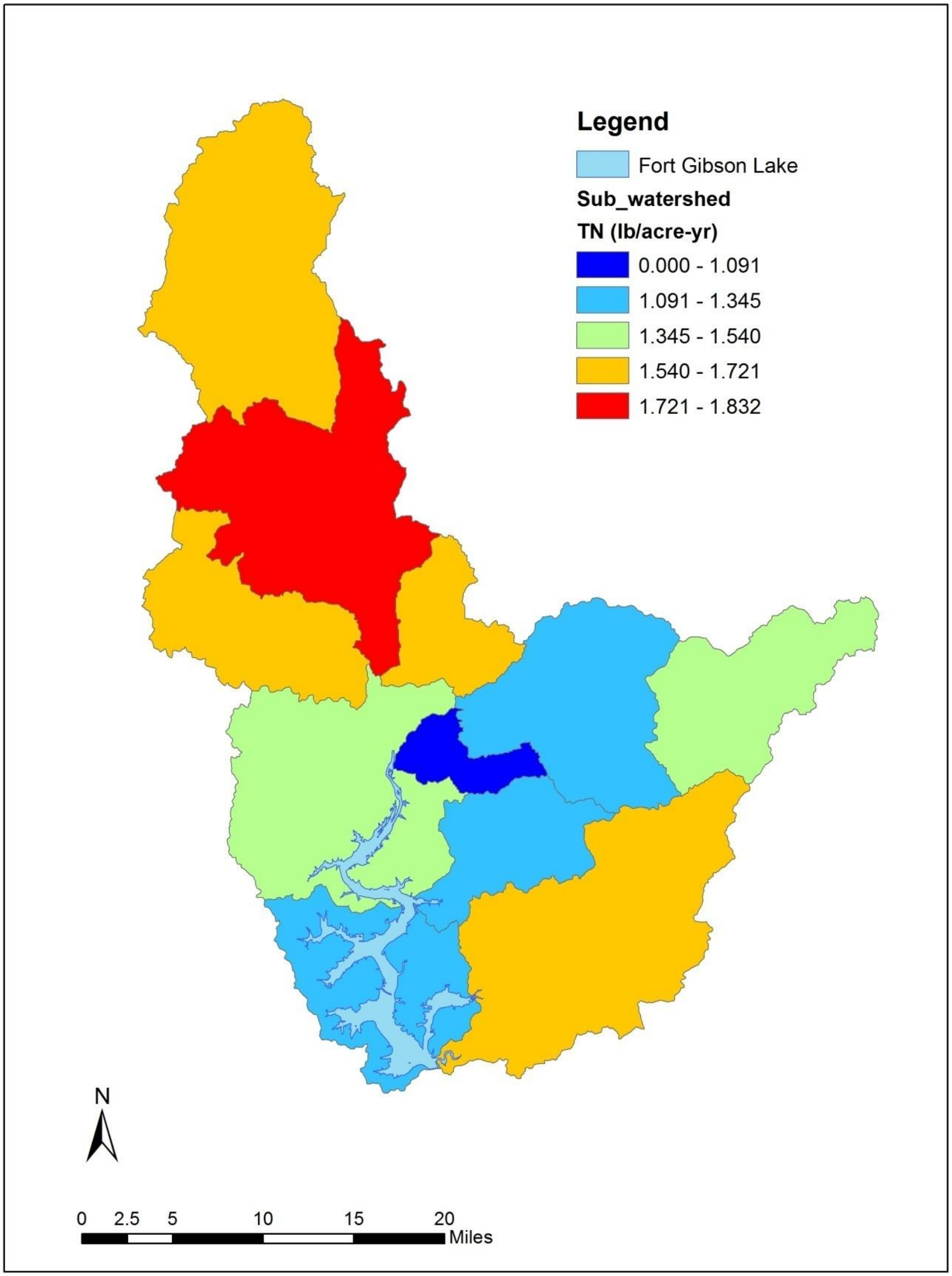

Figure 3-19 Sub-watershed TN loadings by HSPF Model (lbs/acre-yr)

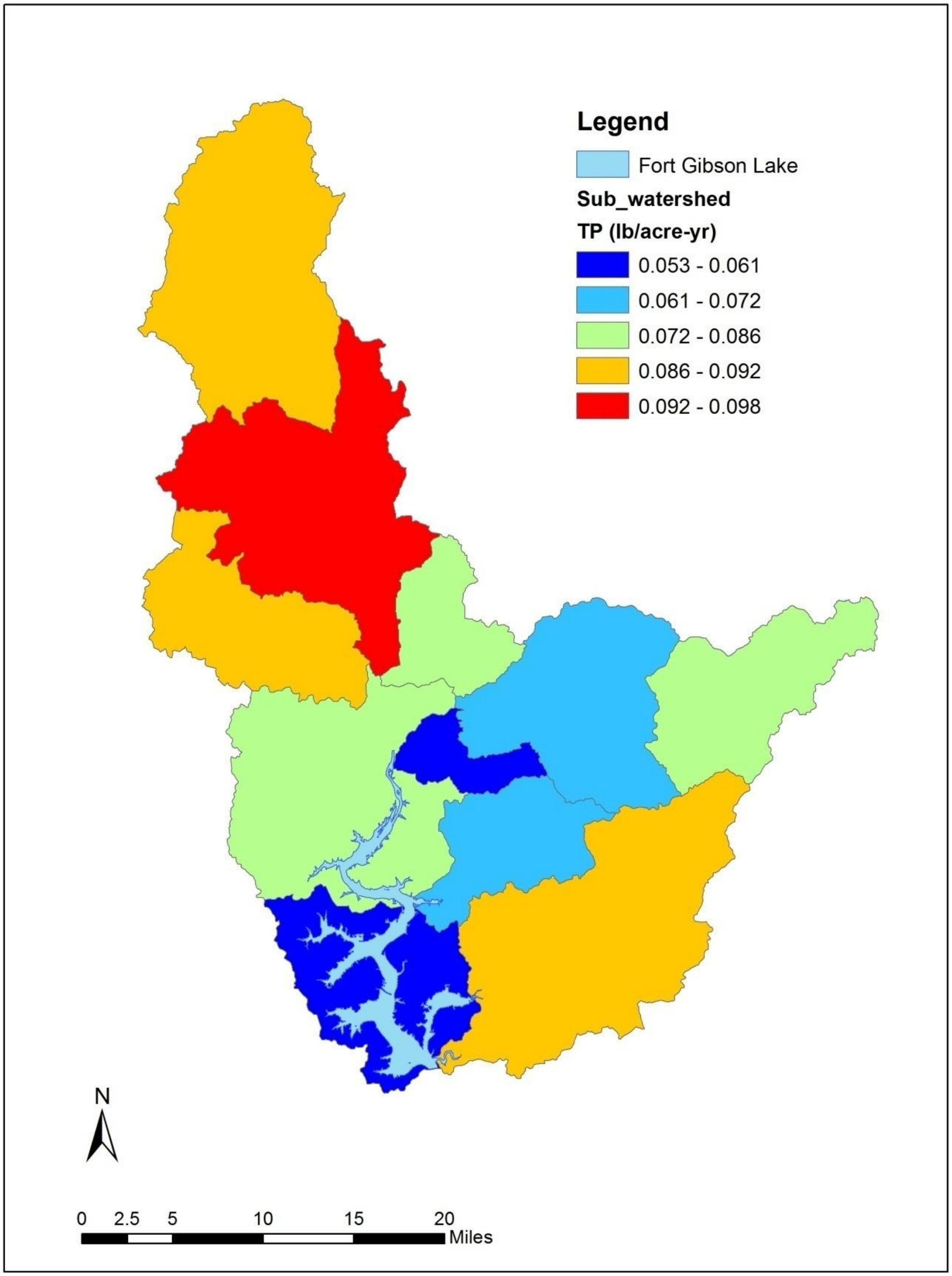

Figure 3-20 Sub-watershed TP loadings by HSPF Model (lbs/acre-yr)

4.0 LAKE MODEL AND WATERSHED-LAKE MODEL LINKAGE

The objective of a TMDL study is to estimate allowable pollutant loads expected to achieve compliance with water quality criteria. The allowable load is then allocated among the known pollutant sources in the watershed so that appropriate control measures can be implemented to reduce pollutant loading. To determine the effect of watershed management measures on in-lake water quality, it is necessary to establish a cause-effect linkage between the external loading of sediments, nutrients and organic matter from the watershed and the waterbody response in terms of lake water quality conditions for sediments, nutrients, organic matter, dissolved oxygen and chlorophyll-*a*. This section describes an overview of the water quality modeling analysis of the EFDC linkage between water quality conditions in Fort Gibson Lake and HSPF watershed pollutant loading. Appendix B of this TMDL report presents a description of the EFDC model, setup of the model, data sources, and model results for existing conditions and analysis of the effect of watershed load reductions on lake water quality.

4.1 EFDC Model Description

EFDC is an advanced surface water modeling package for simulating three-dimensional (3-D) circulation, salinity, water temperature, sediment transport and biogeochemical processes in surface waters including rivers, lakes, reservoirs, estuaries, and coastal systems. The EFDC model has been supported by EPA over the past decade as a public domain, peer reviewed model to support surface water quality investigations including numerous TMDL evaluations (Ji, 2017). EFDC directly couples the hydrodynamic model (Hamrick, 1992, 1996) with sediment transport (Tetra Tech, 2002), water quality (Park et al., 2000; Hamrick, 2007) and sediment diagenesis models (Di Toro, 2000). EFDC state variables include suspended solids, dissolved oxygen, nutrients (N, P), organic carbon, algae, sediment bed organic carbon and nutrients and benthic fluxes of nutrients and dissolved oxygen. The EFDC model is time variable with model results output at user-assigned hourly time intervals. The EFDC model requires input data to characterize lake geometry (shoreline, depth, surface area, and volume), time varying watershed inputs of flow and pollutant loads, time varying water supply withdrawals and release flows, and kinetic coefficients to describe water quality interactions such as nutrient uptake by algae. Observed water quality data collected at lake monitoring sites is used for calibration of the model results to observations. Model setup, data input, and post-processing of model results is facilitated with the EFDC_Explorer graphical user interface (Craig, 2012).

4.2 Data Sources and EFDC Model Setup

<u>Data Sources</u>. Data sources used for development of the lake model included Neosho River monitoring of river flow by the USGS, Neosho River water quality by OWRB; lake water quality monitoring by OWRB and the USACE Tulsa District; lake level, releases and storage volume monitoring by the USACE Tulsa District; and meteorological data from NOAA NCDC and Oklahoma MESONET stations in the vicinity of the watershed. Data was collected by the OWRB in 2012 with an Acoustic Doppler Continuous Profiler (ADCP) to map bathymetry of Fort Gibson Lake. OWRB has monitored Fort Gibson Lake and streams in the watershed on a quarterly basis, most recently in 2006-2007, in support of Oklahoma's BUMP Program. The USACE Tulsa District has monitored water quality in the lake since 2003. Water quality parameters

available for Fort Gibson Lake include chlorophyll-a, nutrients, total suspended sediment, water temperature, turbidity, organic carbon, and dissolved oxygen. Data collected by the USACE in 2005-2006 was used to support development of the EFDC lake model for Fort Gibson Lake. Tables of observed water quality data used for EFDC lake model development are presented in Appendix D of this report.

EFDC Model Domain. The EFDC model allows for the physical representation of the lake with a horizontal mesh of curvilinear grid cells to account for the effect of shoreline, embayments, and bathymetry, particularly the deeper parts of the lake in the remnant river channel of the Neosho River in the reservoir, (Figure 4-3). The computational grid developed to map the geometry of Fort Gibson Lake consisted of 483 horizontal cells. Depth of the water column was represented with 8 vertical layers to account for the effects of seasonal stratification. The shoreline of the lake is defined by the normal pool elevation of 554.0 feet (vertical datum, NGVD29). Bottom elevation of the lake model was interpolated to each grid cell using the high resolution bathymetry data collected by OWRB (Figure 4-3).

Boundary Conditions. The EFDC lake model requires specification of external boundary data to describe: (1) flow and pollutant loading from (a) Neosho River outflow from Lake Hudson; (b) watershed tributaries and distributed runoff from the HSPF model; (c) municipal and industrial wastewater dischargers; (2) flow releases at the dam; (3) withdrawals from water supply intakes; (4) wind forcing, evaporation, precipitation, and other meteorological data; and (5) atmospheric deposition of nutrients.

The Fort Gibson Lake EFDC model grid was extended upstream in the Neosho River to the Lake Hudson dam to define the upstream flow boundary with data from the USGS gage station 07191500 (Figure 4-1). Although flow was available at the USGS station, water quality data were not available to define upstream boundary water quality conditions. Observed water quality data were available, however, at one (1) OWRB and three (3) USACE stations in the Neosho River as shown in Figure 3-9 and Figure 4-2. The availability of water quality parameters at these stations is summarized in Table 4-1.

Water quality time series data for the upstream Neosho River were initially developed based on data available from the Neosho River stations. Final water quality conditions assigned to represent the Neosho River upstream boundary were developed, however, from multiple model runs and trial-and-error adjustments of the observed data available at the monitoring stations. Upstream boundary water quality conditions were adjusted so that EFDC model results showed good agreement with observed water quality data at USACE station 1GIBOKN0008 which is located about 10 miles downstream of the Lake Hudson dam in the upper riverine area of Fort Gibson Lake. This procedure was necessary to ensure confidence in the estimates of the water quality data developed to specify the upstream boundary since an accurate representation of the water quality upstream boundary was critical for calibration and validation of the EFDC lake model. EFDC model results demonstrated reasonable agreement with the observed water quality data records at USACE station 1GIBOKN0008 and the data assigned for the upstream boundary condition was deemed to be acceptable for model input.

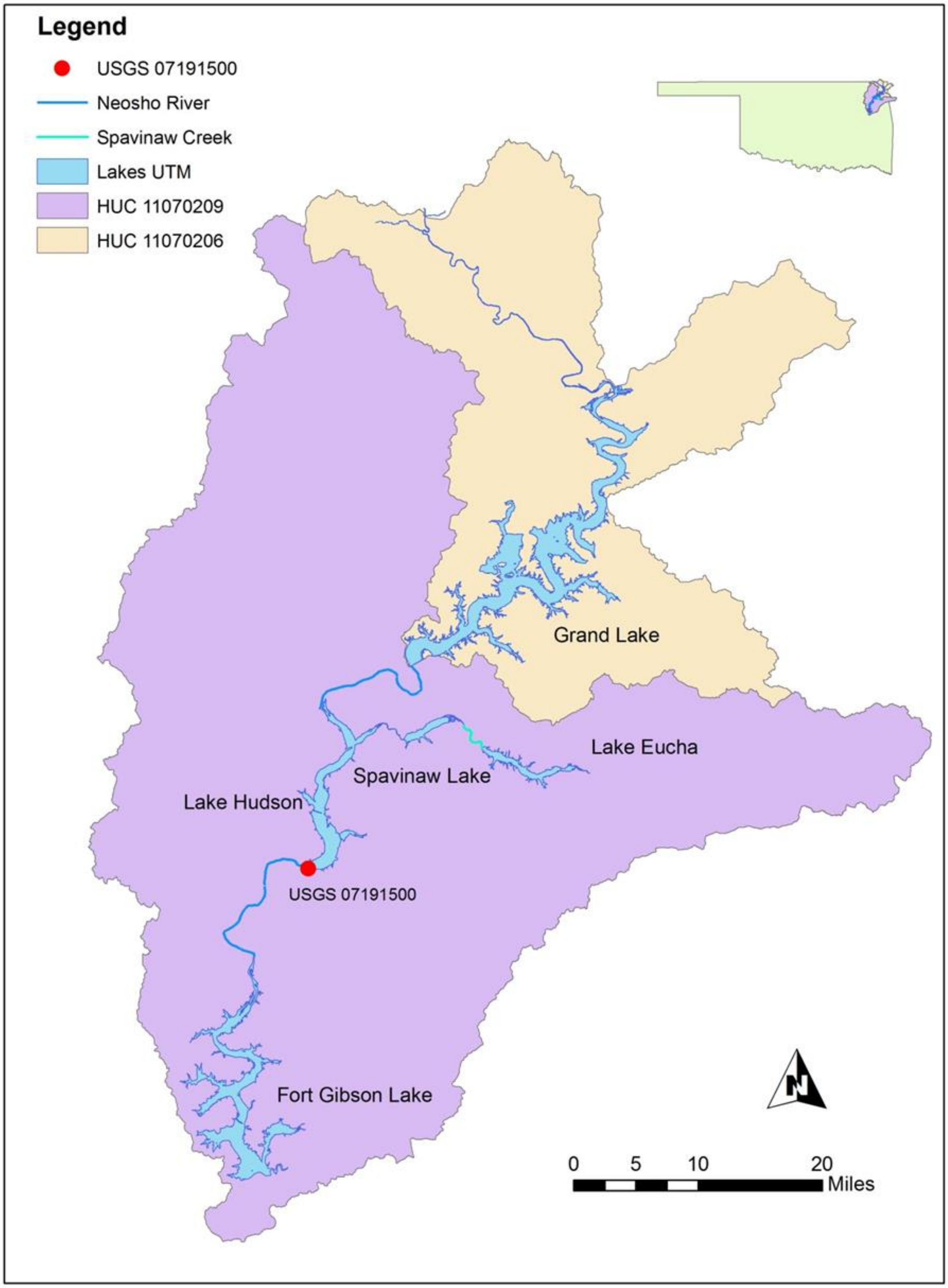

Figure 4-1 Location of USGS Gage in Upstream Neosho River

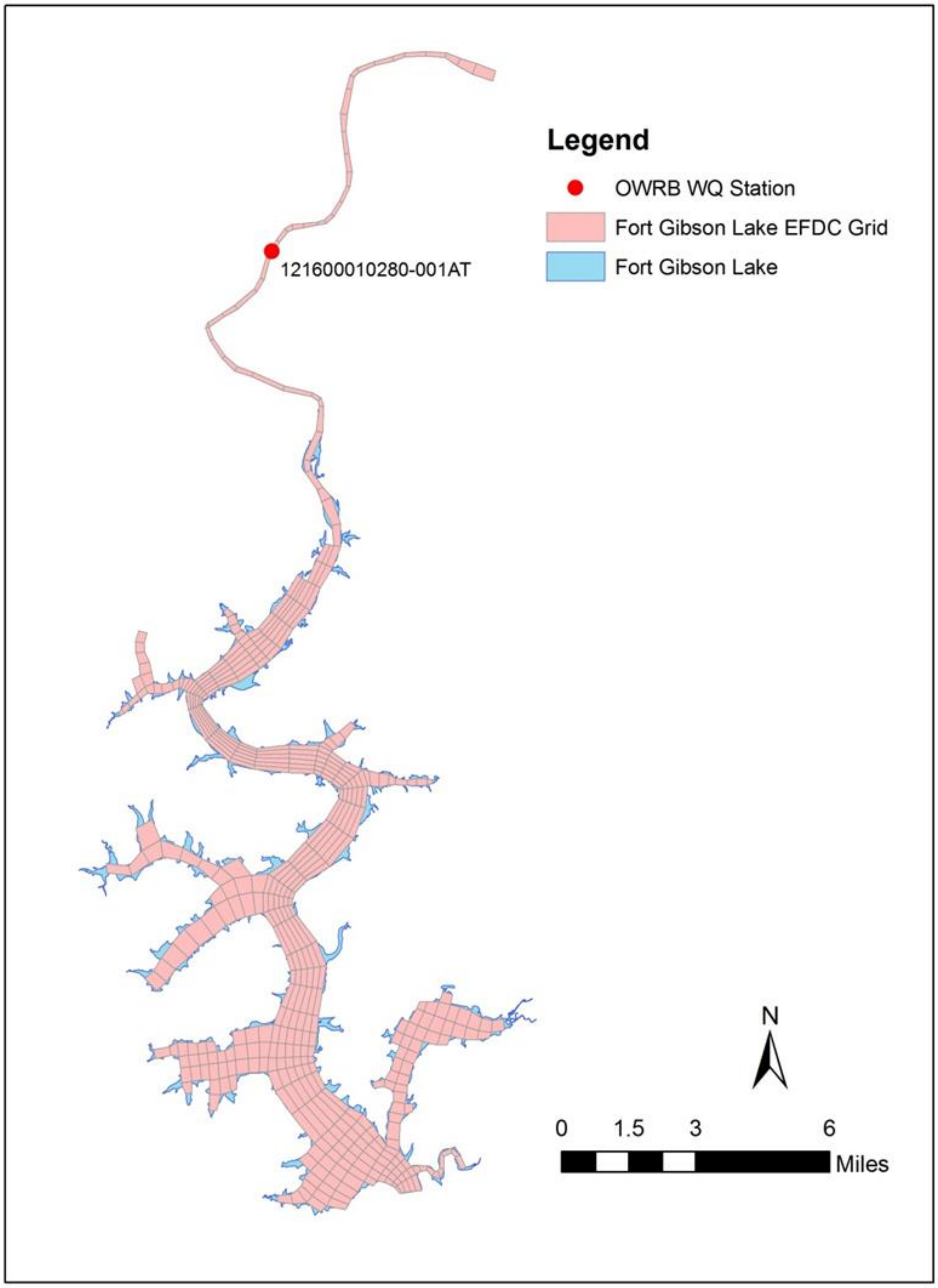

Figure 4-2 Location of OWRB Water Quality Station in Upstream Neosho River

Table 4-1 Data Availability for Development of Upstream Water Quality Boundary for Neosho River

Parameter	OWRB 121600010280-001AT	USACE 1GIBOKN0008	USACE 1GIBOKN0418	USACE 1GIBOKN0419
Water temperature	●	●	●	●
TSS		●		
Chlorophyll a	●	●		●
NH4	●	●		
TKN	●	●	●	●
NO3	●	●		
TPO4	●	●		
TP	●	●	●	●
TOC		●		
DO	Computed as saturated concentration based on monthly water temperature			

* At station USACE 1GIBOKN0418, the observed data are only available on August 24, 2006. At station USACE 1GIBOKN0419, data are only available on April 20, 2005 and July 5, 2006. For stations OWRB 121600010280-001AT and USACE 1GIBOKN0008, monthly data are available, but not complete.

As described in Section 3.3, flow and pollutant loading from the watershed was provided by the HSPF model as time series inflow data for tributaries and overland runoff. Tributary inflows included Chouteau Creek, Clear Creek, Fourteen Mile Creek, Pryor Creek, Spring Creek, and Crutchfield Branch. Linkage and stoichiometric transformation of HSPF water quality results as input to state variables needed for the EFDC lake model are described in Appendix B of this report.

Point source municipal and industrial wastewater dischargers to the Neosho River and Fort Gibson Lake included in the lake model are listed in Table 4-2. Effluent data for the six NPDES facilities, listed in Appendix H, was obtained from EPA's DMR Pollutant Loading Tool. Water supply withdrawal data for Fort Gibson Lake were not readily available. A flow balance analysis was estimated using all inflow data including all HSPF simulated watershed flows, rainfall, observed wastewater flow, observed flow from upstream Lake Hudson and all outflows including evaporation and flow releases at the dam. A flow balance was computed to implicitly account for water supply withdrawals and to ensure that the EFDC model simulation of lake stage was in good agreement with observed lake stage records.

The EFDC model requires time series data to describe the effect of meteorological forcing and winds on lake circulation processes. Wind speed/direction and meteorological data was obtained from the Oklahoma MESONET database at Stations PORT, INOL and TAHL. Meteorological data needed for the model includes wind, air temperature, air pressure, relative humidity, precipitation, evaporation, cloud cover and solar radiation.

The EFDC model requires specification of wet and dry atmospheric deposition of nitrogen and phosphorus over the entire surface area of the lake. Atmospheric deposition of nutrients is represented using the same constant loading rate for both model calibration and validation to existing conditions (2005-2006) and model evaluations of watershed load reduction scenarios. Since atmospheric deposition is uncontrollable on the local watershed scale, there is no load allocation for atmospheric deposition of nutrients for the TMDL. For Fort Gibson Lake, wet and dry deposition data for nitrogen, presented in Appendix B, was estimated as the average of annual data from 2005-2006 for ammonia and nitrate from the National Atmospheric Deposition Program (NADP) for Station AR27 (Fayetteville, AR) and the Clean Air Status and Trends Network (CASTNET) Station CHE185 (Cherokee Nation). Wet deposition input of ammonia and nitrate is based on a constant concentration in rainfall and the time series of precipitation assigned for 2005-2006 input conditions. Since data was not available from the CASTNET or NADP sites for deposition of phosphorus, dry deposition for phosphorus was estimated using the CASTNET and NADP data for nitrogen with annual average N/P ratios for atmospheric deposition of N and P reported for 6 sites located in Iowa (Anderson and Downing, 2006). Annual average wet phosphate concentration was estimated in proportion to the Dry/Wet ratio for phosphate deposition fluxes reported by Anderson and Downing (2006).

Table 4-2 NPDES Municipal and Industrial Wastewater Treatment Facilities Included in Fort Gibson Lake Model

Permit #	Facility Name	Receiving_water	Lat	Lon	Design flow (MGD)
OK0000272	PRYOR IND CONSERVE PICC	Neosho River	36.19	-95.25	3.7
OK0033791	WAGONER CNTY RWD NUMBER 2	Ft Gibson Lake	35.956	-95.28	Report, water treatment plant, no BOD limits
OK0034568	OKLA ORDNANCE WORKS ATHRTY OOWA PRYOR	Neosho River	36.21	-95.25	4.6
OK0035149	GRAND RIVER DAM ATHRTY CHOUTEAU COAL FIRED COMPLEX	Grand Neosho River	36.18	-95.28	Report, no BOD limits
OK0043907	ASSOCIATED ELEC COOP AECI CHOUTEAU PWR PLT	Neosho River	36.218	-95.247	0.6
OKG380001 (changed to OK0046035 in 2012)	WAGONER WTP	Ft Gibson Lake	36.02	-95.30	Report, water treatment plant, no BOD limits

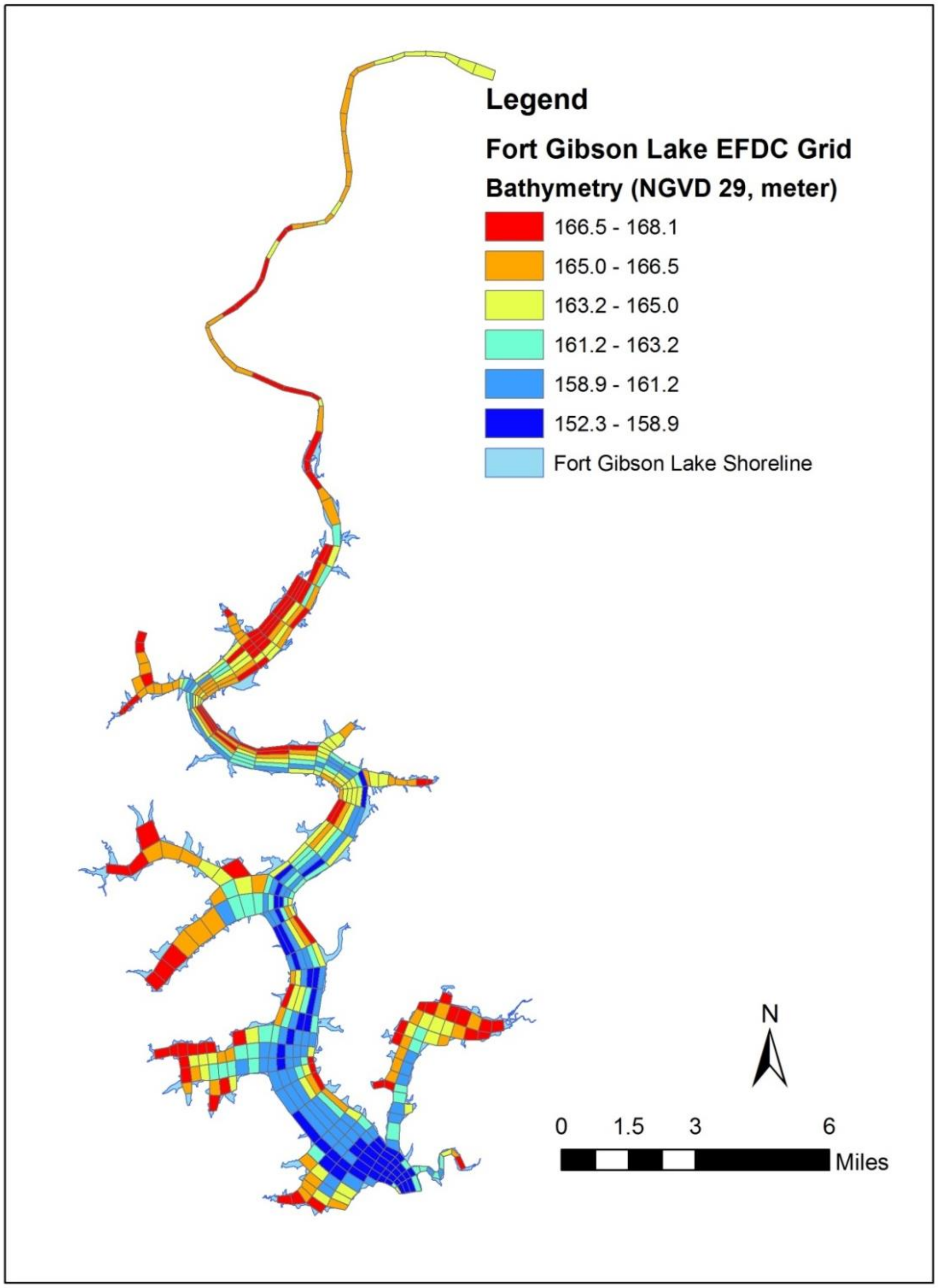

Figure 4-3 Fort Gibson Lake Computational Grid and Bottom Elevation

Initial Conditions. As a time-varying model, EFDC requires the specification of initial distributions of all the model state variables at the beginning of the model simulation period in January 2005. The spatial distribution of initial conditions for the model is based on simulated conditions at the end of the 1-year model simulation run. Restart conditions, written for all state variables of the model at the end of a preliminary model run for 2005, were used to assign a simulated set of initial conditions for January 2005 that accounted for spatial variability of conditions in the water column and sediment bed.

4.3 EFDC Model Calibration and Validation to Existing Conditions

The EFDC lake model was setup for a 2-year period from January 1, 2005 through December 31, 2006. Model results were calibrated and validated against observed data collected at 7 water quality monitoring sites shown in Figure 4-6. Model results were calibrated to observations for water level, water temperature, TSS, nitrogen, phosphorus, dissolved oxygen, and algae biomass (chlorophyll-a). The model-data performance statistics selected for calibration of the hydrodynamic and water quality model are the Root Mean Square Error (RMSE) and the Relative RMS Error. The Relative RMS error, computed as the ratio of the RMSE to the observed range of each water quality constituent, is expressed as a percentage. The Relative RMS Error thus provides a straightforward performance measure statistic to evaluate agreement between model results and observations in comparison to model performance targets. This section provides a brief description of lake model calibration and validation. More details on the procedure used for EFDC model development and the results obtained for EFDC model calibration and validation are given in Appendix B of this report.

Lake Water Level. The Fort Gibson Lake model was developed with eight (8) flow boundaries to define water coming into the lake from the HSPF watershed model, six (6) flow boundaries to define water coming into the lake from the NPDES wastewater point source facilities, one (1) flow boundary to define the discharge from Hudson Lake to the Neosho River, one (1) flow boundary to account for releases of water at the dam, and one (1) flow boundary to account for a flow balance.

In calibrating and validating the hydrodynamic model for water level elevation, a flow balance calculation is necessary to account for unknown flow into or out of the lake as well as observed and simulated errors in boundary flow data assigned as input to the model. As water supply withdrawal records from Fort Gibson Lake were not readily available, water supply demand represents an unknown flow out of the lake. A flow balance was estimated using all known inflows and outflows. Known inflows included HSPF simulated watershed flow, rainfall, NPDES point source wastewater discharges, and boundary flow from the outflow from Lake Hudson. Known outflows included evaporation and flow release at the dam. The flow balance thus accounts for unknown water supply withdrawals, unknown groundwater interaction with the lake, and accuracy of measured and modeled flow data. The flow balance was computed to develop a time series of unknown boundary flow to ensure that simulated water level was in very good agreement with observed water level recorded by the USACE at the dam. As can be seen in Table 4-3 and Figure 4-4 and Figure 4-5, the difference between model (red line) and observed (blue line) water level elevation is very small and model performance is excellent with a Relative RMS Error of only 0.6 -1.1%.

Table 4-3 Hydrodynamic Model Performance Statistics for Calibration and Validation of Water Level

Station ID	Parameter	Layer	Starting	Ending	# Pairs	RMS (m)	Rel RMS (%)	Data Average (m)	Model Average (m)
GIBO2	Stage (m)	Surface	1/2/2005 0:00	12/31/2005 0:00	364	0.032	0.6	169.25	169.23
GIBO2	Stage (m)	Surface	1/1/2006 0:00	12/31/2006 0:00	365	0.029	1.1	169.07	169.05

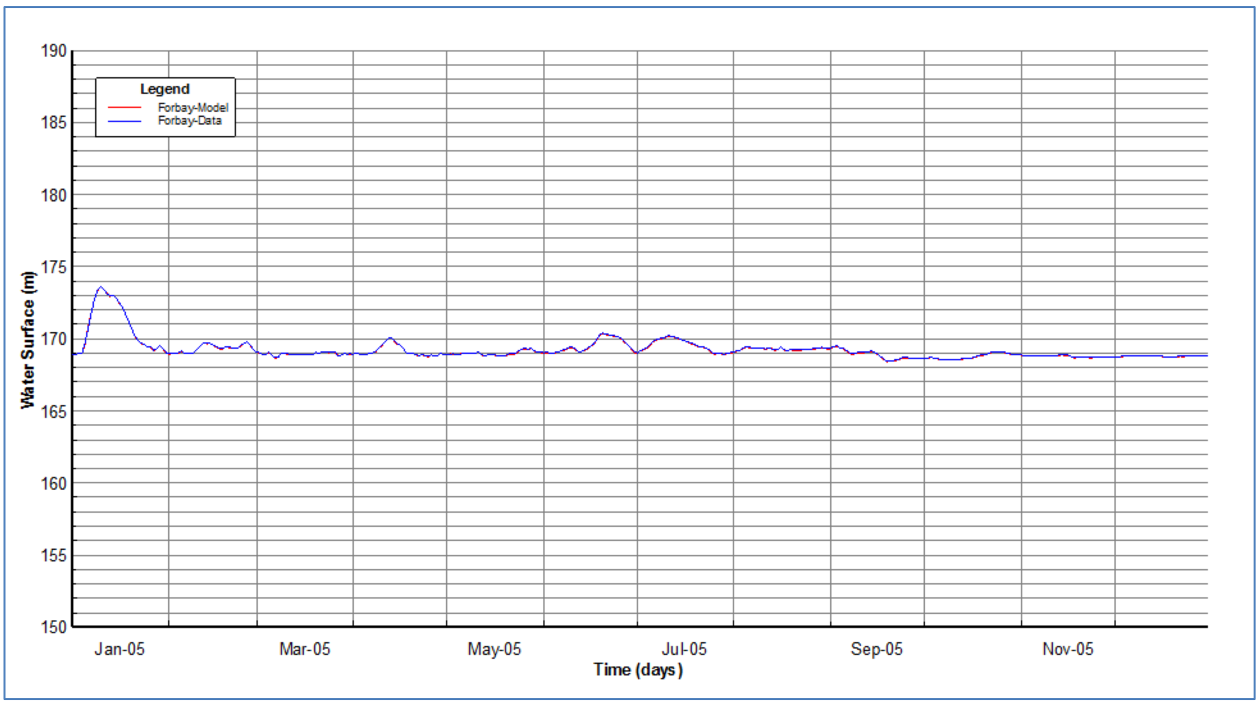

Figure 4-4 Calibration of Simulated and Observed Water Level during January 2005 to December 2005

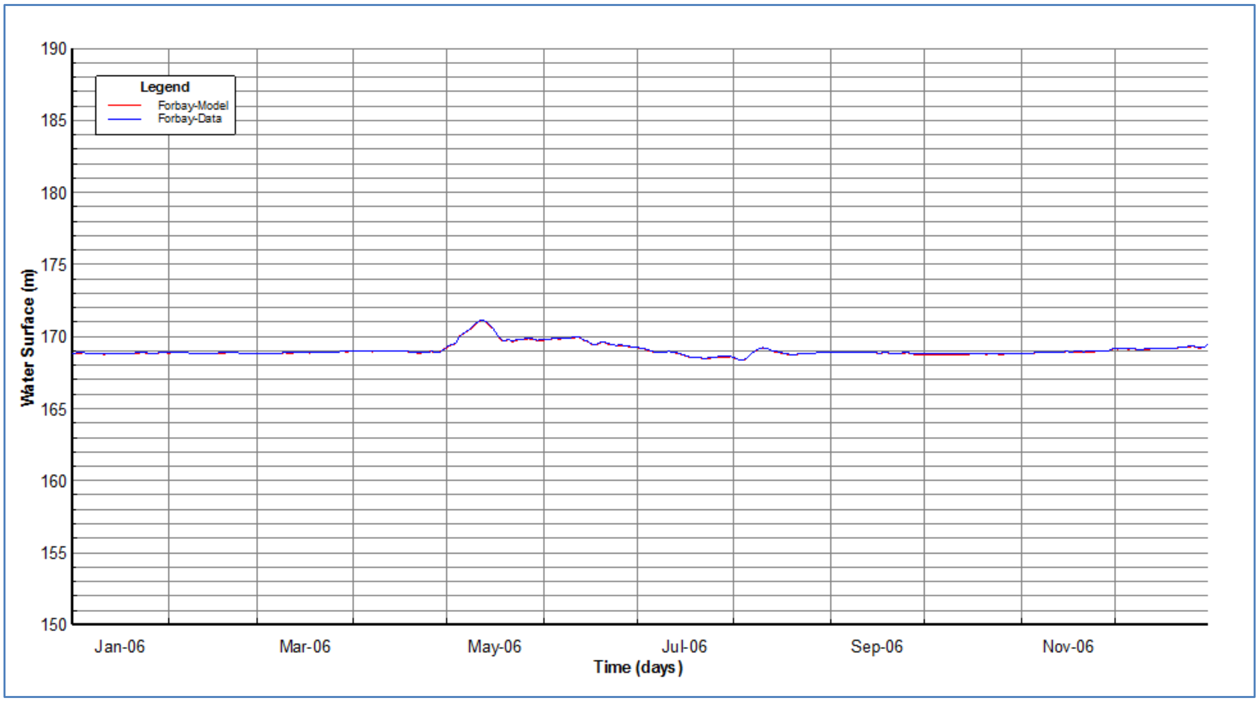

Figure 4-5 Validation of Simulated and Observed Water Level during January 2006 to December 2006

<u>Turbidity and TSS</u>. Water clarity is an issue for impairment of Fish & Wildlife Propagation for the Warm Water Aquatic Community within the Upper segment of Fort Gibson Lake (OK121600010200_00). Turbidity is the water quality parameter used to determine if the lake fully supports designated uses. Oklahoma water quality criteria states that no more than 10% of samples collected over the most recent 10-year period shall be greater than 25 NTU. Turbidity is a measure of the optical properties of water that causes light to be scattered and absorbed by particles in the water sample. Turbidity, as measured with a Nephelometer and reported with units of Nephelometric Turbidity Units (NTU), however, accounts only for the scattering of light. Since turbidity is not a mass-based concentration, a surrogate indicator of water quality must be used to develop a TMDL that addresses compliance with water quality criteria for turbidity. Total Suspended Solids (TSS) is a common water quality measurement that can be used as a surrogate indicator for turbidity. Although turbidity and TSS measure very different properties of water samples, both measurements do provide information about water clarity. TSS vs. turbidity relationships can therefore be developed and applied for TMDL determinations. The TSS vs. turbidity relationship must, however, be developed using site-specific paired data since inconsistencies and interferences in the relationship can result from site-specific properties of a water sample including water color, size, shape and refractive index of sediment particles, the organic and inorganic composition of sediment particles, and the inconsistency of instruments used for the turbidity measurement itself (Thackston and Palermo, 2000; Bash, Berman and Bolton, 2001).

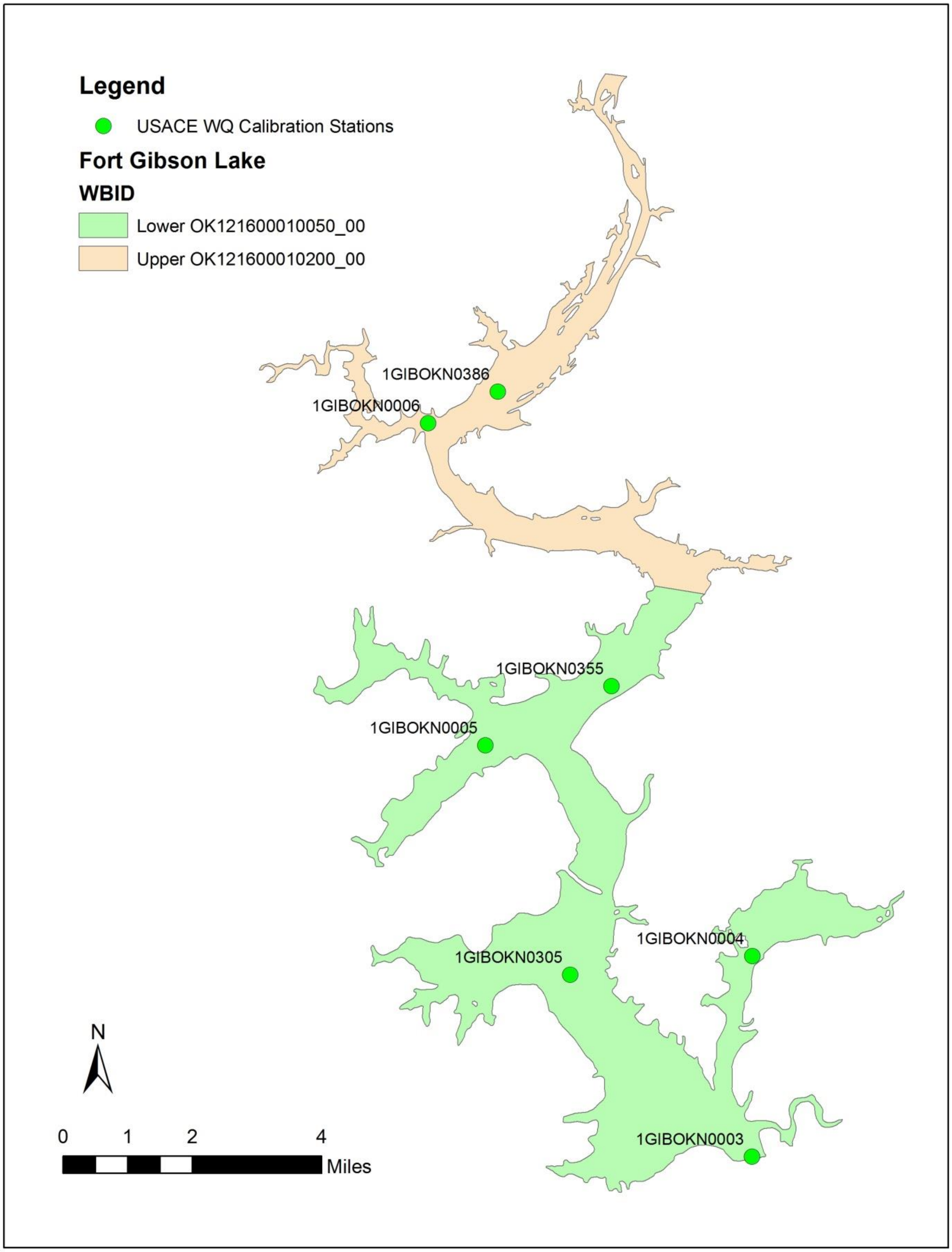

Figure 4-6 Location of USACE Stations for Lake Model Calibration and Validation

For the Fort Gibson Lake study, paired TSS and turbidity measurements from USACE lake stations in the upper segment of the lake (WBID: OK121600010200_00) were used to develop a linear regression relationship as shown in Figure 4-7. Based on the correlation coefficient (r^2 =0.5802, n=26), the relationship was considered acceptable to apply a site-specific correlation to compute simulated turbidity from modeled TSS for Fort Gibson Lake.

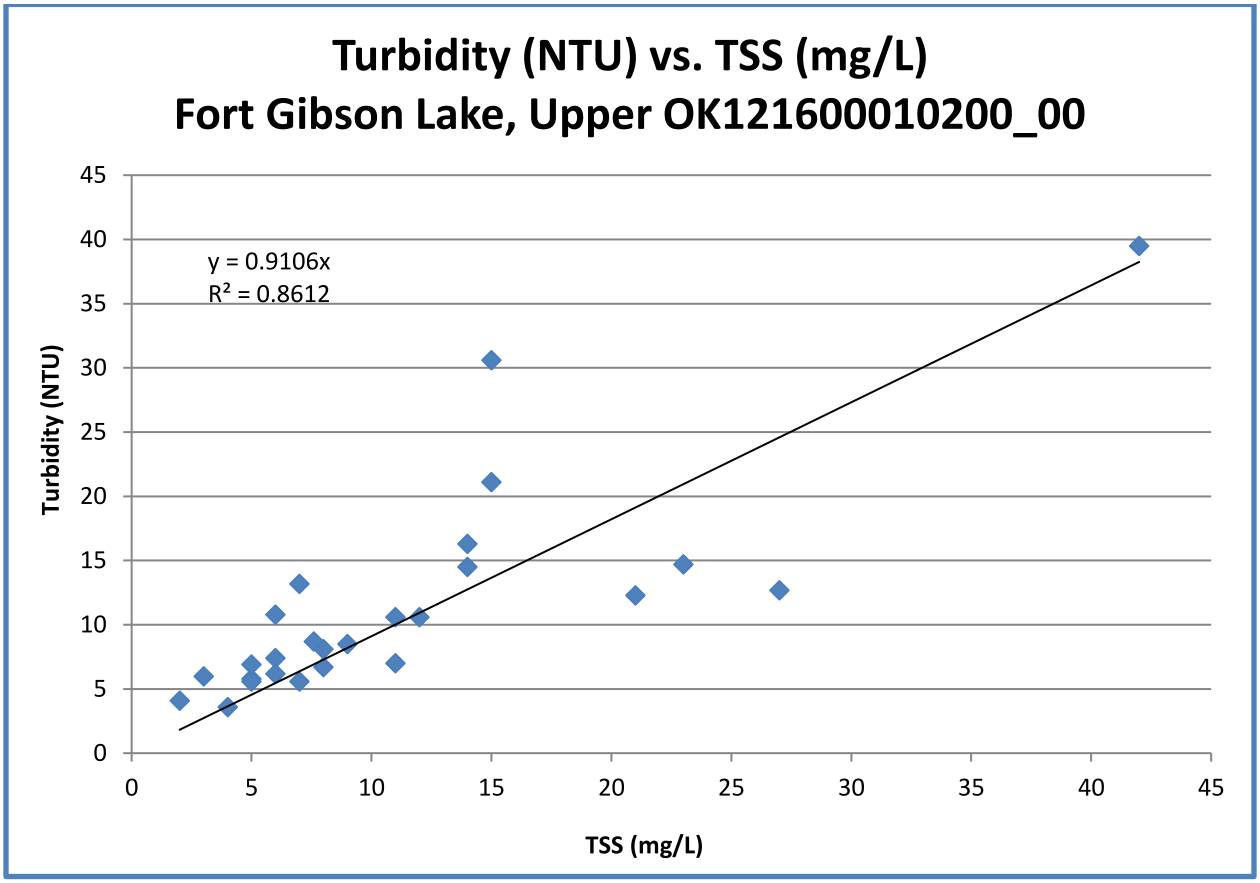

Figure 4-7 Turbidity and TSS Relationship for Fort Gibson Lake, Upper, WBID OK121600010200_00

The TSS vs. turbidity relationship developed for Upper Fort Gibson Lake was used to transform EFDC model results for TSS to turbidity for comparison to the water quality criteria for turbidity of 25 NTU. The model performance statistic for TSS for the USACE station 1GIBOKN0006 in Upper Fort Gibson Lake was very good with a Relative RMS Error of only 26% which was much better than the performance target of 50% defined for TSS.

Based on summary statistics computed by OWRB for turbidity for WBID OK121600010200_00 in the Upper Lake for data collected from 1998-2007, the 90th percentile value for observed turbidity (31 NTU) exceeds the water quality target of 25 NTU (see Table 2-4). As can be seen in Figure 2-2, turbidity values >25 NTU observed by OWRB were recorded in 2001 and 2004 with the highest value of 52 NTU recorded in May 2004. Flow at the outlet of Lake Hudson in May 2004 was much higher than flows recorded during

2006. High turbidity values were not recorded in 2006 in the Upper Lake. As a result of low flow hydrologic conditions during the model validation year of 2006, however, the 90th percentile of observed turbidity (19.6 NTU) for stations in the upper segment of Fort Gibson Lake did not show a violation of the water quality target of 25 NTU.

Trophic State Index (TSI) and Chlorophyll-a. NLW water quality criteria for TSI of 62 are compared to derived model results for TSI that are computed from simulated chlorophyll-a results. Model calibration results for chlorophyll-a, in general, show reasonable agreement with the observed seasonal trend of chlorophyll-a for 2005. Chlorophyll-a data was not available from the USACE Tulsa District for 2006 for comparison to results obtained for model validation. Based on 4 stations in the upper and lower segments of the lake, the mean model performance statistic for chlorophyll-a of 48% for the Relative RMS error is better than the model performance target of 100% defined for algae biomass. Based on summary statistics computed for the 4 USACE stations with chlorophyll observations, the 2005 average for observed surface chlorophyll-a is 26 µg/L. The corresponding average observed TSI is 62.2.

Using simulated chlorophyll-a results to derive modeled TSI for the 4 USACE stations, the comparison of observed and modeled TSI is in good agreement with a mean Relative RMS Error of 61% for observations in 2005. Similar to the results for chlorophyll-a, model calibration results for TSI show good agreement with the observed seasonal trend of TSI recorded for 2005. Model performance for TSI ranged from 34%-90% with a mean of 61% for the Relative RMS error.

Based on summary statistics computed by OWRB for TSI for WBID OK121600010200_00 (Upper Lake) and WBID OK121600010050_00 (Lower Lake) for data collected from 1998-2007, the mean value for observed TSI (61.4-62.0) for the two waterbody segments matches the water quality target of 62 for TSI computed from chlorophyll-a data (see Table 2-5). As can be seen in Figure 2-3, TSI values observed by OWRB in the upper and lower segments of the lake greater than 62 were recorded in 1998, 2000, 2001, 2004, and 2007 with the highest TSI value of 70.1 recorded in January 2001 and June 1998 in the lower segment of the lake. High TSI values were not recorded in 2006. For the model validation period of 2006, the mean value of simulated TSI for the Lower Lake (57.1) was lower than the target TSI of 62 while the mean TSI value of 61.5 for the Upper Lake was very close to the NLW water quality target of 62 for conditions that impair beneficial aesthetic uses of the lake.

The observed seasonal pattern of algae biomass is controlled by water temperature, the availability of nutrients and adequate light for growth. Dzialowski et al. (2005) show that nutrient limitation of phytoplankton growth in Kansas reservoirs can be described with three classification ranges of the TN:TP ratio. In the first category, nitrogen can be limiting for reservoirs described by a TN:TP ratio <8 mg N/mg P. In the second group, nitrogen and phosphorus can be co-limiting for reservoirs characterized by TN:TP ratios of ~ 9-21 mg N/mg P. In the third group, phosphorus is limiting for TN:TP ratios >29 mg N/mg P. In Fort Gibson Lake, the observed TN:TP ratio of 8-11 mg N/mg P reported for the BUMP site data collected by OWRB in 2006-2007 suggests co-limitation of algal growth by nitrogen and phosphorus. Evaluation of the EFDC model results to identify the limiting nutrient is consistent with the findings of Dzialowski et al.

(2005) with the lake model showing an alternating seasonal pattern of nitrogen and phosphorus limitation for algal growth.

Dissolved Oxygen. Proposed Oklahoma water quality standards for dissolved oxygen (OWRB, 2014) for Fort Gibson Lake are specified in relation to (a) the surface layer/epilimnion and (b) the anoxic volume of the hypolimnion of the lake. Within the surface layer/epilimnion during early summer stratified conditions, dissolved oxygen shall be no less than 6 mg/L from April 1 to June 15 for protection of early life stages. During the warmer summer months of stratification, dissolved oxygen shall be no less than 5 mg/L from June 16 to October 15 for protection of other life stages. Under non-stratified conditions during fall and winter, dissolved oxygen shall be no less than 5 mg/L from October 16 to March 31. Within the hypolimnion, the anoxic volume of the lake, defined by a cutoff DO level of 2 mg/L, shall not exceed 50% of the lake volume during the period of seasonal summer stratification. Surface and bottom water temperature data from a station in the deep lacustrine zone of Fort Gibson Lake was used to define April 1 as the date for onset of stratification and October 1 as the date marking the beginning of erosion of stratified conditions.

Model results for dissolved oxygen at sites in the Upper and Lower segments of the lake show good agreement with the observed seasonal trend of both surface layer dissolved oxygen and bottom layer depletion of dissolved oxygen during stratified summer conditions. In the bottom layer, observed anoxic conditions during the summer months are controlled by the onset and erosion of lake stratification and decomposition of organic matter in the hypolimnion and the sediment bed. The model performance statistics for dissolved oxygen were good with a Relative RMS Error of 26% for the surface layer and 15% for the bottom layer. In the surface layer, simulated dissolved oxygen is lower than observations during mid-summer because supersaturated conditions resulting from peak phytoplankton production are not reproduced with the model results. Overall, the combined performance for the surface and bottom layer results matched the model performance target of 20% defined for the Relative RMS Error for dissolved oxygen.

Based on an assessment of water column dissolved oxygen data for the OWRB and USACE monitoring stations near the dam (121600019050-01 and 1GIBOKN0003), OWRB determined that Fort Gibson Lake was not fully supporting its beneficial uses for Fish and Wildlife Propagation for a Warm Water Aquatic Community because dissolved oxygen data at this site showed that more than 70% of the water column was less than the 2 mg/L target for anoxia within the hypolimnion. As discussed in Section 2, vertical profiles of dissolved oxygen near the dam showed that more than 70% of the water column was less than the 2 mg/L target for anoxia within the hypolimnion for 4 of the sampling surveys from 2001-2007. The observed data used by OWRB for the 2010 303(d) list documents that the Warm Water Aquatic Community use for Fish and Wildlife Propagation was not attained because of depletion of dissolved oxygen in the hypolimnion of the deep waters of the lake near the dam.

Model results for dissolved oxygen are post-processed for selected sampling sites to derive time series data sets to compute the percentage of the water column defined as anoxic based on the cutoff target DO of 2 mg/L. Stations in the lacustrine (1GIBOKN0003), transition (1GIBOKN0355) and riverine

(1GIBOKN0386) zones of the lake show a clear spatial pattern with the greatest percentage of anoxia in the water column near the dam and the least percentage of anoxia in the riverine zone. In the deep waters of the lacustrine zone at Station 1GIBOKN0003, the maximum anoxic percentage of the water column is ~75% in late July and early September. In the transition zone at Station 1GIBOKN0355, the largest anoxic percentage is ~50% in mid-July and in the shallow riverine zone at Station 1GIBOKN0386, the largest anoxic portion of the water column is only ~25% in mid-July. As shown in Figure B-44 in Appendix B, the model calibration and validation results for 2005-2006 are in very good agreement with observations for the USACE site 1GIBOKN0003 near the dam. Consistent with the Neosho River flow conditions in 2006 compared to 2005, the data for 2006 shows a larger anoxic percentage of the water column at these stations than in 2005 particularly at the USACE site 1GIBOKN0386 located in the riverine zone.

In the 2010 303(d) assessment of impairment of Fort Gibson Lake (OK121600010050_00), OWRB determined that impairment in the lower lake was controlled by 'worst-case' depletion of dissolved oxygen at the OWRB and USACE monitoring sites near the dam. Several surveys documented that more than 70% of the water column was characterized by dissolved oxygen levels <2 mg/L. In evaluating the effectiveness of load reduction scenarios on improvements in dissolved oxygen, model results are extracted for grid cells located near the dam that correspond to the OWRB and USACE monitoring sites. Figure 4-8 shows model validation results for the percentage of the water column <2 mg/L. As can be seen, the model results are in very good agreement with the observed data for the USACE Station 1GIBOKN0003 near the dam. With a maximum of ~75% of the water column <2 mg/L, model validation results show violations of the 70% target for the water column in late July and early September.

<u>Benthic Flux of Phosphate and Sediment Oxygen Demand</u>. Model results are analyzed to evaluate benthic flux rates of phosphate and sediment oxygen demand (SOD) simulated with the sediment diagenesis model. These coupled water column-sediment bed processes are critical links with the lake model results obtained for nutrients, dissolved oxygen, and chlorophyll-a. Since observed benthic flux measurements of phosphate and SOD are not available for Fort Gibson Lake, mean values of modeled benthic fluxes for phosphate are extracted for the summer stratified anoxic months of 2005-2006 for sites in the lacustrine (1GIBOKN0003, 1GIBOKN0305), transition (1GIBOKN0355), and riverine (1GIBOKN0386) zones for comparison to literature data from other lakes and reservoirs. The mean benthic flux rates for phosphate (20-25 mg P/m^2-day) with a simulated range of ~10-40 mg P/m^2-day for the lacustrine sites are consistent with the observed range of anoxic phosphate fluxes (~10-35 mg P/m^2-day) reported by Dzialowski and Carter (2011) for eutrophic and hypereutrophic reservoirs in the Central Plains. The mean SOD rates for dissolved oxygen (~6 g O_2/m^2-day) for the lacustrine sites and ~1 g O_2/m^2 -day for the transition and riverine sites are also consistent with the observed range of SOD rates reported for Lake Eucha (~2.5-6.1 g O_2/m^2 -day) (Haggard et al., 2005) and Central Plains reservoirs (~1.7-7.4 g O_2/m^2-day) reported by Dzialowski and Carter (2011).

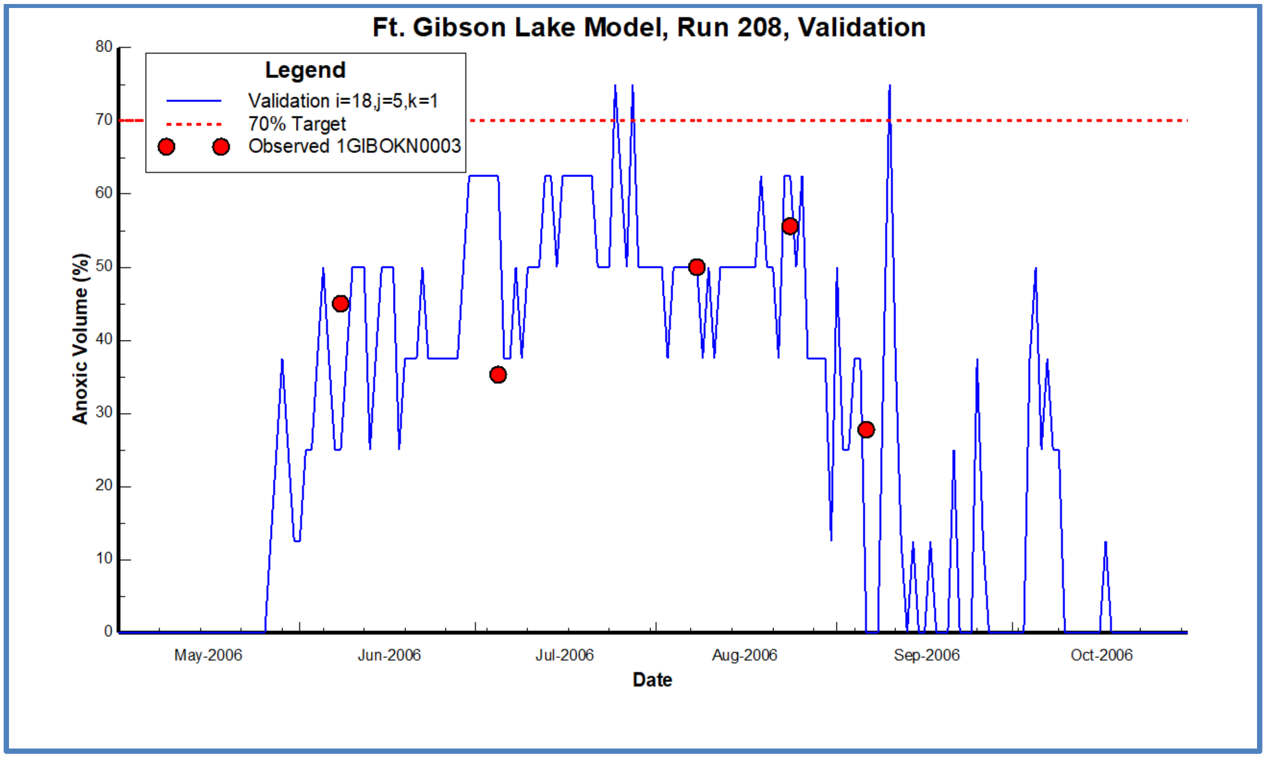

Figure 4-8 Model Validation for the Anoxic Water Column at USACE Station 1GIBOKN0003 in the lower lake segment OK121600010050_00 Near the Dam.

Model-Data Performance. Given the lack of a general consensus for defining quantitative model performance criteria, the inherent errors in input and observed data, and the approximate nature of model formulations, *absolute* criteria for model acceptance or rejection are not appropriate for studies such as the development of the lake model for Fort Gibson Lake. The Relative RMS Errors are used as targets for performance evaluation of the calibration and validation of the lake model, but not as rigid absolute criteria for rejection or acceptance of model results. The “weight of evidence” approach used in this study recognizes that, as an approximation of a waterbody, perfect agreement between observed data and model results is not expected and is not specified as performance criteria for defining the success of model calibration. Model performance statistics are used as guidelines to supplement the visual evaluation of model-data plots for model calibration. The “weight of evidence” approach used for this study thus acknowledges the approximate nature of the model and the inherent uncertainty in both input data and observed data.

The Relative RMS Error performance of the lake model, defined by composite statistics derived from pooled model-observed data pairs for 2005-2006 for 4 lake stations, are consistent with model performance targets recommended for surface water models (Donigian, 2000). As shown in the model performance tables in Appendix B, the model performance targets for dissolved oxygen (20%), water temperature, TSS and nutrients (50%), and chlorophyll (100%) are all attained with the model results for these state variables either better than, or <5% above, the target criteria for model performance.

Representative model performance statistics defined by the Root Mean Square (RMS) and Relative RMS Errors are presented in this section for DO, TSS, chlorophyll-a, NO3, TKN, TPO4, and TP during 2005 and 2006 in Table 4-4 through Table 4-11. A complete set of model performance statistics for the state variables of the EFDC lake model are given in Appendix B.

Table 4-4 Summary Statistics of TSS (mg/l) during 2005 and 2006

Station ID	Layer	Starting	Ending	# Pairs	RMS (mg/l)	Rel RMS (%)	Data Average (mg/l)	Model Average (mg/l)
1GIBOKN0003	Layer 8	3/24/2005 10:20	9/6/2006 9:50	17	5.14	36.71	5.694	7.217
1GIBOKN0003	Layer 1	3/24/2005 10:20	9/6/2006 9:50	13	5.34	53.38	10.246	5.833
1GIBOKN0004	Layer 8	3/24/2005 10:50	9/6/2006 10:21	17	7.21	32.76	7.824	8.679
1GIBOKN0004	Layer 1	3/24/2005 10:50	9/21/2005 12:40	9	9.57	36.80	10.333	9.067
1GIBOKN0005	Layer 8	3/24/2005 12:50	9/6/2006 9:10	16	5.29	44.11	5.975	8.207
1GIBOKN0005	Layer 1	3/24/2005 12:50	9/6/2006 9:10	16	11.37	36.69	11.488	10.155
1GIBOKN0006	Layer 8	3/24/2005 9:25	9/6/2006 8:40	17	5.71	25.97	8.329	6.914

Table 4-5 Model Performance Statistics of DO (mg/l) during 2005 and 2006

Station ID	Layer	Starting	Ending	# Pairs	RMS (mg/l)	Rel RMS (%)	Data Average (mg/l)	Model Average (mg/l)
1GIBOKN0003	Layer 8	3/24/2005 10:20	9/6/2006 9:50	16	2.27	21.95	7.906	7.991
1GIBOKN0003	Layer 1	3/24/2005 10:20	9/6/2006 9:50	16	1.46	14.32	2.604	3.031
1GIBOKN0004	Layer 8	3/24/2005 10:50	9/6/2006 10:20	16	1.82	30.61	8.674	8.138
1GIBOKN0004	Layer 1	3/24/2005 10:50	9/21/2005 12:40	9	2.00	19.61	5.759	4.448
1GIBOKN0005	Layer 8	3/24/2005 12:50	9/6/2006 9:10	16	1.49	29.59	8.562	8.333
1GIBOKN0005	Layer 1	3/24/2005 12:50	9/6/2006 9:10	16	1.33	12.62	3.778	3.726
1GIBOKN0006	Layer 8	3/24/2005 9:25	9/6/2006 8:40	15	1.35	24.28	8.33	8.597

Table 4-6 Model Performance Statistics of Trophic State Index (TSI) during 2005. Data N/A for 2006.

Station ID	Layer	Starting	Ending	# Pairs	RMS	Rel RMS (%)	Data Average	Model Average
1GIBOKN0003	Layer 8	3/24/2005 10:20	9/21/2005 12:05	10	5.03	56.6	59.9	61.7
1GIBOKN0004	Layer 8	3/24/2005 10:50	9/21/2005 12:40	9	6.08	79.0	63.4	60.4
1GIBOKN0005	Layer 8	3/24/2005 12:25	9/21/2005 10:25	10	3.76	59.1	63.0	61.5
1GIBOKN0006	Layer 8	3/24/2005 9:25	9/21/2005 9:45	10	4.25	39.0	62.1	64.0

Table 4-7 Model Performance Statistics of Chlorophyll-a (µg/l) during 2005. Data N/A for 2006

Station ID	Layer	Starting	Ending	# Pairs	RMS (ug/l)	Rel RMS (%)	Data Average (ug/l)	Model Average (ug/l)
1GIBOKN0003	Layer 8	3/24/2005 10:20	9/21/2005 12:05	10	10.69	54.80	20.63	25.958
1GIBOKN0004	Layer 8	3/24/2005 10:50	9/21/2005 12:40	9	12.74	53.74	29.2	22.87
1GIBOKN0005	Layer 8	3/24/2005 12:25	9/21/2005 10:25	10	9.33	55.88	27.92	24.703
1GIBOKN0006	Layer 8	3/24/2005 9:25	9/21/2005 9:45	10	11.51	39.83	26.28	31.856

Table 4-8 Model Performance Statistics of NO3 (mg/l) during 2005 and 2006

Station ID	Layer	Starting	Ending	# Pairs	RMS (mg/l)	Rel RMS (%)	Data Average (mg/l)	Model Average (mg/l)
1GIBOKN0003	Layer 8	3/24/2005 10:20	9/6/2006 9:50	17	0.18	19.66	0.161	0.085
1GIBOKN0003	Layer 1	3/24/2005 10:20	9/6/2006 9:50	13	0.21	23.74	0.247	0.194
1GIBOKN0004	Layer 8	3/24/2005 10:50	9/6/2006 10:21	17	0.11	18.00	0.073	0.038
1GIBOKN0004	Layer 1	3/24/2005 10:50	9/21/2005 12:40	9	0.17	29.28	0.161	0.148
1GIBOKN0005	Layer 8	3/24/2005 12:50	9/6/2006 9:10	16	0.15	20.16	0.102	0.047
1GIBOKN0005	Layer 1	3/24/2005 12:50	9/6/2006 9:10	16	0.13	16.72	0.121	0.147
1GIBOKN0006	Layer 8	3/24/2005 9:25	9/6/2006 8:40	17	0.10	11.40	0.161	0.134

Table 4-9 Model Performance Statistics of TKN (mg/l) during 2005 and 2006

Station ID	Layer	Starting	Ending	# Pairs	RMS (mg/l)	Rel RMS (%)	Data Average (mg/l)	Model Average (mg/l)
1GIBOKN0003	Layer 8	3/24/2005 10:20	9/6/2006 9:50	17	0.18	42.00	0.628	0.585
1GIBOKN0003	Layer 1	3/24/2005 10:20	9/6/2006 9:50	13	0.41	43.06	0.788	0.541
1GIBOKN0004	Layer 8	3/24/2005 10:50	9/6/2006 10:21	17	0.28	76.48	0.741	0.498
1GIBOKN0004	Layer 1	3/24/2005 10:50	9/21/2005 12:40	9	0.26	69.43	0.68	0.471
1GIBOKN0005	Layer 8	3/24/2005 12:50	9/6/2006 9:10	16	0.17	37.75	0.727	0.611
1GIBOKN0005	Layer 1	3/24/2005 12:50	9/6/2006 9:10	16	0.23	50.56	0.739	0.545
1GIBOKN0006	Layer 8	3/24/2005 9:25	9/6/2006 8:40	17	0.11	34.87	0.674	0.717

Table 4-10 Model Performance Statistics of TPO4 (mg/l) during 2005 and 2006

Station ID	Layer	Starting	Ending	# Pairs	RMS (mg/l)	Rel RMS (%)	Data Average (mg/l)	Model Average (mg/l)
1GIBOKN0003	Layer 8	3/24/2005 10:20	9/6/2006 9:50	17	0.04	48.13	0.034	0.052
1GIBOKN0003	Layer 1	3/24/2005 10:20	8/24/2006 9:30	12	0.09	47.84	0.104	0.103
1GIBOKN0004	Layer 8	3/24/2005 10:50	9/6/2006 10:21	17	0.03	47.91	0.023	0.022
1GIBOKN0004	Layer 1	3/24/2005 10:50	9/21/2005 12:40	9	0.03	91.02	0.017	0.034
1GIBOKN0005	Layer 8	3/24/2005 12:50	9/6/2006 9:10	16	0.03	27.38	0.033	0.038
1GIBOKN0005	Layer 1	3/24/2005 12:50	9/6/2006 9:10	16	0.05	63.64	0.044	0.076
1GIBOKN0006	Layer 8	3/24/2005 9:25	9/6/2006 8:40	17	0.05	28.05	0.06	0.09

Table 4-11 Model Performance Statistics of TP (mg/l) during 2005 and 2006

Station ID	Layer	Starting	Ending	# Pairs	RMS (mg/l)	Rel RMS (%)	Data Average (mg/l)	Model Average (mg/l)
1GIBOKN0003	Layer 8	3/24/2005 10:20	9/6/2006 9:50	17	0.05	77.32	0.084	0.1
1GIBOKN0003	Layer 1	3/24/2005 10:20	9/6/2006 9:50	13	0.10	33.04	0.157	0.138
1GIBOKN0004	Layer 8	3/24/2005 10:50	9/6/2006 10:21	17	0.04	115.92	0.074	0.055
1GIBOKN0004	Layer 1	3/24/2005 10:50	9/21/2005 12:40	9	0.03	60.29	0.082	0.063
1GIBOKN0005	Layer 8	3/24/2005 12:50	9/6/2006 9:10	16	0.04	52.86	0.096	0.087
1GIBOKN0005	Layer 1	3/24/2005 12:50	9/6/2006 9:10	16	0.04	49.79	0.112	0.121
1GIBOKN0006	Layer 8	3/24/2005 9:25	9/6/2006 8:40	17	0.06	44.06	0.133	0.167

4.4 Pollutant Loads for Existing Model Validation (2006)

Using data developed for calibration of the watershed model and the lake model to 2006 conditions, mass loads for sediment and nutrients are compiled to identify the relative magnitude of the external and internal sources of pollutant loading to the lake. External sources include the outflow from Lake Hudson, tributary inputs, point source wastewater inputs, wet and dry atmospheric deposition, and overland runoff from the watershed. Internal sources include the benthic fluxes of inorganic nutrients across the sediment-water interface of the lake. Loading rates (as kg/day) are compiled for the 364-day simulation period from January to December 2006.

Table 4-12 presents a summary of nutrient, organic carbon and sediment loads for the existing 2006 validation conditions for the outflow from Lake Hudson and HSPF watershed loads. The table presents a summary, and comparison, of sources from Lake Hudson, the watershed, NPDES wastewater discharges to the Neosho River and Fort Gibson Lake, atmospheric deposition and internal benthic flux loading rates for the existing 2006 validation conditions. The percentage contribution of Lake Hudson, watershed, atmospheric deposition, NPDES wastewater and benthic flux loading to the total loads is given in Table 4-12. The internal benthic flux of total phosphorus accounts for 22.2% of the total phosphorus loading to the lake on an annual basis while external loading of phosphorus from Lake Hudson (38.7%) and the watershed (12.8%) accounts for 51.5% and wastewater inputs account for 26.2% (Table 4-13). The load budget for total nitrogen is dominated by loading from Lake Hudson (62.9%) with 20.9% derived from the watershed, 8.7% of the nitrogen load from NPDES wastewater inputs and 6.1% of the load derived from the internal benthic flux of nitrogen. Atmospheric deposition of both phosphorus and nitrogen accounts for only minor contributions to the total loading to the lake.

Table 4-12 Annual Loading from Lake Hudson, Watershed, Atmospheric Deposition, Sediment Flux, and NPDES Wastewater of Nutrients, TOC and Sediment for Existing Validation Conditions (2006) Delivered to Fort Gibson Lake

Model Validation, 2006	**Annual**	**Annual**	**Annual**	**Annual**	**Annual**	**Annual**
Source	**Lake Hudson**	**HSPF**	**AtmDep**	**SedFlux**	**NPDES**	**Total**
Water Quality Parameter	**kg/day**	**kg/day**	**kg/day**	**kg/day**	**kg/day**	**kg/day**
Total Nitrogen (TN)	5,012.2	1,663.9	102.3	489.2	696.4	7,964.0
Total Phosphorus (TP)	565.8	187.4	0.7	324.8	382.5	1,461.2
Total Organic Carbon (TOC)	9,211.8	23,794.4	0.0	0.0	1,597.4	34,603.6
Total Suspended Solids (TSS)	27,556.7	147,275.7	0.0	0.0	652.8	175,485.2

Table 4-13 Percentage Contribution of Annual Loading from Lake Hudson, Watershed, Atmospheric Deposition, Sediment Flux, and NPDES Wastewater for Nutrients, TOC and Sediment for Existing Validation Conditions (2006)

Model Validation, 2006	**Annual**	**Annual**	**Annual**	**Annual**	**Annual**	**Annual**
Source	**Lake Hudson**	**HSPF**	**AtmDep**	**SedFlux**	**NPDES**	**Total**
Water Quality Parameter	**%**	**%**	**%**	**%**	**%**	**%**
Total Nitrogen (TN)	62.9%	20.9%	1.3%	6.1%	8.7%	100.0%
Total Phosphorus (TP)	38.7%	12.8%	0.05%	22.2%	26.2%	100.0%
Total Organic Carbon (TOC)	26.6%	68.8%	0.0%	0.0%	4.6%	100.0%
Total Suspended Solids (TSS)	15.7%	83.9%	0.0%	0.0%	0.4%	100.0%

4.5 Water Quality Response to Modeled Load Reduction Scenarios

The validated lake model was used to evaluate the water quality response to reductions in watershed loading of sediment and nutrients. Load reduction scenario “spin-up” simulation runs were performed to determine if water quality targets for turbidity, chlorophyll-a and dissolved oxygen could be attained with watershed-based load reductions of 20%, 30%, 40%, 45%, and 50%. Based on an evaluation of the load reduction scenario results the 45% removal alternative was selected to describe the long-term water quality response of the lake to changes in watershed loads. The 45% removal scenario was used to simulate 10 years of sequential “spin-up” runs to evaluate the long-term response of water quality conditions in the lake to the 45% removal change in external loads from the watershed. For the set of spin-up runs, watershed flow and reduced pollutant loading from the HSPF model were repeated for each of the 10 spin-up years. The results derived from the 10 years of spin-up simulations did not, therefore, account for any projected, or future, conditions of hydrologic variability within the watershed.

The 45% pollutant removal scenario identified for the TMDL for Fort Gibson Lake is based on a simple uniform reduction of all sediment, BOD, TOC, TN and TP loads contributed by all tributaries, distributed runoff from the watershed, and all NPDES wastewater point sources to represent the reduction of external pollutant loads to Fort Gibson Lake. The methodology applied for developing the load reduction scenarios did not attempt to represent changes in external watershed loading based on implementation of specific BMPs or point source waste load allocations.

Results of the spin-up model runs for the 45% removal scenario are presented to show long-term trends in turbidity, chlorophyll, dissolved oxygen, benthic phosphate flux, and sediment oxygen demand. The spin-up results are also used to evaluate long-term changes in the relative contribution of internal phosphate loading from the sediment bed to external phosphate loads from the watershed and atmospheric deposition.

Turbidity and Trophic State Index (TSI). As discussed in Section 2 of this report, Oklahoma water quality standards for turbidity and the NLW criteria for TSI are as follows:

- *Turbidity*: no more than 10% of turbidity samples greater than 25 NTU based on compilation of historical records of the most recent 10 years
- *Trophic State Index (TSI)*: Average value of TSI no greater than 62 where TSI is computed from historical records for chlorophyll-a of the most recent 10 years

Turbidity. Table 4-14 summarizes annual statistics for turbidity for (a) the validated model results and the results generated with (b) ten years of spin-up runs for the 45% removal scenario, respectively. Summary statistics are computed from model results extracted for 2 USACE and 3 OWRB sites located within the Upper segment of Fort Gibson Lake (WBID: OK121600010200_00). Statistics are computed for the annual simulation period from January 2006 to December 2006. Turbidity statistics are computed as the average of the model results for the OWRB and USACE sites in the upper lake (see Figure 2-1). The number of simulation records for the model statistics (N=1,820) are based on 364 records per site for 5 sites.

Table 4-14 Summary Statistics for Turbidity: Observations (2006), Model Validation (2006) and 10 Years Spin-Up of the 45% Removal Scenario. Annual Data for Fort Gibson Lake, Upper (WBID: OK121600010200_00). Target for Turbidity is 25 NTU for 90th Percentile Statistic Based on Annual Data.

TURBIDITY (NTU), UPPER LAKE	ANNUAL								
OK121600010200_00	N_OBS	MEAN	MIN	10Pct	25Pct	50Pct	75Pct	90Pct	MAX
OBS DATA 2006	156	11.9	4.0	5.9	6.9	10.3	14.7	19.6	37.4
VALIDATION 2006	1,820	11.3	4.0	6.8	8.9	10.1	12.8	16.4	56.5
YR0	1,820	10.4	3.2	5.1	7.3	9.5	12.0	15.3	58.8
YR2	1,820	10.2	3.1	4.9	7.0	9.6	11.8	14.9	59.2
YR4	1,820	10.2	3.0	4.9	6.9	9.5	11.8	14.9	59.2
YR6	1,820	10.1	3.0	4.9	6.9	9.5	11.8	14.9	58.5
YR8	1,820	10.1	3.0	4.9	6.9	9.5	11.8	14.9	59.3
YR10	1,820	10.1	3.0	4.9	6.9	9.5	11.8	14.9	59.3

As discussed in Section 2, the 90th percentile of observed turbidity (31 NTU) that exceeded the target of 25 NTU and resulted in the designation of impairment for the upper lake was based on high turbidity levels measured in 2001 and 2004 when river flow was much higher than during the 2006 validation year for the model. As a result of low flow hydrologic conditions during the model validation year of 2006, the 90th percentile of observed turbidity (19.6 NTU) and simulated turbidity (16.4 NTU) presented in Table 4-14 for the upper segment of Fort Gibson Lake did not show violation of the water quality target of 25 NTU. The model validation results (16.4 NTU) are seen to be in good agreement with the 90th percentile of observed turbidity (19.6 NTU). Figure 4-9 presents the simulated long-term trend of the 90th percentile of annual turbidity based on 10 years of simulated spin-up results. The load reduction scenario results in

~9% decrease of the 90th percentile of annual turbidity (from 16.4 to 14.9 NTU) in the upper segment of the lake.

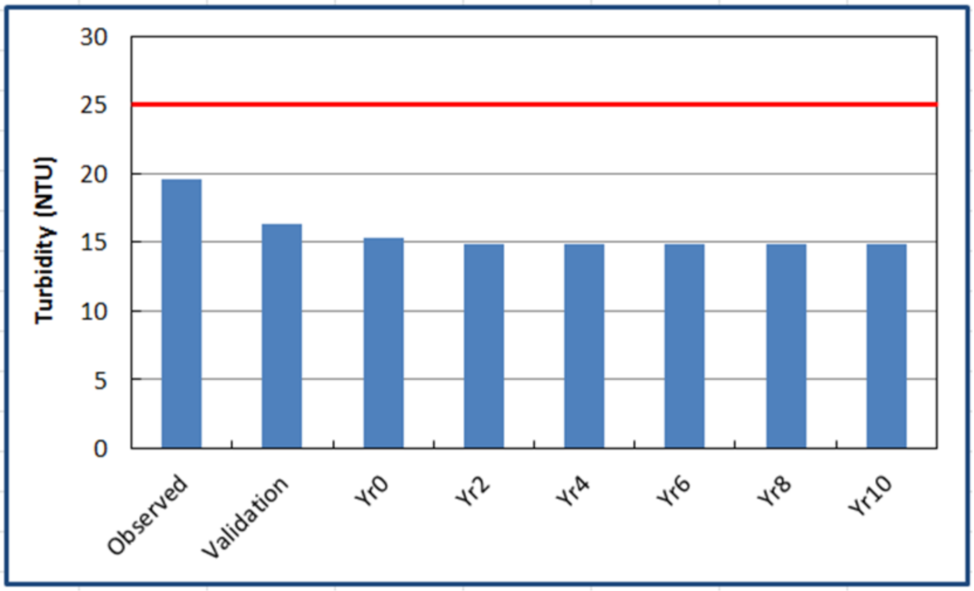

Figure 4-9 Turbidity, 90th Percentile: Observations (2006), Model Validation (2006) and 10 Years Spin-Up of the 45% Removal Scenario. Annual data for Fort Gibson Lake, Upper (OK121600010200_00).

The period of record from June 1998 through June 2007 used by OWRB to determine impairment of the Upper segment of Fort Gibson Lake showed OWRB turbidity measurements at three stations ranging from 4 to 52 NTU. Highest turbidity levels were recorded in May 2004 (52), April 2001 (35), and July 2001 (32) and the 90th percentile value of 31 NTU exceeded the 25 NTU target criteria for the lake. Based on USGS flow records at 07191500 for the Neosho River at Choteau, high turbidity tended to be associated with high flow conditions while low turbidity in October 2006 (10 NTU) was associated with very low flow conditions in the drought year of 2006.

Annual flow conditions in the years after 2006 were lower than average only in 2011, 2012, 2014, and 2016. Flow in all other years was higher than average and flow in 2008, 2009, and 2015 ranked in the highest 10 years of record from 1964-2017. Without analyzing turbidity observations collected since 2007 in the upper segment of Fort Gibson Lake, it is likely that turbidity levels would be high during the high flow years recorded since 2006 and thus could have been a contributing factor for possible designation of impairment for the upper segment of the lake. The OWRB BUMP report for quarterly sampling from October 2014-November 2015 at 3 stations in the upper segment of the lake, however, showed an average of 9 NTU with 100% of samples less than the 25 NTU criteria for turbidity. The analysis of turbidity records used by the OWRB for the 2014 and 2016 303(d) assessment of compliance in the upper segment of Fort Gibson Lake thus supported the conclusion that turbidity fully supported beneficial uses in this segment for the 2014 and 2016 Integrated Reports.

Based on 2006 hydrologic conditions, the model was used to determine that a 45% uniform reduction of sediment (TSS), nutrients and organic matter from all point and nonpoint sources would result in attainment of water quality targets for turbidity, DO and chlorophyll-a. The simulated 90th percentile turbidity (16.4 NTU), in good agreement with the observed 90th percentile (19.6 NTU), was lower than the 25 NTU turbidity target because of much lower flow and sediment loading conditions in 2006 compared to 2005. As the model results showed that 45% removal of 2006 loading resulted in a turbidity level of ~16 NTU, there is available capacity for additional loading in the 2006 loading analysis that would still be in compliance with the 25 NTU target for turbidity. The statistical basis of the MDL determined for total suspended sediments (TSS) is derived from 45% removal of existing 2006 loading and the additional incremental loading associated with the upper bound of the 95% confidence interval. Under higher flow conditions experienced during each year since the drought conditions of 2006, the TMDL may still be protective of turbidity in the lake because of the excess capacity demonstrated for the 2006 loading analysis, the additional loading provided by the 95% confidence limit used for derivation of the MDL for TSS, and the fact that the turbidity data collected by OWRB from October 2014 through and November 2015 was all less than the 25 NTU criteria for the lake.

Trophic State Index.
Table 4-15 summarizes annual statistics computed for TSI for (a) the validated model results and the results generated with (b) ten years of spin-up runs for the 45% removal scenario, respectively. Summary statistics are computed from model results for both WBID segments of the lake (OK121600010050_00 and OK121600010200_00) for the annual simulation period from January 2006 to December 2006. TSI statistics are computed as averages of the model results for sites located in the upper and lower segments of the lake (see Figure 2-1). In the upper lake (OK121600010200_00), the number of simulation records for the model statistics (N=1,820) are based on 364 records per site for 5 sites. In the lower lake (OK121600010050_00), the number of simulation records for the model statistics (N=3,640) are based on 364 records per site for 10 sites.

As can be seen in Figure 2-3 and Figure 2-4, observed data are not available for TSI or Chlorophyll-a in 2006. OWRB collected Chlorophyll-a in 2004 and 2007 and the USACE collected Chlorophyll-a data in 2004 and 2005. With the exception of only one survey in October 2006 by OWRB, the observed data set for TSI and Chlorophyll-a are not sufficient to support an evaluation of model performance for the validation year of 2006. As shown in

Table 4-15, annual mean TSI model results for the upper segment of the lake (61.5) and the lower segment of the lake (57.1) are lower than the water quality TSI target of 62. As can be seen in Table 4-6 model performance statistics, ranging from 39 to 79% for TSI, are presented only for the calibration year of 2005. The lack of observed TSI and Chlorophyll-a data for 2006 is discussed in Appendix B (“EFDC Water Quality Model Setup, Calibration and Validation, Fort Gibson Lake, Oklahoma”).

Table 4-15 Summary Statistics for TSI: Observations (2006), Model Validation (2006) and 10 Years Spin-Up of the 45% Removal Scenario. Annual data for Fort Gibson Lake, Upper (OK121600010200_00) and Fort Gibson Lake (OK121600010050_00).

TSI, UPPER LAKE OK121600010200_00	ANNUAL N_OBS	MEAN	MIN	10Pct	25Pct	50Pct	75Pct	90Pct	MAX
OBS DATA (2006)	0	ND	ND	ND	ND	ND	ND	ND	ND
VALIDATION 2006	1,820	61.5	26.5	32.8	42.6	61.9	65.7	68.4	71.2
YR0	1,820	57.3	27.6	34.0	40.9	57.5	61.3	64.1	66.1
YR2	1,820	56.1	23.3	27.2	39.4	56.3	59.8	62.9	65.4
YR4	1,820	55.9	23.3	27.2	39.4	56.1	59.7	62.8	65.4
YR6	1,820	55.9	23.2	27.2	39.3	56.1	59.6	62.8	65.4
YR8	1,820	55.9	23.3	27.2	39.4	56.1	59.6	62.8	65.4
YR10	1,820	55.9	23.2	27.2	39.4	56.1	59.6	62.8	65.4
TSI, LOWER LAKE OK121600010050_00	ANNUAL N_OBS	MEAN	MIN	10Pct	25Pct	50Pct	75Pct	90Pct	MAX
OBS DATA (2006)	0	ND	ND	ND	ND	ND	ND	ND	ND
VALIDATION 2006	3,640	57.1	18.8	26.5	39.8	58.3	62.2	63.5	65.7
YR0	3,640	54.4	19.8	27.7	38.7	55.5	59.4	60.7	62.6
YR2	3,640	52.1	13.8	22.0	34.7	52.6	57.0	58.9	61.7
YR4	3,640	51.6	13.0	21.3	34.2	52.1	56.6	58.4	61.6
YR6	3,640	51.5	12.8	21.0	34.1	52.0	56.4	58.3	61.6
YR8	3,640	51.4	12.7	20.9	34.0	52.0	56.3	58.2	61.6
YR10	3,640	51.4	12.6	20.9	33.9	52.0	56.3	58.1	61.6

Figure 4-10 and Figure 4-11 show the 10 year TSI spin-up trends for the upper and lower lakes, respectively, for the TSI data presented in

Table 4-15 for the 45% removal scenario. There is a decrease in the TSI in both the upper and lower segments of the lake in Year 0 in response to the load reduction scenario. After Year 4 of the spin-up trend, TSI has attained compliance with the NLW target with a new level of 55.9 within the upper lake segment. In the lower lake segment, compliance with NLW target is also achieved with a new TSI level of 51.4 after Year 8 of the model spin-up.

TSI is computed using Carlson's (1977) relationship with chlorophyll-a measurements. The long-term spin-up trend for chlorophyll-a is presented in Table 4-16 for the 45% removal scenario. Since TSI is computed from chlorophyll-a, the spin-up trend for chlorophyll-a follows the trend described above for TSI for the upper and lower lake segments. As discussed above for the availability of TSI data, the observed data for Chlorophyll-a, limited to a single survey by OWRB in October 2006, are not sufficient to support an evaluation of model performance for Chlorophyll-a for the validation year of 2006. As shown in Table 4-16, mean annual Chlorophyll-a model results for the upper segment of the lake (23.3) and the lower segment of the lake (14.9) are lower than the equivalent Chlorophyll-a level of 24.5 µg/L for the TSI water quality target of 62. As can be seen in Table 4-7 model performance statistics, ranging from 40% to 56% for Chlorophyll-a, are presented only for the calibration year of 2005. The lack of observed Chlorophyll-a data for 2006 is discussed in Appendix B ("EFDC Water Quality Model Setup, Calibration and Validation, Fort Gibson Lake, Oklahoma").

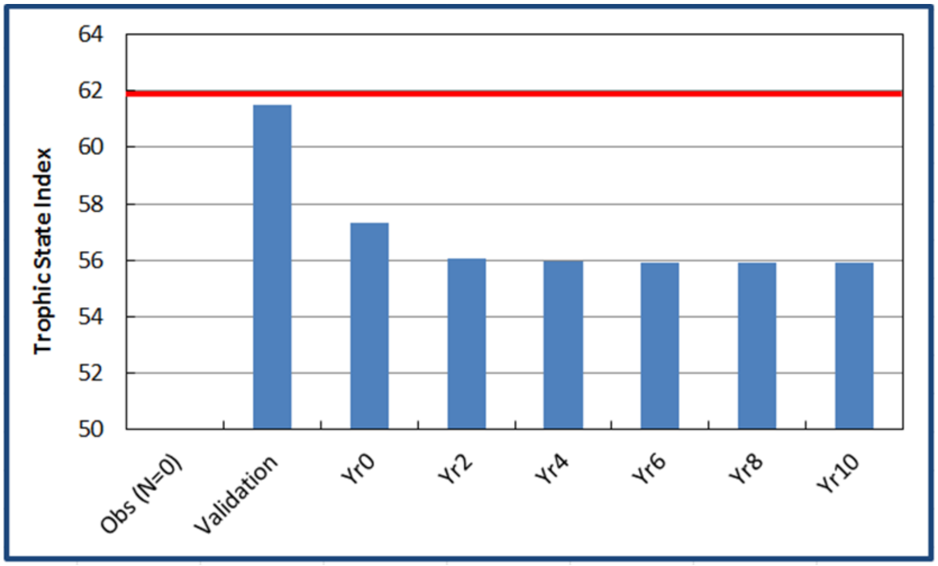

Figure 4-10 TSI: Surface, Mean Value: Observations (N=0 for 2006), Model Validation (2006) and 10 Years Spin-Up of the 45% Removal Scenario. Annual data for Fort Gibson Lake, Upper, (OK121600010200_00).

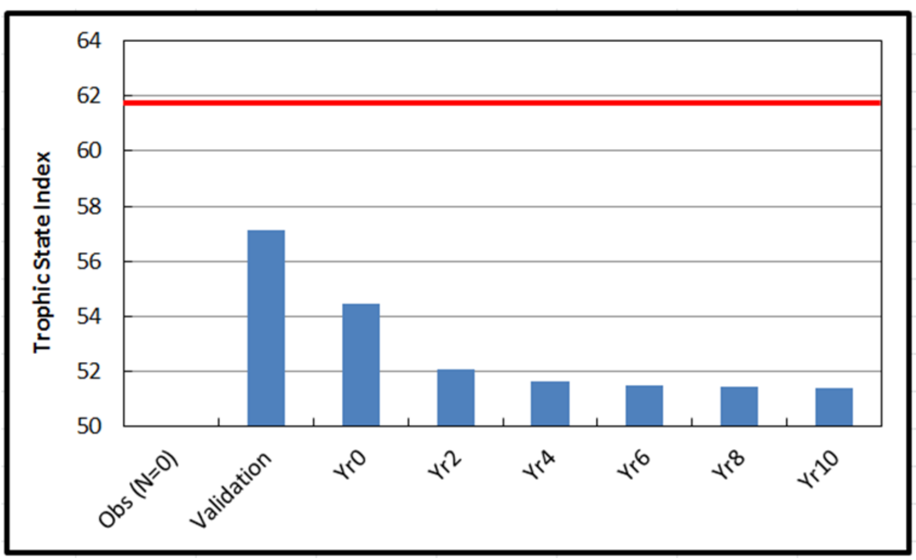

Figure 4-11 TSI: Surface, Mean Value: Observations (N=0 2006), Model Validation (2006) and 10 Years Spin-Up of the 45% Removal Scenario. Annual data for Fort Gibson Lake, OK121600010050_00).

Table 4-16 Summary Statistics for Chlorophyll-a: Observations (N=0 2006), Model Validation (2006) and 10 Years Spin-Up of the 45% Removal Scenario. Annual Data for Fort Gibson Lake, Upper (OK121600010200_00) and Fort Gibson Lake (OK121600010050_00).

CHL (µg/L) UPPER OK121600010200_00	ANNUAL N_OBS	MEAN	MIN	10Pct	25Pct	50Pct	75Pct	90Pct	MAX
OBS DATA 2006	0	ND	ND	ND	ND	ND	ND	ND	ND
VALIDATION 2006	1,820	23.3	0.7	1.2	3.4	24.3	35.7	46.9	62.9
YR0	1,820	15.3	0.7	1.4	2.9	15.6	22.9	30.5	37.3
YR2	1,820	13.4	0.5	0.7	2.5	13.7	19.6	26.9	34.7
YR4	1,820	13.2	0.5	0.7	2.4	13.4	19.3	26.6	34.7
YR6	1,820	13.2	0.5	0.7	2.4	13.5	19.3	26.6	34.6
YR8	1,820	13.2	0.5	0.7	2.5	13.4	19.3	26.6	34.9
YR10	1,820	13.2	0.5	0.7	2.5	13.4	19.3	26.5	34.6
CHL (µg/L) LOWER OK121600010050_00	ANNUAL N_OBS	MEAN	MIN	10Pct	25Pct	50Pct	75Pct	90Pct	MAX
OBS DATA 2006	0	ND	ND	ND	ND	ND	ND	ND	ND
VALIDATION 2006	3,640	14.9	0.3	0.7	2.6	16.9	25.1	28.7	35.9
YR0	3,640	11.4	0.3	0.7	2.3	12.7	18.9	21.6	26.1
YR2	3,640	8.9	0.2	0.4	1.5	9.5	14.8	17.9	23.8
YR4	3,640	8.5	0.2	0.4	1.4	9.0	14.1	17.1	23.6
YR6	3,640	8.4	0.2	0.4	1.4	8.9	13.9	16.8	23.6
YR8	3,640	8.4	0.2	0.4	1.4	8.8	13.8	16.7	23.5
YR10	3,640	8.3	0.2	0.4	1.4	8.8	13.7	16.6	23.6

As shown in Figure 4-12 and Figure 4-13, chlorophyll-a decreases immediately in Year 0 in response to the load reduction scenario in both the upper and lower segments of the lake. By Year 4 to Year 6, chlorophyll-a decreased by ~44% from the existing validation conditions and has attained new levels in both the upper (13.2 ug/L) and lower (8.4 ug/L) segments of the lake. The response of chlorophyll-a to the load reduction scenario is controlled by the supply of phosphorus available to support primary production. The supply in the euphotic zone diminishes both from the reduction in watershed loading of nutrients as well as a gradual decrease of internal phosphorus loading from benthic phosphate flux. The internal loading of phosphate to the lake, controlled by hypoxic bottom water oxygen conditions, occurs during the summer stratified period from June through October. As can be seen in Figure 4-14, benthic phosphate flux in WQ Zone 1 of the lower segment of the lake decreases from 19 mg P/m^2-day for the existing validation conditions to 9 mg P/m^2-day after 10 years of model spin-up. WQ Zone 1 includes the lower segment of the lake from OWRB Site 1 at the dam to OWRB Site 4 (see Figure 2-1). OWRB Site 4 is located just upstream of State Highway 51 and the Taylor Ferry boat launch site. Nutrient release from the sediment bed gradually decreases as the coupled interaction of the sediment-water system attains a new equilibrium condition that is balanced with the external nutrient loading scenario and primary production in the euphotic zone.

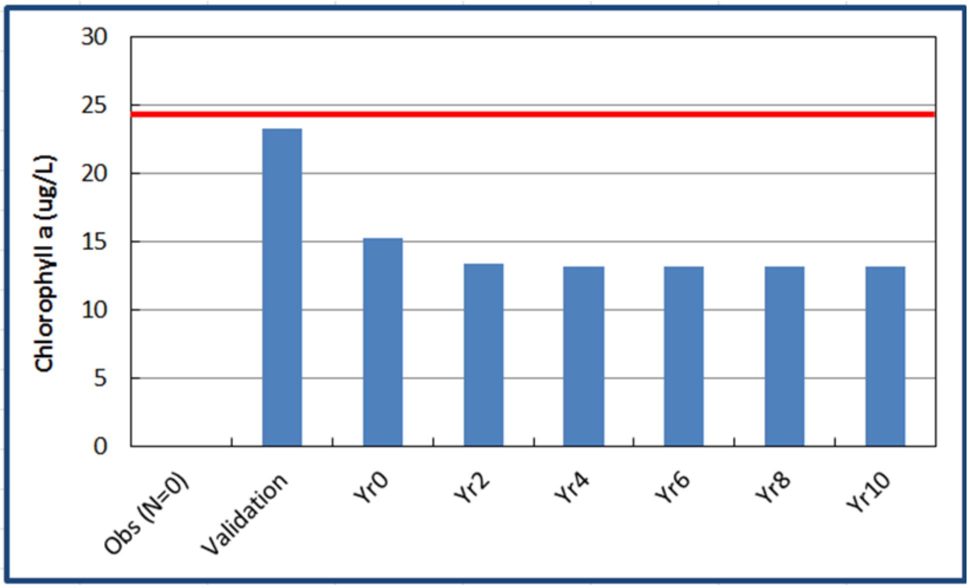

Figure 4-12 Chlorophyll-a, Surface, Mean Value: Observations (N=0 for 2006), Model Validation (2006) and 10 Years Spin-Up of the 45% Removal Scenario. Annual data for Fort Gibson Lake, Upper (OK121600010200_00).

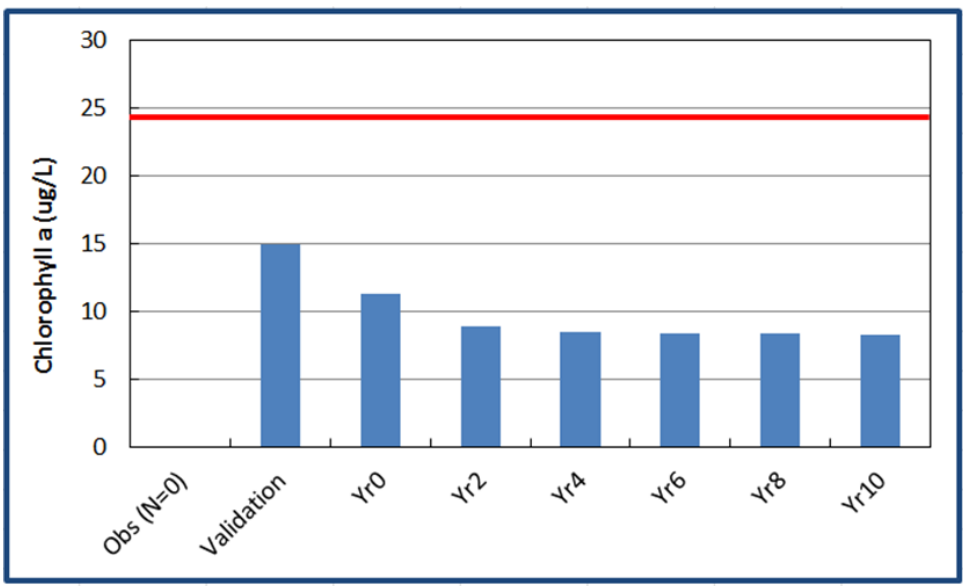

Figure 4-13 Chlorophyll-a, Surface, Mean Value: Observations (N=0 for 2006), Model Validation (2006) and 10 Years Spin-Up of the 45% Removal Scenario. Annual data for Fort Gibson Lake (OK121600010050_00).

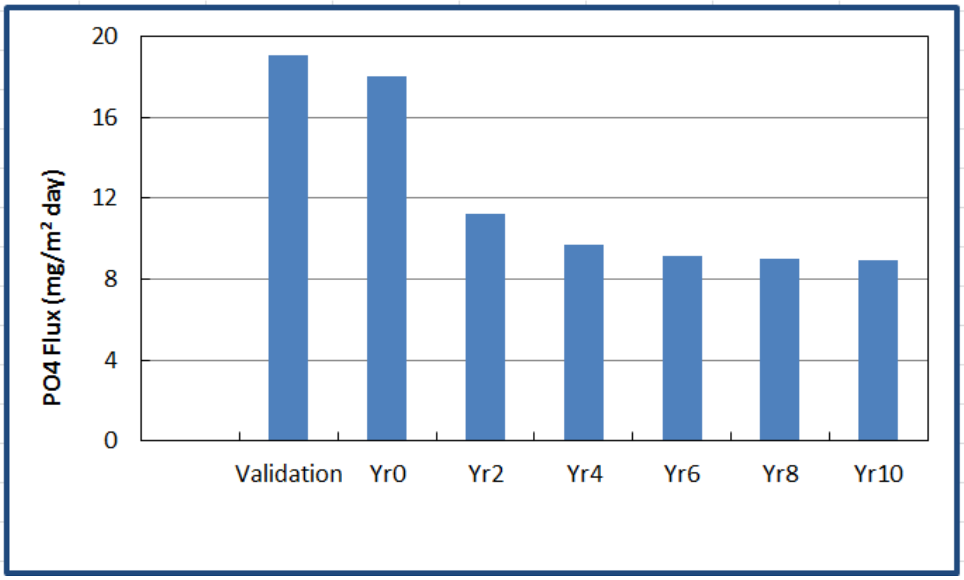

Figure 4-14 Sediment Flux of Phosphate (mg P/m^2-day), Spin-Up Model Results for 45% Removal, Summer Seasonal Average from June 16 to October 15 over WQ Zone 1 of Lower WBID of Fort Gibson Lake, OK121600010050_00.

The spin-up simulation analysis of the coupled water column-sediment bed response to the 45% reduction in watershed and wastewater loading of sediment and nutrients indicates that compliance with water quality criteria for turbidity of 25 NTU and the NLW target for TSI of 62 can be attained within a reasonable time frame. **It is important to emphasize that the model spin-up results are not a prediction of the number of years required for lake recovery because of the idealized spin-up conditions of a precisely maintained watershed and wastewater discharge load reduction level and repeated climatic and hydrologic conditions of 2006.** The model results, do, however, provide technically credible evidence that future conditions can be in compliance with water quality targets for turbidity and TSI within a reasonable time frame if watershed and wastewater loads are reduced as recommended and the reduction is sustained.

Dissolved Oxygen. The recently revised Oklahoma water quality standards for dissolved oxygen for Fort Gibson Lake are specified in relation to (a) spring and summer stratified conditions for the surface layer (epilimnion) and the anoxic volume of the lake within the hypolimnion and (b) non-stratified conditions for the surface layer (OWRB, 2014). Within the surface layer (epilimnion) during the early period of thermal stratification in spring, 10% or less of the dissolved oxygen samples shall be no less than 6 mg/L from April 1 to June 15. During the summer period of stratification from June 16-October 15, 10% or less of the dissolved oxygen samples shall be no less than 5 mg/L. During the remainder of the year (October 16 to March 31) 10% or less of the dissolved oxygen samples shall be no less than 5 mg/L for the months when the lake is non-stratified.

The period of seasonal thermal stratification for Fort Gibson Lake is determined using water temperature observations from the USACE monitoring site near the dam (1GIBOKN0003) in the lacustrine zone of the lake. Dates for the onset and erosion of thermal stratification were based on analysis of the vertical temperature gradient between surface layer and bottom layer observations. Figure 4-15 shows surface and bottom layer temperature observations for 1GIBOKN0003 for January 2005 through December 2006. Figure 4-16 shows the temperature gradient as the difference between surface and bottom temperature for the site. April 1 is defined as the date for the onset of stratification when the vertical temperature gradient begins to increase. By October 1, the temperature gradient decreases and remains small through the well-mixed, non-stratified winter-spring months until the onset of stratification begins again in early April. The time series plots show marker lines for April 1 and October 1 for 2005 and 2006 to indicate the beginning and end of thermal stratification in Fort Gibson Lake.

Under the 45% load reduction determined for the TMDL, compliance with the water quality criteria for dissolved oxygen is demonstrated for (a) spring and summer stratified conditions for the surface layer (epilimnion), (b) anoxic volume of lake during stratification; and (c) the surface layer of the lake for the fall-winter period when the lake is not stratified from October 16 through March 31.

Spring Stratified Period, Surface Layer (Epilimnion). The revised OWRB water quality criteria for the surface layer require that DO levels be 6 mg/L or more during stratified conditions from April 1 through June 15. As presented in Table 4-17 and shown in Figure 4-17, model results, extracted for the spring stratified period from April 1 through June 15 for surface layer dissolved oxygen, are seen to be (a) in good agreement with observed data for the existing validation conditions and (b) in compliance with the water quality criteria for surface DO levels with the 10^{th} percentile values of DO greater than the stratified season criteria of 6 mg/L. In the lower lake (OK121600010050_00), the number of simulation records for the model statistics (N=750) are based on 75 records per site for 10 sites.

Table 4-17 Summary Statistics for Dissolved Oxygen, Surface: Observations (2005-2006), Model Validation and 10 Years Spin-Up of the 45% Removal Scenario. Spring Season (April 1- June 15) for Lower Fort Gibson Lake (OK121600010050_00).

DO (MG/L), LOWER OK121600010050_00	SURFACE N_OBS	SPRING MEAN	MIN	10Pct	25Pct	50Pct	75Pct	90Pct	MAX
OBS DATA	18	9.38	6.86	8.03	8.46	9.36	10.62	10.86	11.23
VALIDATION 2006	750	9.11	6.75	7.71	8.44	9.25	9.87	10.29	10.84
YR0	750	9.01	6.95	7.76	8.36	9.14	9.67	10.08	10.54
YR2	750	9.01	7.05	7.80	8.43	9.14	9.66	10.01	10.33
YR4	750	9.03	7.06	7.83	8.44	9.16	9.66	10.02	10.33
YR6	750	9.03	7.04	7.82	8.43	9.17	9.66	10.03	10.34
YR8	750	9.03	7.05	7.82	8.45	9.19	9.65	10.03	10.34
YR10	750	9.03	7.05	7.83	8.45	9.18	9.66	10.02	10.34

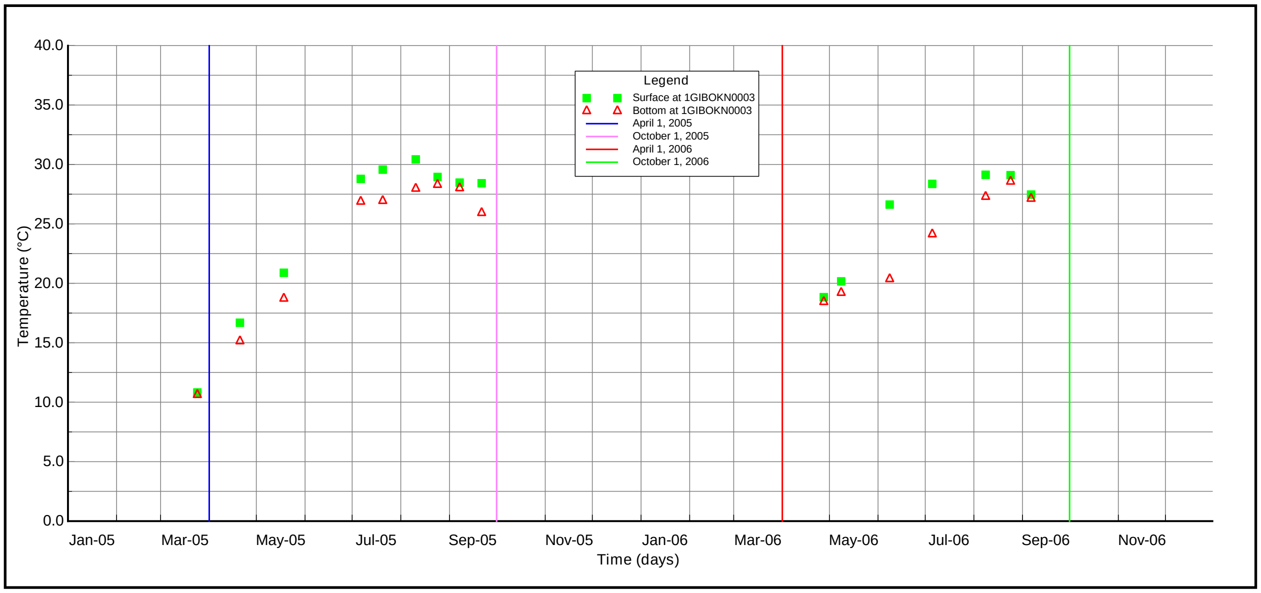

Figure 4-15 Surface and Bottom Layer Water Temperature for Lacustrine Site 1GIBOKN0003 in Fort Lake, 2005-2006.

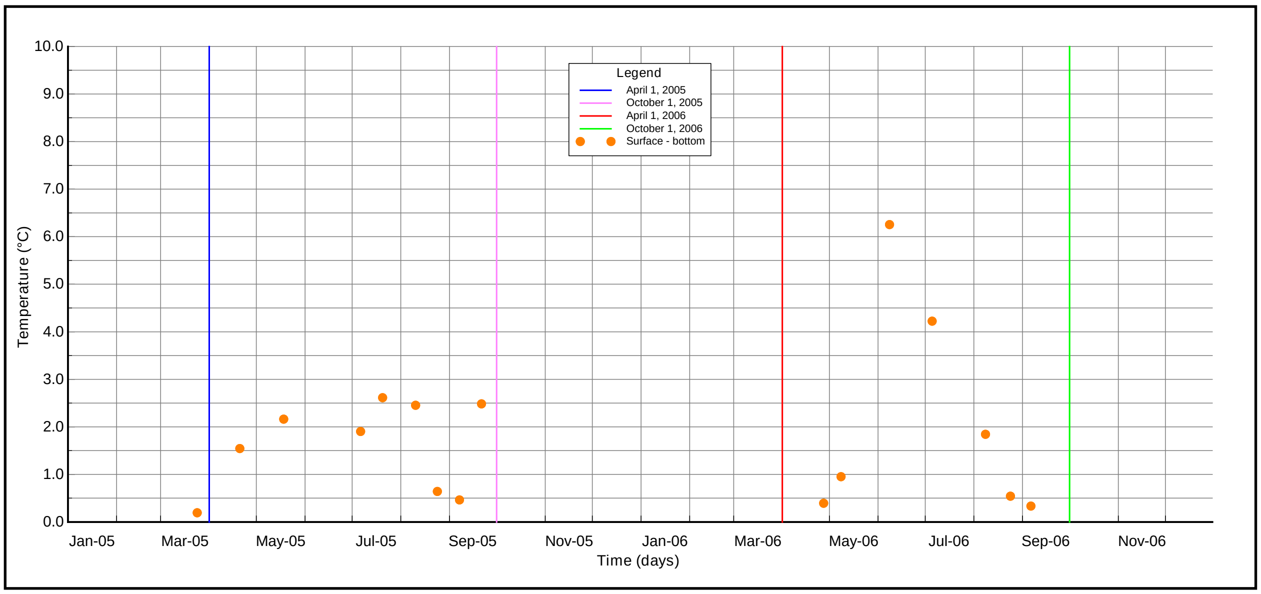

Figure 4-16 Temperature Stratification (Surface-Bottom) for Lacustrine Site 1GIBOKN0003 in Fort Lake, 2005-2006.

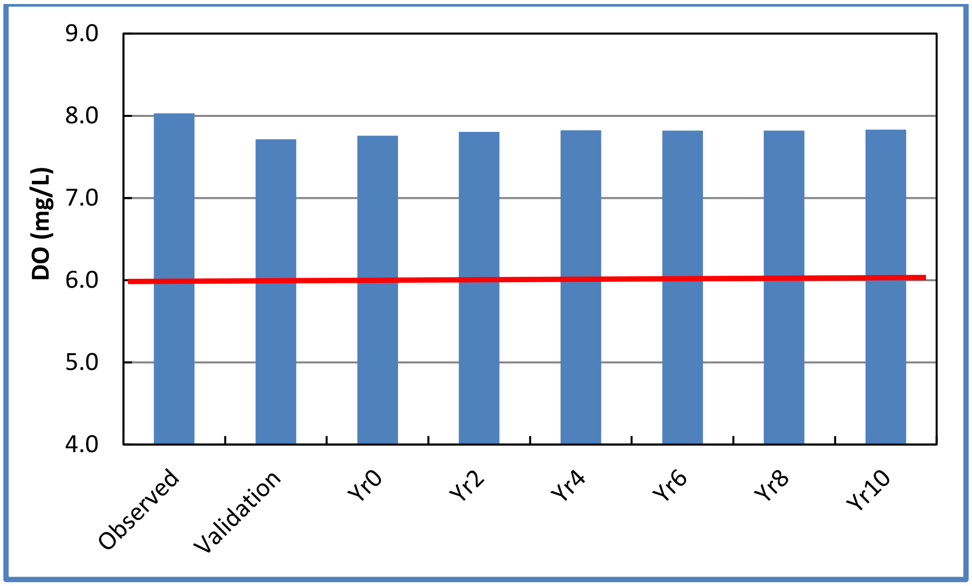

Figure 4-17 Dissolved Oxygen, Surface, 10th percentile: Observations (2005-2006), Model Validation and 10 Years Spin-Up of the 45% Removal Scenario. Spring Season (April 1- June 15) for Lower Fort Gibson Lake (OK121600010050_00).

Summer Stratified Period, Surface Layer (Epilimnion). The revised OWRB water quality criteria for the surface layer require that DO levels be 5 mg/L or more during summer stratified conditions from June 16 through October 15. As presented in Table 4-18 and shown in Figure 4-18, model results, extracted for the stratified period from June 16 through October 15 for surface layer dissolved oxygen for the lower WBID segment of Fort Gibson Lake (OK121600010050_00), are seen to be in compliance with the water quality criteria for surface DO levels with the 10th percentile values of DO greater than the stratified season criteria of 5 mg/L. Model results for the bottom layer of the lower WBID segment of the lake show a gradual 63% improvement in dissolved oxygen from the validation conditions of 1.1 mg/L to 1.8 mg/L after 10 years of the model spin-up (Figure 4-19). In the lower segment of the lake (OK121600010050_00), the number of simulation records for the model statistics (N=1,210) are based on 121 records per site for 10 sites.

The OWRB and USACE stations located near the dam, however, were shown by OWRB in the 2010 303(d) assessment to be in violation of the surface DO criteria with several sampling dates characterized by surface DO concentrations less than 5 mg/L (see Table 2-8). As presented in Table 4-19 and shown in Figure 4-20, the observed 10th percentile surface layer concentration of 4.1 mg/L for the lower segment of the lake is in very good agreement with the model surface layer validation results of 4.2 mg/L. Observed data and model data for this station clearly indicate non-compliance with the surface DO criteria of 5 mg/L for the 10th percentile under existing watershed loading conditions. With the 45% reduction of watershed loading, the 10th percentile of surface DO for the site near the dam is seen to gradually improve over the 10 years of model spin-up from 4.3 mg/L at Year 0 to 4.8-4.9 mg/L by Year 8 to Year 10. Surface DO at the location near the dam, although slightly less than the 5 mg/L criteria, has clearly improved and is very close to the target of 5 mg/L by the end of a 10-year spin-up of the lake model.

Table 4-18 Summary Statistics for Dissolved Oxygen: Surface and Bottom Observations (2005-2006), Model Validation and 10 Years Spin-Up of the 45% Removal Scenario. Summer Season (June 16-October 15) for Lower Fort Gibson Lake (OK121600010050_00).

DO (MG/L), LOWER OK121600010050_00	SURFACE N_OBS	SUMMER MEAN	MIN	10Pct	25Pct	50Pct	75Pct	90Pct	MAX
OBS DATA	30	7.78	2.23	5.07	6.20	7.69	9.06	11.27	12.57
VALIDATION 2006	1,210	7.05	4.91	6.22	6.67	7.10	7.48	7.85	8.28
YR0	1,210	7.04	4.92	6.23	6.66	7.09	7.47	7.83	8.27
YR2	1,210	7.07	5.01	6.35	6.68	7.08	7.49	7.86	8.26
YR4	1,210	7.10	5.13	6.39	6.71	7.09	7.51	7.89	8.27
YR6	1,210	7.10	5.11	6.40	6.71	7.10	7.52	7.91	8.29
YR8	1,210	7.10	5.12	6.40	6.70	7.08	7.50	7.90	8.29
YR10	1,210	7.10	5.15	6.39	6.70	7.08	7.51	7.90	8.30
DO (MG/L), LOWER OK121600010050_00	BOTTOM N_OBS	SUMMER MEAN	MIN	10Pct	25Pct	50Pct	75Pct	90Pct	MAX
OBS DATA	36	2.40	0.23	0.46	0.62	2.02	3.55	5.66	6.89
VALIDATION 2006	1,210	2.88	0.51	1.09	1.58	2.39	3.94	5.49	7.34
YR0	1,210	3.16	0.63	1.33	1.84	2.69	4.32	5.83	7.79
YR2	1,210	3.60	0.94	1.65	2.24	3.09	4.92	6.26	8.13
YR4	1,210	3.75	1.03	1.72	2.38	3.24	5.10	6.44	8.07
YR6	1,210	3.77	1.03	1.76	2.41	3.26	5.15	6.39	8.20
YR8	1,210	3.80	1.04	1.76	2.44	3.31	5.17	6.52	8.09
YR10	1,210	3.82	1.05	1.79	2.44	3.30	5.19	6.56	8.10

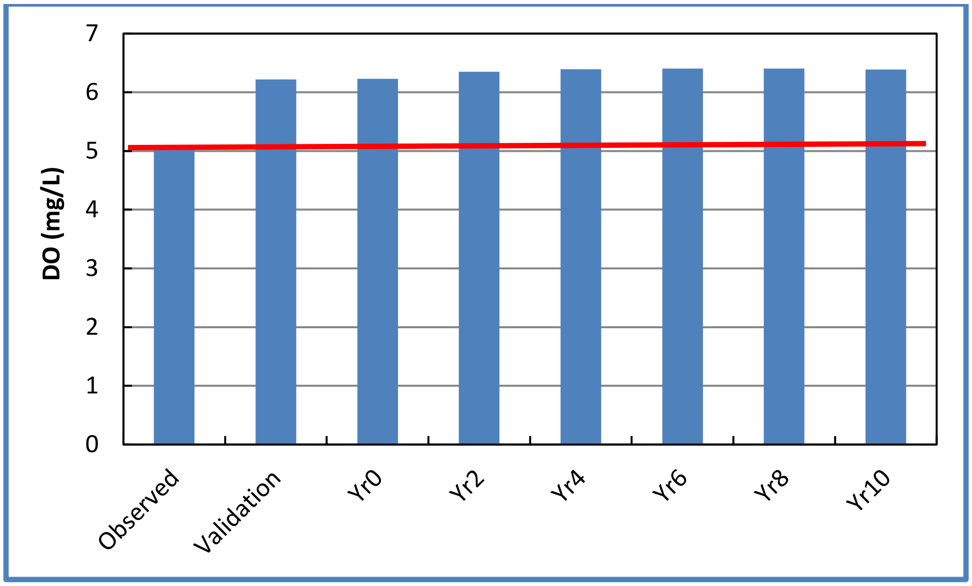

Figure 4-18 Dissolved Oxygen, Surface: 10th percentile Observations (2005-2006), Model Validation and 10 Years Spin-Up of the 45% Removal Scenario. Summer Season (June 16-October 15) for OWRB and USACE sites for Lower Fort Gibson Lake (OK121600010050_00).

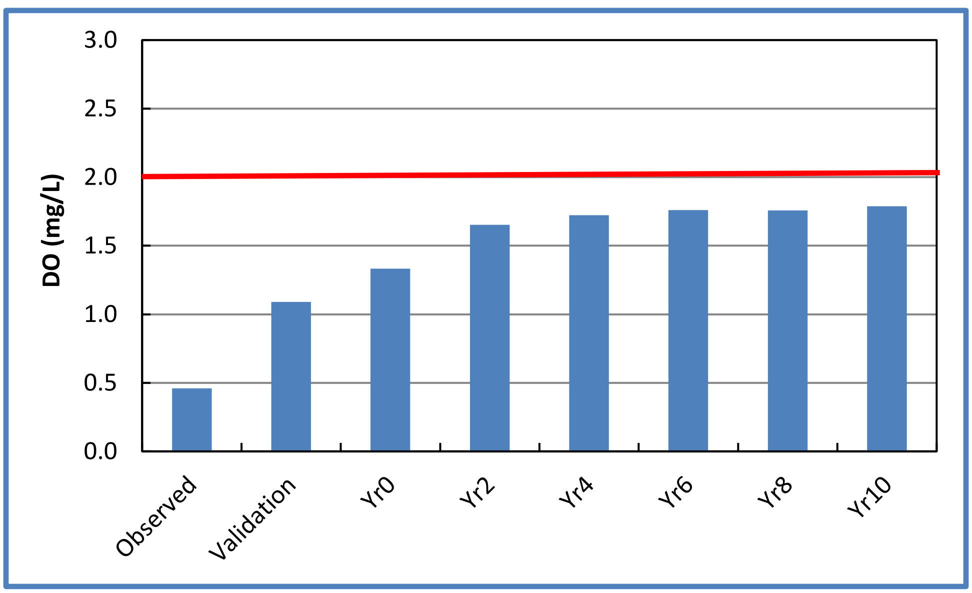

Figure 4-19 Dissolved Oxygen, Bottom, 10th percentile: Observations (2005-2006), Model Validation and 10 Years Spin-Up of the 45% Removal Scenario. Summer Season (June 16-October 15) for Fort Gibson Lake (OK121600010050_00).

Table 4-19 Summary Statistics for Dissolved Oxygen: Surface and Bottom Observations (2005-2006), Model Validation and 10 Years Spin-Up of the 45% Removal Scenario. Summer Season (June 16-October 15) for USACE Station 1GIBOKN003 Near the Dam in Fort Gibson Lake (OK121600010050_00).

DO (MG/L), DAM 1GIBOKN0003	SURFACE N_OBS	SUMMER MEAN	MIN	10Pct	25Pct	50Pct	75Pct	90Pct	MAX
OBS DATA	10	7.18	2.23	4.13	4.89	6.23	10.15	10.80	12.57
VALIDATION 2006	121	5.68	2.39	4.20	5.08	5.86	6.38	6.90	7.41
YR0	121	5.82	2.32	4.31	5.22	6.06	6.53	6.92	7.68
YR2	121	5.88	2.35	4.62	5.23	6.03	6.58	6.99	7.38
YR4	121	5.94	2.37	4.85	5.26	6.06	6.66	7.05	7.37
YR6	121	5.96	2.50	4.83	5.26	6.07	6.74	7.10	7.50
YR8	121	5.97	2.49	4.89	5.31	6.02	6.63	7.07	7.50
YR10	121	5.96	2.48	4.79	5.27	6.05	6.69	7.07	7.49

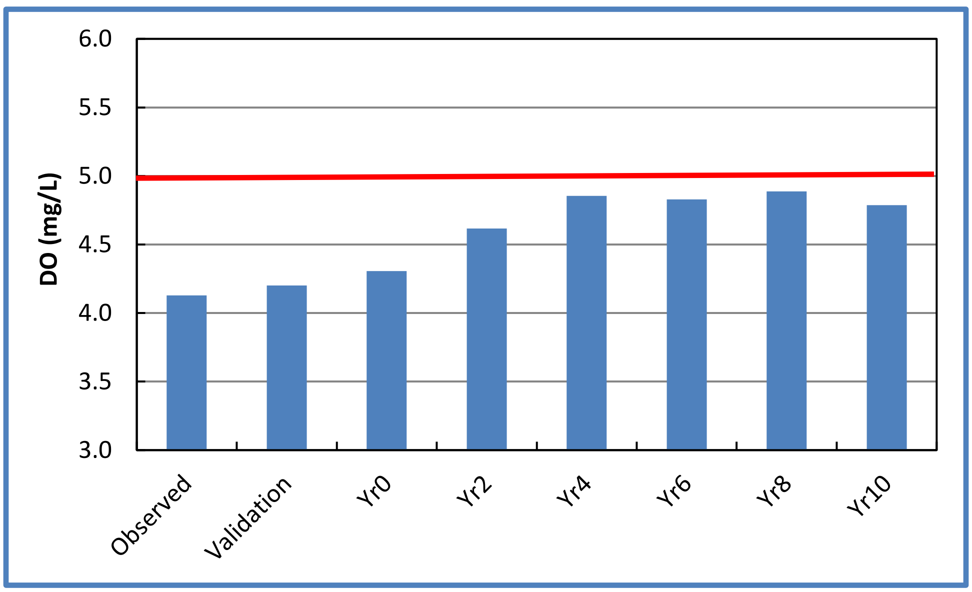

Figure 4-20 Dissolved Oxygen, Surface: 10th percentile Observations (2005-2006), Model Validation and 10 Years Spin-Up of the 45% Removal Scenario. Summer Season (June 16-October 15) for USACE 1GIBOKN0003 in Fort Gibson Lake (OK121600010050_00).

Stratified Period, Anoxic Water Column. The revised water quality criteria for dissolved oxygen require that, on a volumetric basis, 50% or less of the lake volume must be lower than a 2 mg/L cutoff concentration for DO during the period of seasonal stratification. The revised criteria also indicate that no more than 70% of the DO measurements in a water column profile at a sampling site can be less than 2 mg/L (OWRB, 2014). The results of the computations of the anoxic portion of the water column, based on a target DO level of 2 mg/L, are presented in Figure 4-21 as snapshot maps of the anoxic volume of the lacustrine zone of the lake for the existing conditions of model validation (Figure 4-21A) and the spin-up conditions after 10 years (Figure 4-21B). Under existing conditions for model validation, several grid cells (colored red) near the dam show an anoxic volume of 75%. After 10 years of spin-up simulations, the response of the model to the load reduction scenario shows that DO in the deep-water grid cells near the dam has improved from a peak of 75% <2 mg/L for existing conditions to a peak of 62% for Year 10.

Time series of the model results for the anoxic water column are extracted for the USACE site at the dam (1GIBOKN0003). As can be seen in Figure 4-8 for model validation, the model results for the percentage of the water column <2 mg/L are in very good agreement with observations near the dam at the USACE Station 1GIBOKN0003. Although observed data are not available for confirmation, the model results indicate that a maximum of 75% of the water column is <2 mg/L in late July and early September. Figure 4-21, discussed above, shows the spatial distribution of the anoxic volume of the lacustrine zone of the lake as a snapshot for July 25, 2006 when the model showed 75% of the water column <2 mg/L for several grid cells near the dam including the USACE sampling site.

If spin-up of the load reduction scenario succeeds in decreasing the peak anoxic percentage of the water column to less than 70% then compliance with the criteria for water column dissolved oxygen at a sampling site will be attained. Figure 4-22 presents time series results for model validation and spin-up of the 45% removal scenario for Year 5 and Year 10. As can be seen by comparison of the model validation results to the spin-up results after 10 years, the peak anoxic percentage in late July and early September is seen to decrease from 75% for the existing conditions to less than 70% for the 45% removal scenario. In response to the load reduction scenario, the fluctuations of anoxia in the water column ranging from 10-50% in September-October that are seen under existing conditions for model validation are eliminated after 5 years of the model spin-up.

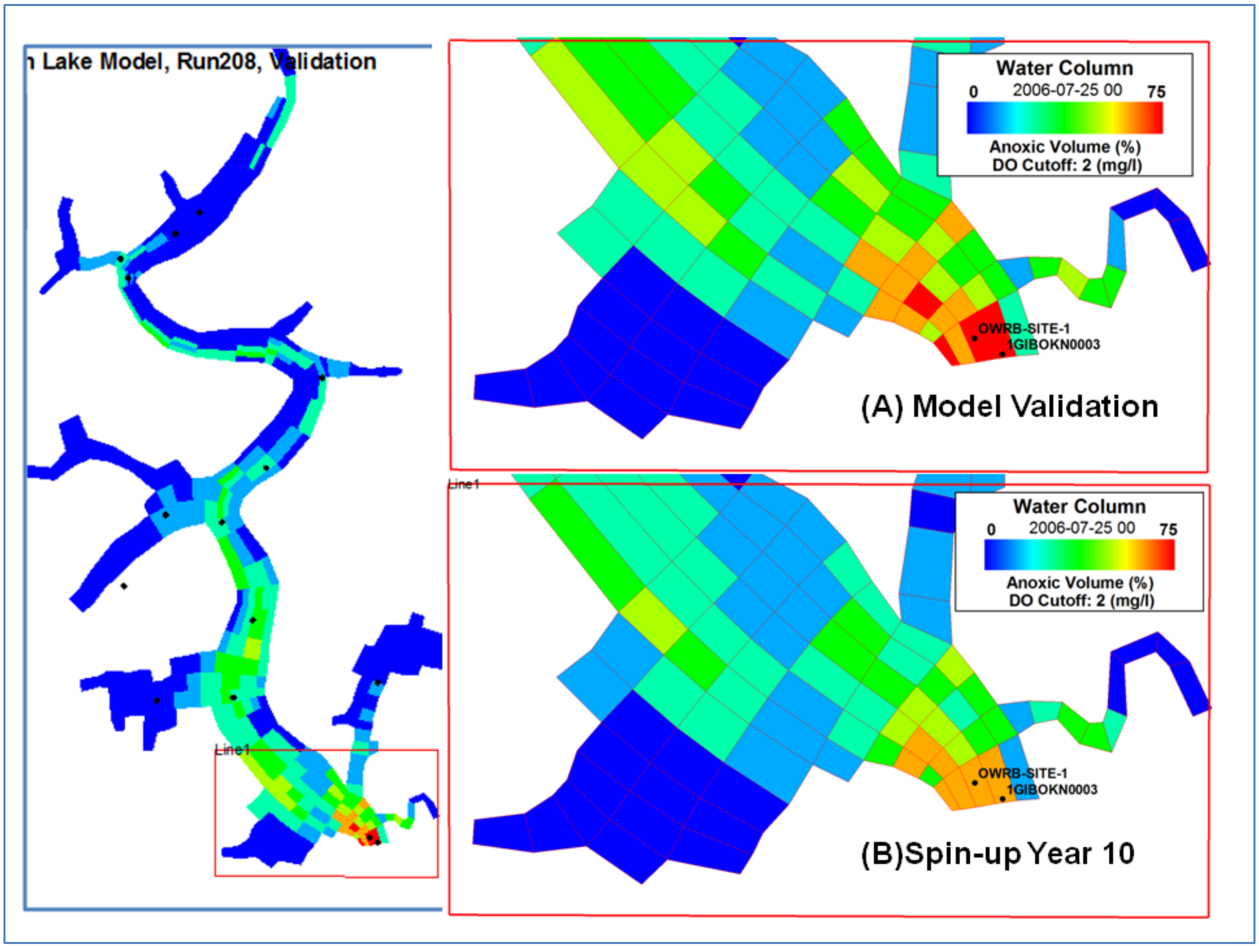

Figure 4-21 Spatial Distribution of Anoxic Volume of Fort Gibson Lake.
Snapshot of results for July 25, 2006 for detail of lower WBID segment of Fort Gibson Lake for (A) Model Validation and (B) Model Spin-up for Year 10.

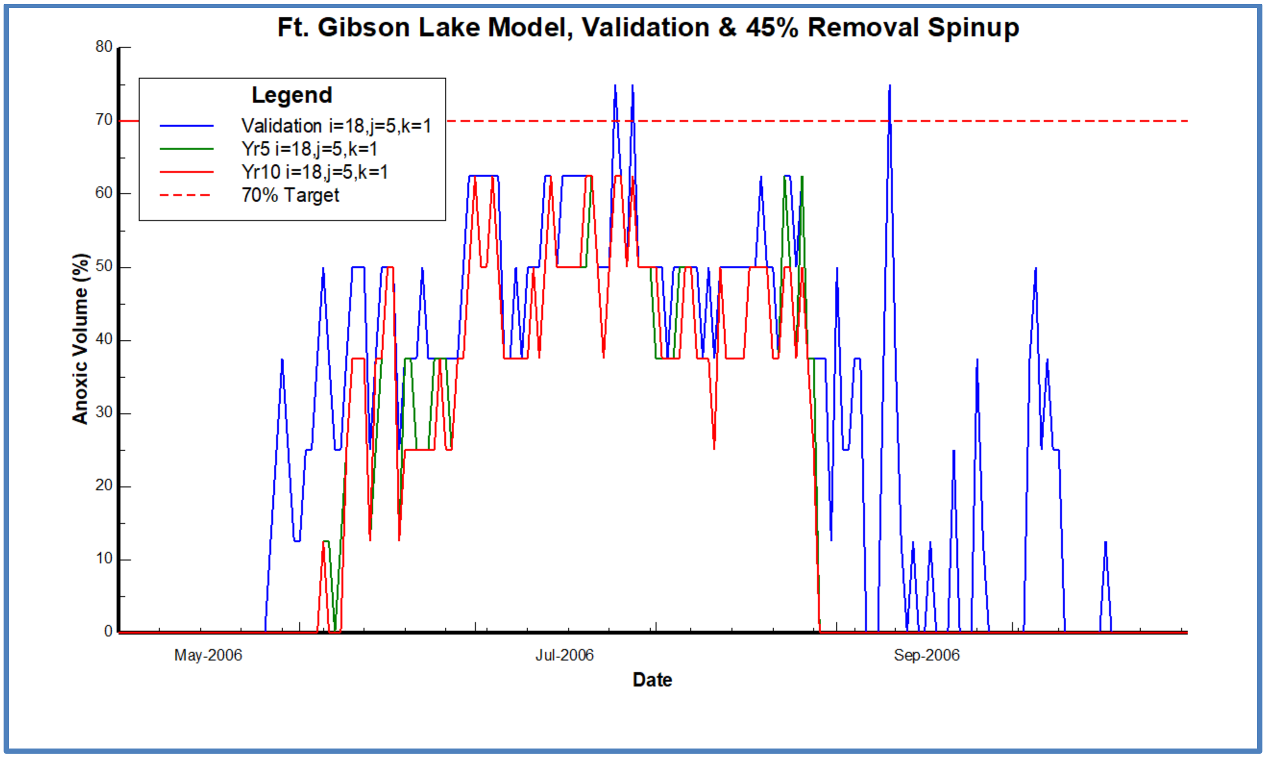

Figure 4-22 Time Series of Anoxic Water Column for Selected Spin-up Years of the 45% Removal Scenario. Model validation results are shown as blue line. Percentage of anoxic water column is based on extraction of grid cell model results for COE Station 1GIBOKN0003 near the dam. DO cutoff target is 2 mg/L.

Sediment Oxygen Demand (SOD). The anoxic volume of the lacustrine zone of the lake gradually decreases because the sediment oxygen demand (SOD) is reduced with each spin-up year of the 45% removal scenario. As shown in

Figure 4-23, SOD gradually declines from the existing validation condition (6.2 g O_2/m^2-day) to 4.6 g O_2/m^2-day after 2 years and 4.1 O_2/m^2-day after 10 years of spin-up for the 45% removal scenario. The decline in SOD reflects the response of the coupled water column and sediment bed of the lake to the load reduction scenario and new equilibrium conditions for algal production (see

Figure 4-23, Figure 4-12, and Figure 4-13) and particulate organic matter deposition to the sediment bed.

Nonstratified Period, Surface Layer (Epilimnion). The revised OWRB water quality criteria for the surface layer require that DO levels be 5 mg/L or more during fall-winter non-stratified conditions from October 16 through March 31. As presented in Table 4-20 and shown in Figure 4-24, model results, extracted for the non-stratified winter period for surface layer dissolved oxygen, are seen to be in compliance with the water quality criteria for surface DO. The 10th percentile values of DO are all greater than the non-stratified season criteria of 5 mg/L. In the lower segment of the lake (OK121600010050_00), the number of simulation records for the model statistics (N=1,680) are based on 168 records per site for 10 sites.

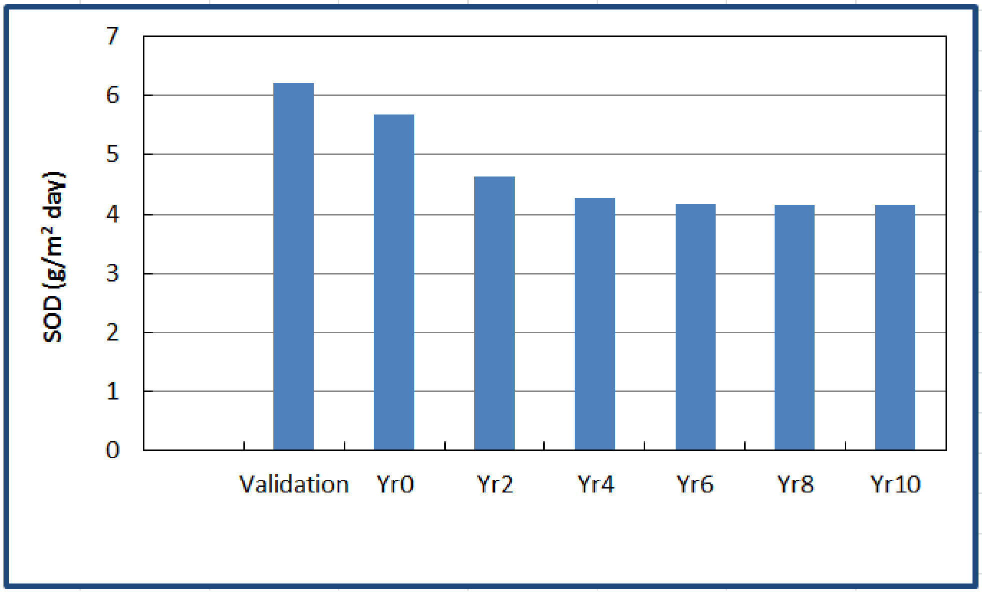

Figure 4-23 Sediment Oxygen Demand (g O_2/m^2-day). Spin-Up Model Results for 45% Removal, Summer Seasonal Average from June 16 to October 15 over WQ Zone 1 of Lower WBID of Fort Gibson Lake, OK121600010050_00.

Table 4-20 Summary Statistics for Dissolved Oxygen: Surface Observations (2005-2006), Model Validation and 10 Years Spin-Up of the 45% Removal Scenario. Winter Season (October 16-March 31) for Fort Gibson Lake (OK121600010050_00).

DO (MG/L), LOWER OK121600010050_00	SURFACE N_OBS	WINTER MEAN	MIN	10Pct	25Pct	50Pct	75Pct	90Pct	MAX
OBS DATA	3	10.99	10.84	10.85	10.87	10.90	11.07	11.16	11.23
VALIDATION 2006	1,680	10.40	7.07	8.80	9.71	10.77	11.28	11.48	11.96
YR0	1,680	10.39	7.23	8.99	9.84	10.73	11.06	11.34	11.89
YR2	1,680	10.52	7.56	9.16	9.99	10.85	11.17	11.43	11.98
YR4	1,680	10.55	7.66	9.20	10.01	10.89	11.19	11.46	12.00
YR6	1,680	10.56	7.69	9.21	10.02	10.90	11.20	11.46	12.00
YR8	1,680	10.56	7.69	9.22	10.02	10.90	11.20	11.46	12.00
YR10	1,680	10.56	7.68	9.22	10.03	10.90	11.21	11.46	12.00

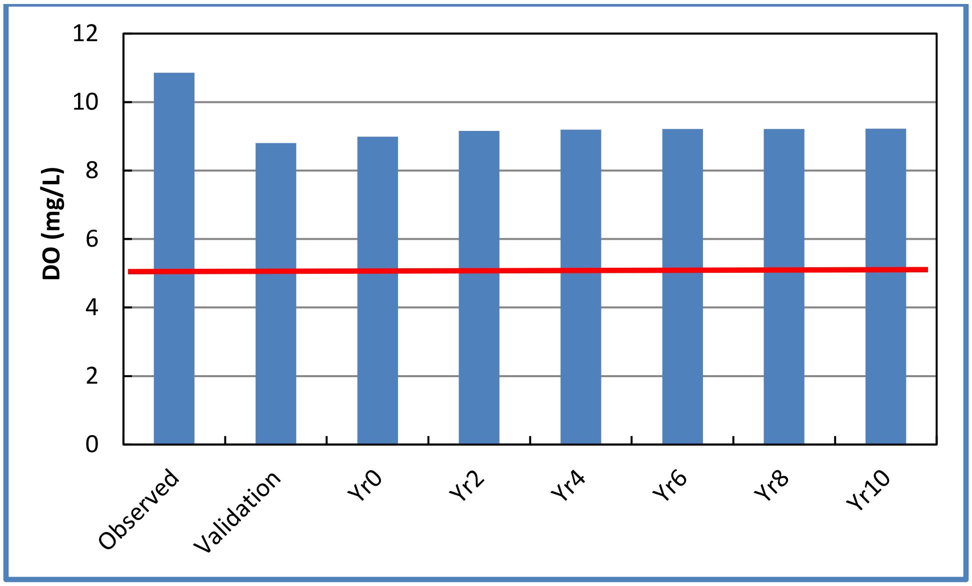

Figure 4-24 Dissolved Oxygen, Surface: 10th percentile Observations (2005-2006), Model Validation and 10 Years Spin-Up of the 45% Removal Scenario. Winter Season (October 16-March 31) for Fort Gibson Lake (OK121600010050_00).

As demonstrated with the analysis of model results for the spin-up years, the 45% reduction of nutrients and sediment loads determined for the TMDL is expected to result in compliance with Oklahoma water quality criteria for surface layer dissolved oxygen under both stratified and non-stratified conditions. The 45% reduction scenario also results in improvement of the anoxic conditions at the deep-water sites near the dam with the peak anoxic percentage of the water column shown to be less than the 70% target.

4.6 Pollutant Loads for 45% Removal Scenario

Pollutant loads from the watershed model and direct discharges into Fort Gibson Lake were systematically reduced until water quality targets for the lake were shown to be in compliance. The water quality targets for the load reduction analysis are the conservative assumptions adopted for the more stringent water quality standards for turbidity, TSI and dissolved oxygen. A water quality target for nutrients is not explicitly specified for the TMDL analysis because targets are only designated for the water quality constituents are directly linked to impairments.

The 45% load reduction determined for the load allocation analysis was assigned a uniform reduction of 45% for (a) nonpoint loading from Lake Hudson outflow; (b) nonpoint loading from HSPF watershed inflows to the lake; and (c) each of the 6 NPDES wastewater dischargers to the lake model. The NPDES loads for TN, TP, TOC and TSS are defined for the 6 wastewater dischargers [listed in Table 4-1] that discharge directly into the EFDC model domain of the Neosho River and Lake Ft. Gibson. The 45% load reductions for TN, TP, TOC and TSS are determined from existing conditions loads (ca. 2005-2006) as follows:

- The LA reduction for upstream inflow from Lake Hudson nonpoint loading is computed from the existing Lake Hudson inflow nonpoint loading x (1-45% Reduction).
- The LA reduction for watershed nonpoint loading is computed from the existing watershed nonpoint loading x (1-45% Reduction).
- The WLA reduction for NPDES wastewater loading is computed from the existing NPDES wastewater loading directly to the lake x (1-45% Reduction).
- There is no LA assigned for the sediment flux of nutrients since this is an internal response to external reductions for LA for Lake Hudson inflow to the lake, LA for watershed inflow to the lake and WLA for wastewater loads directly to the lake. The decreased load shown for sediment flux loading is computed internally in the EFDC lake model as the modeled response of the sediment bed for nutrient flux to the 45% reduction in external point (WLA) and nonpoint (LA) source loading.
- There is no LA reduction for atmospheric deposition of nutrients since this is considered to be an uncontrollable source.

Table 4-21 presents a summary of the January 2006-December 2006 loads for the 45% removal scenario for HSPF watershed loads, and comparison, of the external sources and internal benthic flux loading rates for the 45% removal scenario. Table 4-22 presents the percentage contributions of watershed, atmospheric deposition and benthic flux loading to the total nutrient load for the 45% removal scenario.

As shown in Table 4-21 and Table 4-22, the TP contribution percentage from the internal sediment flux (22.7%) is much higher than the TN contribution percentage from the internal sediment flux (1.5%). In addition, the TP contribution percentage from the internal sediment flux (22.7%) is slightly lower than that from the NPDES point sources (26.0%). The nutrient contributions from atmospheric deposition are minor compared with the other sources. Comparison of the relative contributions of phosphorus from each source between the existing validation condition and the 45% removal scenario are essentially the same. Comparisons of nitrogen loading, however, show that internal loading from the sediment bed decreases while the contribution from the watershed and atmospheric deposition increase somewhat. As shown in Figure 4-14 for WQ Zone 1 of the lower WBID segment of the lake, internal loading of phosphorus for summer stratified conditions gradually decreases over the spin-up years. Using benthic flux results for all WQ zones of the model, aggregation of model results for benthic phosphate flux over the entire year and the bottom area of the whole lake, the phosphorus contribution from internal sediment flux is reduced from 324.8 kg/day for the existing validation conditions (see Table 4-12) to 183.4 kg/day at Year 10.

Table 4-21 Annual Loading of Nutrients and Sediment from Lake Hudson, Watershed, Atmospheric Deposition, Internal Sediment Flux, and NPDES Wastewater for 45% Removal Scenario Delivered to Fort Gibson Lake.

Model Validation	Annual	Annual	Annual	Annual	Annual	Annual
Source	Lake Hudson	HSPF	AtmDep	SedFlux	NPDES	Total
45% Reduction at Year 10	kg/day	kg/day	kg/day	kg/day	kg/day	kg/day
Total Nitrogen (TN)	2,756.7	915.1	102.3	61.8	383.0	4,219.0
Total Phosphorus (TP)	311.2	103.1	0.7	183.4	210.4	808.7
Total Organic Carbon (TOC)	5,066.5	13,086.9	0.0	0.0	878.6	19,032.0
Total Suspended Solids (TSS)	15,156.2	81,001.6	0.0	0.0	359.0	96,516.8

Table 4-22 Percentage Contribution of Annual Loading of Nutrients and Sediment from Lake Hudson, Watershed, Atmospheric Deposition, Internal Sediment Flux, and NPDES Wastewater for 45% Removal Scenario.

Model Validation	Annual	Annual	Annual	Annual	Annual	Annual
Source	Lake Hudson	HSPF	AtmDep	SedFlux	NPDES	Total
45% Reduction at Year 10	%	%	%	%	%	%
Total Nitrogen (TN)	65.3%	21.7%	2.4%	1.5%	9.1%	100.0%
Total Phosphorus (TP)	38.5%	12.7%	0.1%	22.7%	26.0%	100.0%
Total Organic Carbon (TOC)	26.6%	68.8%	0.0%	0.0%	4.6%	100.0%
Total Suspended Solids (TSS)	15.7%	83.9%	0.0%	0.0%	0.4%	100.0%

4.7 Summary

The EFDC lake model incorporates watershed loading and internal coupling of organic matter deposition to the sediment bed with decomposition processes in the bed that, in turn, produce benthic fluxes of nutrients and sediment oxygen demand (SOD) across the sediment-water interface. Fort Gibson Lake, like many reservoirs, is characterized by seasonal thermal stratification and hypolimnetic anoxia. Summer anoxic conditions, in turn, are associated with internal nutrient loading from the benthic release of phosphate and ammonia into the water column that is triggered, in part, by low oxygen conditions. The mass balance-based model, validated to 2006 data, accounts for the cause-effect interactions of water clarity, nutrient loading, nutrient cycling, algal production, particulate organic matter deposition, decay of organic matter in the sediment bed, and internally generated sediment-water fluxes of nutrients and dissolved oxygen.

The spin-up results for the 45% removal scenario suggest that the TSI and chlorophyll-a will decrease because, over time, the sediment bed reservoir of nitrogen and phosphorus will diminish, benthic release of nutrients to the lake will be reduced, and the pool of nutrients available to support algal production in the epilimnion will be reduced. The model spin-up results for the 45% removal scenario demonstrate a gradual reduction in internal loading of nutrients from the sediment bed, an improvement in water quality conditions over the years, and compliance with the NLW water quality target for the TSI.

The model indicates that water quality conditions are expected to be in compliance with the water quality criteria for turbidity of 25 NTU and TSI of 62 within a reasonable timeframe. It is important to note, however, that the spin-up results for the 45% removal scenario should not be taken as absolute projections of future water quality conditions in the lake with certainty as to some future calendar date. The model results reflect the idealized spin-up conditions of a precisely maintained watershed and wastewater load reduction level and repeated climatic conditions of the hydrologic conditions of 2006. The model, does however, provide a technically credible framework that clearly shows that water quality improvements can be achieved in Fort Gibson Lake within a reasonable time frame to support the desired beneficial uses if watershed and wastewater loading can be controlled and sustained to a level based on an a uniform 45% reduction of the existing loading conditions for nutrients, organic matter and sediment. Attainment of water quality standards will occur, however, only over a period of time and only after full implementation of NPDES point source controls and BMPs considered necessary to achieve an overall 45% removal of sediment, organic matter and nutrients from the watershed.

Although the model demonstrates that internal loading of phosphate is a significant controlling factor for eutrophication in the lake, external loading from the watershed and wastewater dischargers is a direct factor in the deterioration of water quality conditions and ultimately the accumulation over decades in the lake sediment bed of excessive nutrients and organic matter. Reductions in watershed and wastewater loading are, therefore, required to achieve improvements in lake water quality. The model results suggest that compliance with water quality criteria for dissolved oxygen and the TSI can be achieved with an overall 45% removal of sediments and nutrients from watershed loading to the lake within a reasonable time frame. The model results thus support the development of TMDLs for sediment, organic carbon, total nitrogen and total phosphorus to achieve compliance with water quality standards for turbidity, TSI and dissolved oxygen. The calibrated and validated watershed and lake model of Fort Gibson Lake provides DEQ with a scientifically defensible surface water model framework to support determination of TMDLs and development of water quality management plans for Fort Gibson Lake.

5.0 TMDLS AND LOAD ALLOCATIONS

The linked watershed (HSPF) and lake (EFDC) models were used to calculate average annual sediment, TOC, nitrogen and phosphorus loads (as kg/yr), that, if achieved, should meet the water quality targets established for turbidity, chlorophyll-a, and dissolved oxygen. For reporting purposes, the final TMDLs, according to EPA guidelines (Grumbles, 2007), are expressed for Fort Gibson Lake on the basis of daily maximum loads (as kg/day).

5.1 Wasteload Allocation (WLA)

The waste load allocation for the TMDL for Fort Gibson Lake will be assigned to regulated NPDES point source facilities that discharge directly to the Neosho River or Fort Gibson Lake, as described below.

5.1.1 NPDES Municipal and Industrial Wastewater Facilities

Municipal and industrial wastewater discharge facilities included in the lake model are listed in Table 4-2. NPDES facilities listed in the table were selected for input to the lake model if the effluent flow rate was larger than 0.1 MGD. Effluent flow rate and effluent concentration data used to assign input data for these wastewater point sources to the lake model are presented in Appendix H of this report.

5.1.2 No-Discharge WWTPs

A no-discharge WWTP facility does not discharge wastewater effluent to surface waters. For the purposes of this TMDL, it is assumed that no-discharge wastewater facilities do not contribute sediment, organic matter, or nutrient loading to watershed streams and Fort Gibson Lake. It is possible, however, that the wastewater collection system associated with no-discharge facilities could be a source of pollutant loading to streams, or that discharges may occur during large rainfall events that exceed the storage capacity of the wastewater system. These types of unauthorized wastewater discharges are typically reported as sanitary sewer overflows (SSOs) or bypass overflows. As discussed in Section 3, four no-discharge facilities are located within the watershed study area. Pollutant loads from bypass overflows are not considered in the waste load allocation of point sources for the TMDL determination because any mitigation of bypass overflows is considered to be an enforcement action rather than a load allocation as bypass overflows are not allowed.

5.1.3 NPDES Municipal Separate Storm Sewer System (MS4)

Within the domain of the Fort Gibson Lake watershed model, Wagoner County and Tahlequah have been issued Phase II MS4 permits for stormwater discharges and stormwater management. Pollutant loading is contributed by the small portions of the Wagoner County MS4 and the Tahlequah MS4 that are within the watershed model domain. As discussed in Section 3.1.3, the urban stormwater load from Wagoner County and Tahlequah combined account for only a very small contribution (0.14%) to the total area of the watershed model domain. The MS4 permits for Wagoner County and Tahlequah will, therefore, not be included as WLAs determined for this TMDL study. The small

MS4 area for Wagoner County and the even smaller portion of the MS4 area for Tahlequah in the HSPF model domain will be accounted for by the Load Allocation (LA) estimated for the watershed.

5.1.4 NPDES Construction Site Permits

NPDES permit authorizations are required for stormwater discharges from construction activities that disturb more than one acre or less than one acre if the construction activity is part of a larger common plan of development that totals at least one acre. As discussed in Section 3.1.4 of this report, a total of 13 construction site permits have been issued within the Fort Gibson Lake watershed from 2007-2012. Sediment and nutrient loading from construction site permit activities will be accounted for as part of the overall LA determined for the watershed.

5.1.5 NPDES Multi-Sector General Permits (MSGP) for Industrial Sites

NPDES permit authorizations are required for stormwater discharges from industrial activities listed in the OKR05 General Permit (DEQ, 2011). Within the Fort Gibson Lake watershed, 39 MSGP permits have been issued for ready-mixed concrete operations, used motor vehicle parts and scrap yards, asphalt paving mixtures and other categories of industrial activity as identified in Table 3-6. The MSGP permits will be accounted for in this TMDL as part of the overall LA determined for the watershed.

5.1.6 NPDES Confined Animal (CAFOs) and Poultry Feeding Operations (PFOs)

There are no Confined Animal Feeding Operations (CAFO) in the Fort Gibson Lake watershed. There are, however, a number of Poultry Feeding Operations (PFOs) located in the Spring Creek and the Pryor Creek sub-watersheds (see Figure 3-6). The Agricultural Environmental Management Services (AEMS) of the Oklahoma Department of Agriculture, Food and Forestry (ODAFF) estimates that only 20% of the chicken litter generated by producers in the Fort Gibson Lake watershed is land applied within the watershed. The remainder of chicken litter is trucked outside of the watershed for disposal. Sediment and nutrient loading from PFO activities in the agricultural land uses of the watershed will be accounted for as part of the overall LA determined for the watershed.

5.2 Load Allocation (LA)

EPA regulations require that a TMDL include LAs, which identify the portion of the loading capacity for a waterbody attributed to existing and future nonpoint sources and to natural background. Load allocations may range from reasonably accurate estimates to gross allotments (40 CFR §130.2(g)). Where possible, load allocations should be described separately for nonpoint sources and natural background conditions.

5.2.1 Nonpoint Sources

The nonpoint source Load Allocation for the TMDL for Fort Gibson Lake will be based on 45% reduction of the sediment and nutrient loads developed for existing conditions from the (a) inflow from Lake Hudson, and (b) watershed model. The load allocations assigned for the inflow from Lake Hudson and watershed runoff will be proportional to the existing contribution of the Lake Hudson inflow and watershed runoff to total external point and nonpoint source loading estimated for the 2006 model validation conditions (see Section 4.13).

5.2.2 Natural Background Conditions

EPA TMDL guidance on natural background conditions states: "*The TMDL submittal must include a description of the point and nonpoint sources of the pollutant of concern, including the magnitude and location of the sources. Where it is possible to separate natural background from nonpoint sources, a description of the natural background must be provided, including the magnitude and location of the source(s). Such information is necessary for EPA's review of the load and wasteload allocations that are required by regulation.*"

As described in Section 3.2.6, streamflow, nonppoint source runoff, and pollutant loading to Fort Gibson Lake are provided as time series output from the HSPF watershed model for input to the EFDC lake model. Simulated flow and watershed pollutant loading are dependent on land use characteristics, soils, topography and hydrologic inputs for each sub-watershed of the watershed model domain. In contrast to a water quality model framework that does not incorporate linkage from a watershed model to a receiving water model, natural background conditions are not represented as an explicit component of nonpoint source loading to Fort Gibson Lake. All flow and pollutant loading data assigned for input to the EFDC lake model are derived from the HSPF watershed model.

5.3 Seasonal Variability

Federal regulations [40 CFR §130.7(c)(1)] require that TMDLs account for seasonal variability in watershed hydrologic conditions and pollutant loading. Seasonal variation was accounted for in the TMDL determination for Fort Gibson Lake in two ways: (1) water quality standards, and (2) the time period represented by the watershed and lake models. As described in Section 2, Oklahoma's water quality standards for dissolved oxygen (recently revised by OWRB, 2014) for lakes are developed on a seasonal basis to be protective of fish and wildlife propagation for a warm water aquatic community at all life stages, including spawning. Within the surface layer, dissolved oxygen standards state that the 10th percentile of DO levels shall be no less than 6 mg/L from April 1 to June 15 to be protective of early life stages. For the summer months from June 16 through October 15, the 10th percentile of surface DO shall be no less than 5 mg/L. For the fall-winter non-stratified period from October 16-March 31, the 10th percentile DO shall be no less than 5 mg/L. In addition to criteria for the surface layer DO, the hypoxic volume of the lake during seasonal stratification, defined by a DO target of no less than 2 mg/L, is not to be greater than 50% of the lake volume on a volumetric basis or no greater than 70% of the water column at sampling sites.

Seasonality was also accounted for in the TMDL analysis by developing the models based on two years of water quality data collected in 2005-2006 as part of routine monitoring efforts initiated by the USACE in 2003 for Fort Gibson Lake. As discussed in Section 1.3, flow and water quality data collected during 2005-2006 for this TMDL study is considered to be representative of dry hydrologic conditions. The watershed (HSPF) and lake (EFDC) models developed to support this TMDL study are both time variable models with results reported at hourly and daily intervals for the two-year study period from January 2005 through December 2006. The watershed and lake models thus included both hydrologic and limnological conditions over two full annual cycles of the four seasons.

5.4 Margin of Safety (MOS)

Federal regulations [40 CFR §130.7(c)(1)] require that TMDLs include a Margin of Safety (MOS). The MOS is a conservative measure incorporated into the TMDL determination that accounts for uncertainty and the lack of knowledge associated with calculating the allowable pollutant loading to ensure WQS are attained. EPA guidance about the Margin of Safety for development of TMDLs states that: *A margin of safety expressed as unallocated assimilative capacity or conservative analytical assumptions used in establishing the TMDL; e.g., derivation of numeric targets, modeling assumptions, or effectiveness of proposed management actions which ensures attainment and maintenance of water quality standards for the allocated pollutant [40 CFR 130.33(b)(7)].*

EPA guidance allows for use of either explicit or implicit expressions of the MOS, or both, to account for any lack of knowledge concerning the relationship between load and allocations and ambient water quality conditions. When a specific percentage of the TMDL is set aside to account for lack of knowledge, then the MOS is considered explicit and the MOS quantifies a loading rate allocation separate from other Load Allocations and Wasteload Allocations. An implicit MOS, however, is not specifically quantified as a loading rate but it does incorporate conservative assumptions or factors used for development of the TMDL. If the MOS is implicit, the conservative assumptions or factors adopted for the TMDL determination that account for the MOS must be described.

The TMDL determined for Fort Gibson Lake accounts for an implicit Margin of Safety (MOS) based on a conservative assumption to adopt more stringent numeric water quality targets for turbidity, TSI, dissolved oxygen, and the anoxic portion of the water column. Using an implicit MOS for turbidity the water quality target is decreased by a factor of 10% from 25 NTU to a reduced target of 22.5 NTU. The implicit MOS for Carlson's TSI is decreased by a factor of 10% from a TSI target of 62 to a reduced TSI target of 55.8 which is more stringent than the NLW TSI criteria of 62. As discussed in Section 2.3, chlorophyll-a observations from 1998-2007 for the upper and lower WBID segments of Fort Gibson Lake were used for the designation of both WBIDs of Fort Gibson Lake as NLW based on the TSI criteria of 62 for aesthetic uses of the lake. Based on Carlson's TSI relationship, a TSI value of 62 is equivalent to a concentration of 24.5 µg/L for chlorophyll-a. With an implicit MOS adopted for 10% reduction of the TSI target from 62 to 55.8, the equivalent target chlorophyll-a level is reduced by 47% from 24.5 µg/L to 13 µg/L. Under the revised criteria for the anoxic portion of the water column, OWRB (2014) determined that no more than 70% of the water column for a sampling site shall be less than the cutoff DO concentration of 2 mg/L. Using an implicit MOS for the anoxic water column criteria, the water quality target is decreased by a factor of 10% from 70% of the water column to a more stringent target of no more than 63% of the water column for a sampling site shall be less than the cutoff DO concentration of 2 mg/L.

Adoption of an implicit MOS for more stringent water quality targets for turbidity, TSI for NLW, and the anoxic percentage of the water column will ensure an adequate implicit Margin of Safety (MOS) for the determination of wasteload (WLA) and load allocations (LA) for the Fort Gibson Lake TMDL.

5.5 Future Growth

Future growth in the watershed may include changes in land use from rural and agricultural uses to accommodate new residential areas and increases in municipal wastewater discharges to accommodate population growth. As pollutant loading changes due to future growth were not explicitly considered in developing the TMDLs, more efficient removal strategies may need to be adopted for NPDES permit limits to reduce point source loading from urban stormwater and municipal and industrial wastewater discharges to maintain compliance with the Waste Load Allocations. Similarly, more efficient BMPs may need to be implemented to maintain compliance with the Load Allocations determined for the Fort Gibson Lake TMDL.

5.6 TMDL Calculations

A TMDL is expressed as the sum of all WLAs (point source loads), LAs (nonpoint source loads), and the MOS. This definition of the TMDL can be expressed by the following equation:

$$TMDL = \Sigma\ WLA + \Sigma\ LA + MOS$$

Load reduction scenario simulations were run using the linked watershed (HSPF) and lake (EFDC) models to calculate annual average suspended solids, total organic carbon, phosphorus and nitrogen loads (in kg/yr) that, if achieved, should improve dissolved oxygen concentrations and decrease turbidity and chlorophyll-*a* concentrations to meet the water quality targets for Fort Gibson Lake. Given that mass transport, assimilation, and dynamics of suspended solids, total organic carbon, and nutrients vary both temporally and spatially, pollutant loading to Fort Gibson Lake from a practical perspective must be managed on a long-term basis with loads expressed typically as pounds or kilograms per year. However, a recent court decision (*Friends of the Earth, Inc. v. EPA, et al.,* often referred to as the Anacostia Decision) states that TMDLs must include a daily load expression (Grumbles, 2006). It is important to recognize that the dissolved oxygen, turbidity and chlorophyll-*a* response to sediment and nutrient loading in Fort Gibson Lake is affected by many factors such as: internal lake nutrient loading, hypolimnetic oxygen depletion, water residence time, wind action, resuspension and the interaction between light penetration, nutrients, suspended solids and algal response. As such, it is important to note that expressing this TMDL on a daily basis does not imply that a daily response to a daily load from the watershed is practical from an implementation perspective.

Three documents available from EPA provide the statistical basis for determination of a daily loading rate from an annual loading rate. "*Options for Expressing Daily Loads in TMDLs"* was published by EPA (2007) in response to the Anacostia Decision discussed above. The statistical basis for the calculation of a daily loading rate from an annual load was previously documented by EPA (1991b) in *"Technical Support Document for Water Quality-Based Toxics Control"* and by EPA (1984) in "*Technical Guidance Manual for Performing Wasteload Allocations, Book VII: Permit Averaging Periods*". These documents provide the statistical methods for identifying a maximum daily limit based on a long-term average load and temporal variability in the time series for the load.

The methodology for the Maximum Daily Load (MDL) is based on calculations of the (a) long-term average load (LTA) of reduced pollutant loading data calculated with data derived from the upstream boundary inflow from Lake Hudson, NPDES wastewater dischargers and the watershed (HSPF) model; and (b) an estimation of the statistical variability of the time series for loading data based on calculation of the mean (μ), standard deviation (σ), variance (σ^2) and the coefficient of variation (CV). The CV, a measure of temporal variability of the loading data, is computed as the ratio of the standard deviation (σ) to the mean (μ). Based on the long-term average annual reduced loading rate (LTA) required to attain compliance with water quality standards, the MDL is computed to represent the allowable upper limit of the loading data that is consistent with the LTA determined by the TMDL study. The allowable upper limit takes into account temporal variability of the loading data, the desired confidence interval of the upper bound for the MDL determination (e.g., 95%) and the equations used to represent the statistical distribution of the pollutant loading data. The lognormal distribution is used to represent loading from watershed runoff from the HSPF model and NPDES wastewater sources. The delta lognormal distribution is used to represent loading from the inflow from Lake Hudson to the Neosho River and upper Fort Gibson Lake.

<u>Lognormal Distribution</u>

The equations used for calculating the MDL from the LTA reduced load are based on analyses demonstrating that streamflow, water quality, wastewater effluent and watershed loading data are typically lognormal distributed. It is well documented in numerous studies that a two-parameter lognormal distribution defined by the mean and variance of the log transformed data set provides a very useful approximation to the probabilistic distribution of streamflow (Nash, 1994; Limbrunner et al., 2000; Vogel et al., 2005). In addition, Van Buren et al., (1997) and Di Toro (1984) determined that water quality analyses based on an assumption of the lognormal probability distribution for effluent, streamflow and water quality concentration are quite realistic for wastewater facilities and many streams and rivers, including waterbodies investigated in the United States.

Although it is well documented in the literature, data are presented to show that the assumption of a lognormal distribution for watershed runoff from the HSPF model and NPDES wastewater loading data holds true for the TMDL analysis for Fort Gibson Lake. Total Phosphorus (TP) loading data derived from watershed runoff, the inflow from Lake Hudson, and NPDES wastewater sources are used as an example data set to demonstrate that (a) natural log transformed TP data follows a normal distribution; and (b) the lognormal distributions for watershed runoff from the HSPF model and wastewater load data are appropriate assumptions for TMDL determinations for Fort Gibson Lake.

Histograms generated from the log transformed TP load data for watershed runoff (Figure 5-1) and wastewater sources (Figure 5-3) show an approximation to a bell shaped curve normal distribution of the log transformed data sets. Probability plots for the log transformed time series of watershed runoff and wastewater TP data are presented as the natural log of the TP load plotted against the Z-score statistic computed from the percentile ranking of the TP load data. The log transformed TP loading data for watershed runoff (r^2=0.996) (Figure 5-2) and wastewater sources (r^2=0.95) (Figure 5-4) demonstrate approximate linear relationships with the Z-score statistic which confirms the validity of the assumption of a lognormal distribution. As flow is common to all loads derived from wastewater and watershed runoff, total suspended sediment (TSS), Total Nitrogen (TN) and Total Organic Carbon (TOC) loads also display similar lognormal distributions.

Delta Lognormal Distribution

As described above, pollutant loading from watershed runoff and wastewater dischargers can be represented as a lognormal distribution. Analysis of log transformed loading data from the outflow from Lake Hudson as the upstream boundary inflow to upper Fort Gibson Lake as a lognormal distribution, however, exhibits considerable skewness at the low end of the distributions. Because of the skewness of the loading data, the lognormal distribution is not an appropriate statistical distribution for the 2006 data set used to specify the Lake Hudson inflow to the Fort Gibson Lake EFDC model.

EPA (1991b) documents three statistical distributions in Appendix E for calculating TMDLs: (1) normal; (2) lognormal; and (3) delta lognormal distribution. The pronounced skewness of the pollutant loads at the low end of the loading data from the Lake Hudson inflow suggests that, with censoring of the load data for a minimum value that accounts for the skewness, the delta lognormal distribution can be an appropriate representation of pollutant loads for the inflow from Lake Hudson to the lake during the drought conditions of 2006. After censoring of the TP load data from the Lake Hudson inflow, the histogram (Figure 5-5) and probability plot (Figure 5-6) of the log transformed TP loading data show good approximations to the bell shaped curve normal distribution and a linear relationship (r^2=0.977) with the z-score. As flow is common to all loads derived from water quality data and the inflow from Lake Hudson, pollutant loads of TSS, TP, TN and TOC also display similar mixes of censored and non-censored load data that can be represented by the delta lognormal distribution.

The delta lognormal distribution is a more general form of the lognormal distribution that represents the data set as a mix of lognormal transformed data and zeros (or censored data). Observations greater than the detection (lower) limit for censored data are described by the lognormal distribution and the distribution of records lower than the detection limit are represented with a discrete probability of recording a measurement at, or below, the detection limit. The delta lognormal distribution was adopted by EPA as a methodology for development of effluent guidelines for the Organic Chemicals, Plastics and Synthetic Fibers industry (EPA, 1987) and other industry groups (e.g., Iron and Steel; EPA, 2002a). The delta lognormal methodology, briefly described in Appendix E of EPA (1991), is discussed in much more detail by Kahn and Rubin (1989) and in Appendix I of this TMDL report for Fort Gibson Lake.

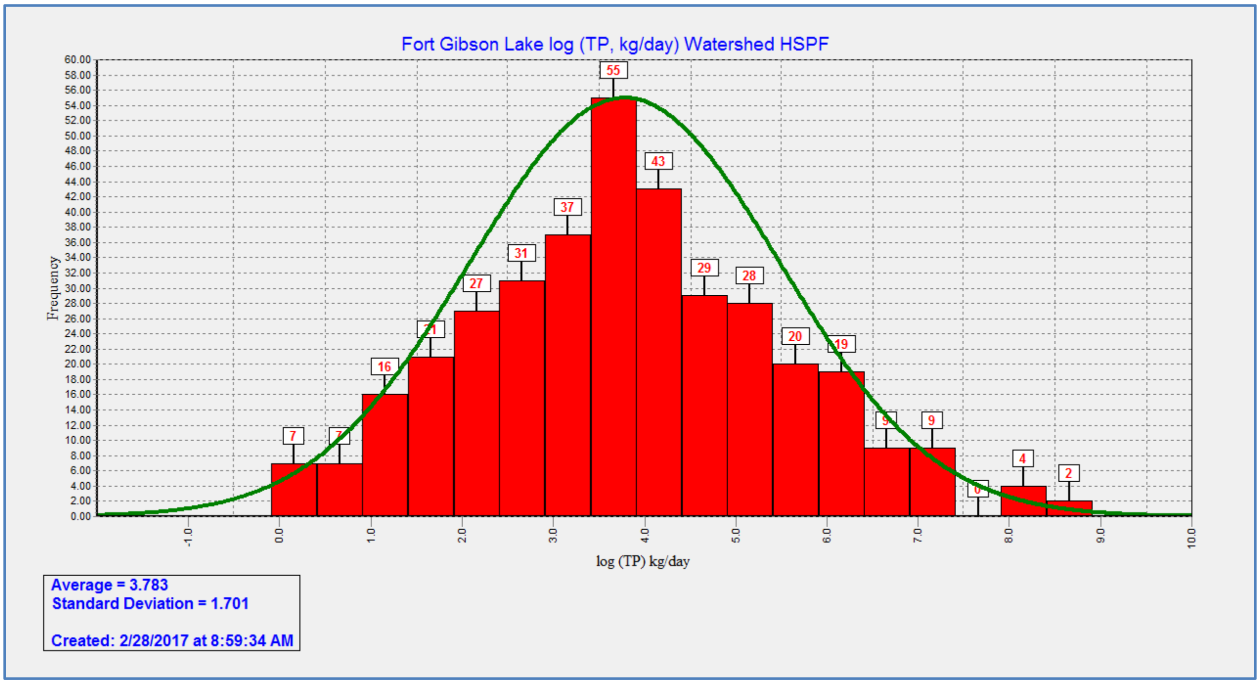

Figure 5-1 Density Distribution of the Log Transformed Total Phosphorus Existing Watershed Runoff Load from the HSPF model for 2006 to Fort Gibson Lake

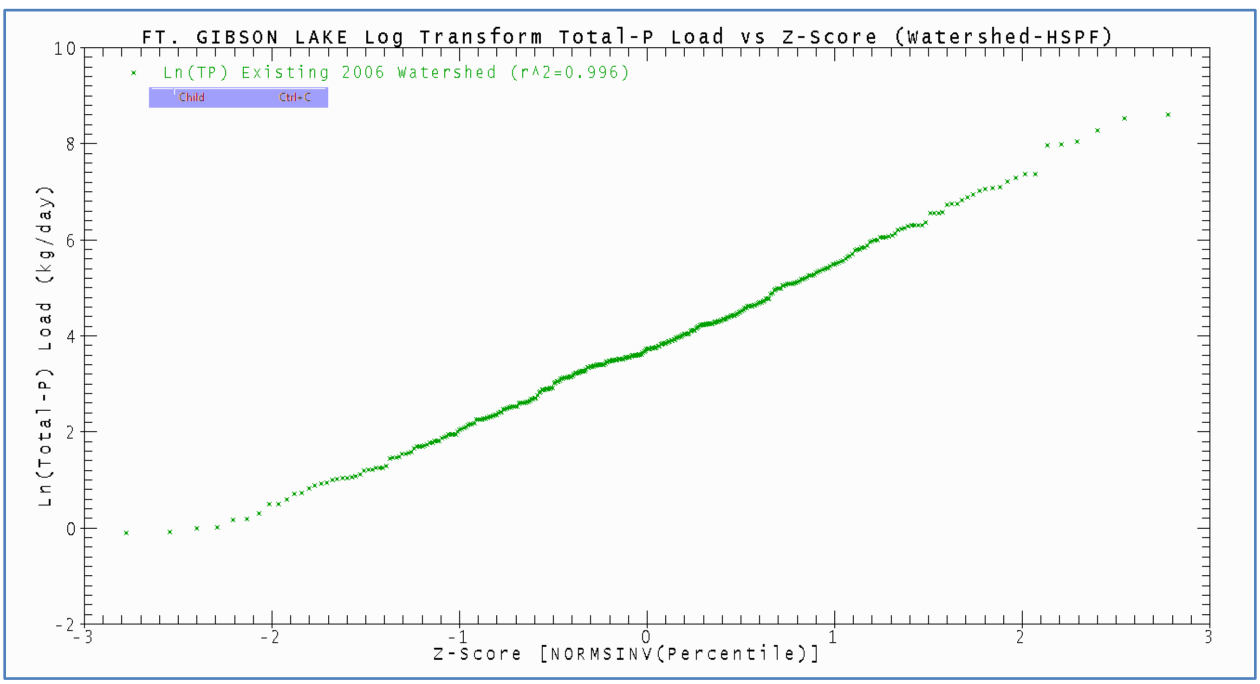

Figure 5-2 Probability Plot of Log Transformed Total Phosphorus Existing Watershed Runoff Load from the HSPF model for 2006 to Fort Gibson Lake (r^2=0.996)

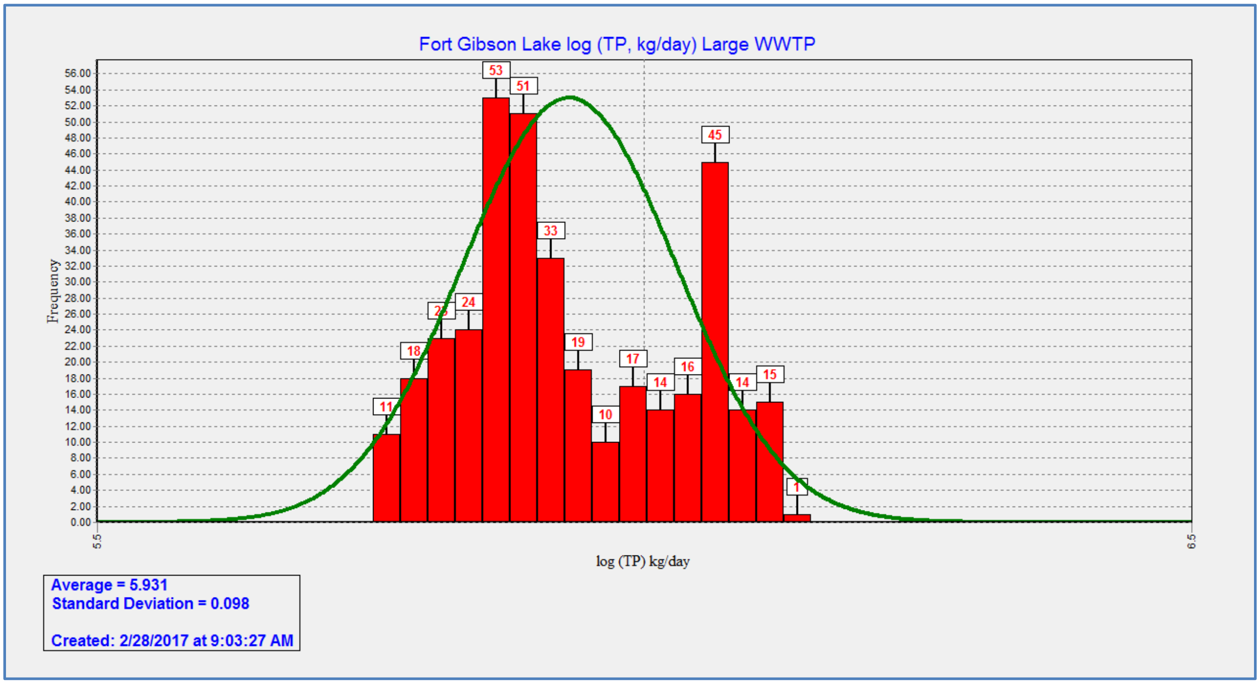

Figure 5-3 Density Distribution of the Log Transformed Total Phosphorus Existing Large Wastewater Load for 2006 to Fort Gibson Lake

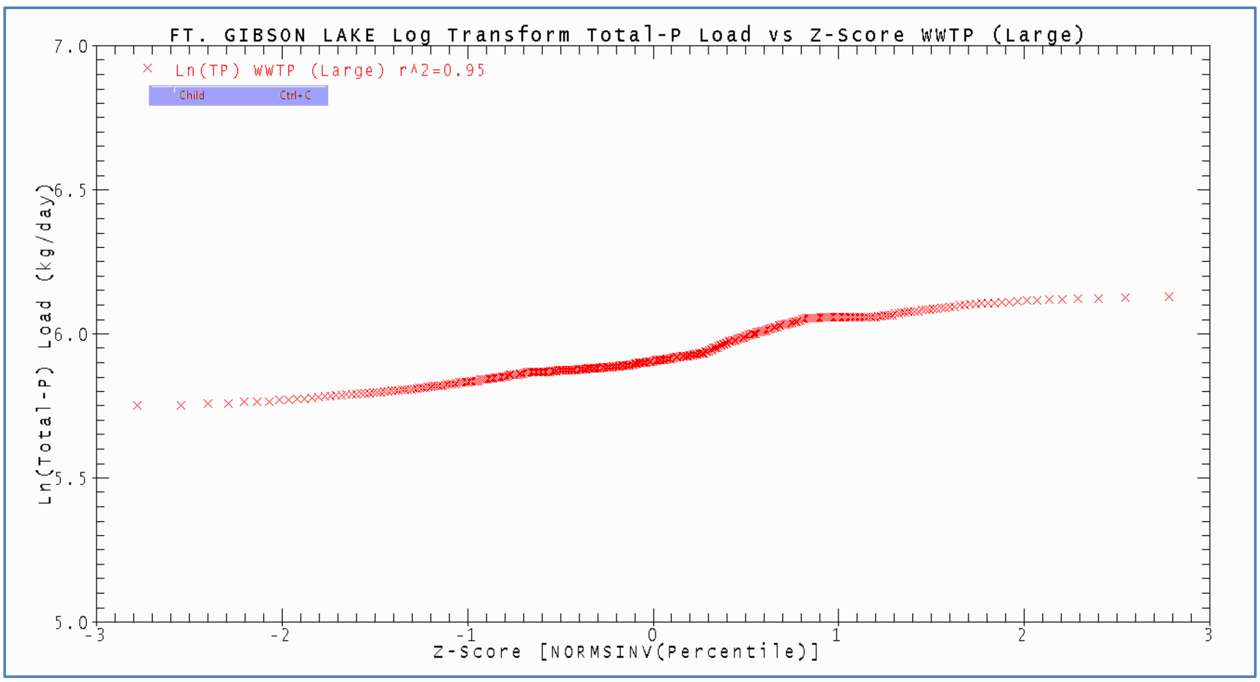

Figure 5-4 Probability Plot of Log Transformed Total Phosphorus Existing Large Wastewater Load for 2006 to Fort Gibson Lake (r^2=0.95)

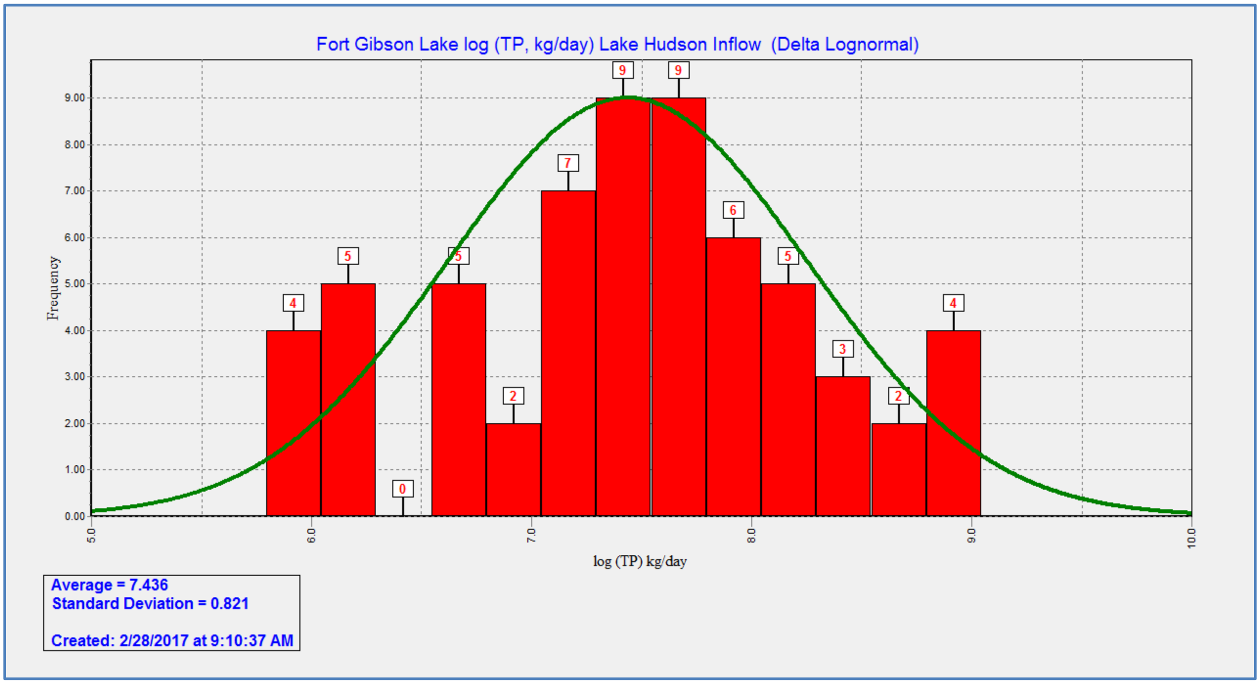

Figure 5-5 Histogram of upstream boundary inflow from Lake Hudson for non-censored daily average log transformed TP load for 2006 drought year.

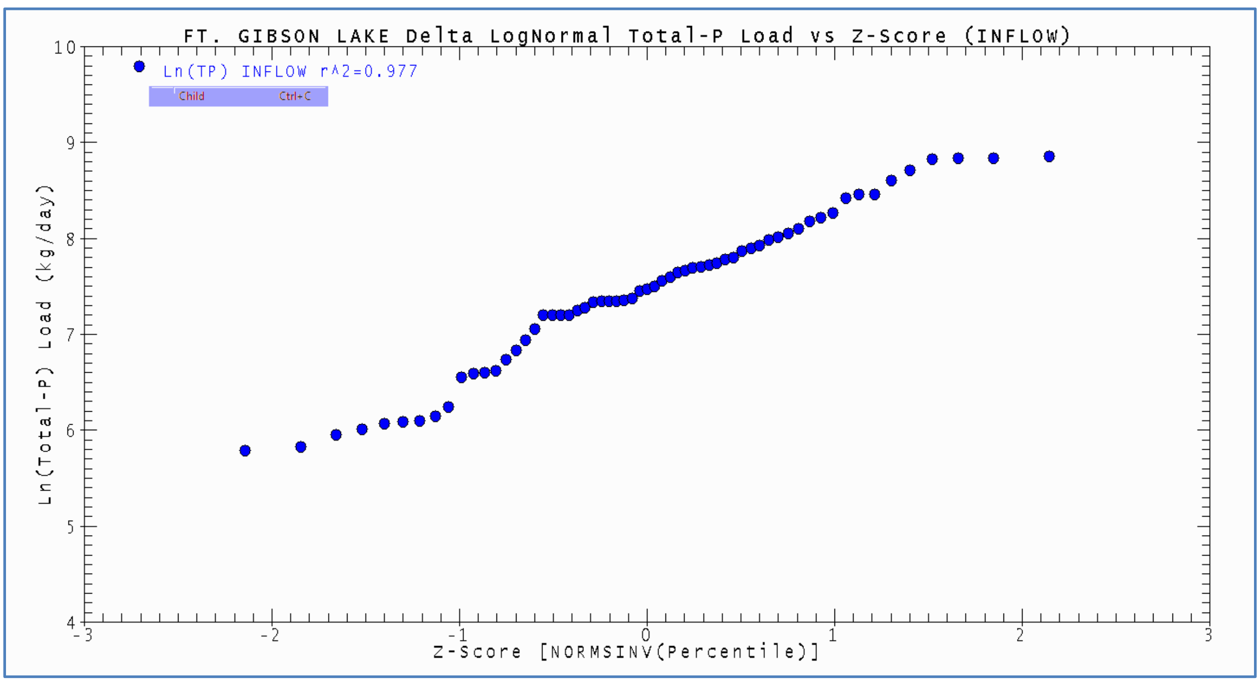

Figure 5-6 Probability plot of upstream boundary inflow from Lake Hudson for non-censored daily average log transformed TP load for 2006 drought year (r^2=0.977)

Time series derived from the daily loads contributed by the (a) inflow from Lake Hudson, (b) watershed runoff, and (c) NPDES wastewater facilities were used to compute the mean, standard deviation and the coefficient of variation parameters of the load distributions for TSS, TN, TP and TOC. Variability of the loading data was determined using the CV's computed from the daily time series (N=365) of the 2006 loads accounted for by the inflow from Lake Hudson, watershed runoff, and NPDES wastewater inputs. With load distribution parameters calculated separately for the Lake Hudson inflow, watershed runoff, and wastewater, loads from each group were summed to compute long-term averages of the reduced total mass loading over a 365-day period from January 1 to December 31, 2006. For the MDL calculated from the lognormal distribution for watershed runoff and wastewater loads, a 95% probability level of occurrence was used and the corresponding one-tailed Z-score statistic was assigned a value of Z=1.645. For the MDL calculated from the delta lognormal distribution for the inflow from Lake Hudson, the 95% probability z-score statistic was computed using the equations and parameters of the delta lognormal distribution as described in Appendix I of this TMDL report.

The WLA and LA for TN, TP, TOC and TSS, determined from the lake model response to external load reductions, are based on 45% reduction of the existing 2006 inflow from Lake Hudson, NPDES wastewater dischargers, and watershed runoff loads. Load reductions are needed because the criteria for the NLW TSI in the upper and lower WBID segments of the lake are not in compliance under the existing loading conditions. Critical conditions for dissolved oxygen at the sampling site near the dam are also not satisfied under the existing loading conditions.

The equations and parameter values used for calculation of the MDL's based on the lognormal distribution and the delta lognormal distribution are presented in Appendix I of this TMDL document. Details of the load distribution parameters used to compute the MDL's for the inflow from Lake Hudson, watershed runoff, and NPDES wastewater sources are also presented in Appendix I.

Summary tables of the existing 2006 loads, the percentage contribution of the existing loads, and the load allocation and wasteload allocations for the inflow from Lake Hudson, watershed runoff, and wastewater dischargers are presented in this section for TP, TN, TOC, and TSS. The summary tables present the load-based percentages of the existing 2006 loads for the inflow from Lake Hudson, watershed runoff, and NPDES wastewater discharges derived from the total existing load contributed by each of these external sources. See Table 5-1, Table 5-2, Table 5-3, and Table 5-4 for the LA and WLA calculations.

WLA and LA for these sources are computed from the derived TMDL and the percentage share of the existing load contributed by each source term except TSS. Due to negligible contribution of TSS from NPDES wastewater dischargers, TSS reduction from these sources benefit little to improve turbidity in the lake. Therefore, TSS WLAs are set at the permit limits. As described above in Section 5.4, the implicit Margin of Safety (MOS) is based on conservative assumptions for derivation of more stringent numeric water quality targets for turbidity, TSI and dissolved oxygen. The WLA for each of the six NPDES wastewater facilities is computed from the TMDL and the percentage split of the total point and nonpoint source load accounted for by each NPDES discharger. The TMDL is split between the LA for the inflow from Lake Hudson, watershed runoff and the WLA for the six NPDES wastewater facilities.

Table 5-1 Maximum Daily Load (MDL) for Total Phosphorus to Meet Water Quality Targets for Turbidity, TSI and Dissolved Oxygen in Fort Gibson Lake

Fort Gibson Lake Total-Phosphorus			% R= 45% TMDL= 2,087.6 kg/day			
Source	Existing E(X) Mean	Existing % Share	LA kg/day	WLA kg/day	LA+WLA kg/day	Margin of Safety
Lake Hudson Inflow	565.8	49.8%	1,039.95	0.0	1,039.9	Implicit
Watershed HSPF	187.4	16.5%	344.56	0.0	344.6	Implicit
Small WWTP	4.0	0.4%	0.00	7.4	7.4	Implicit
Large WWTP	378.5	33.3%	0.00	695.7	695.7	Implicit
Total	**1,135.7**	**100.0%**	**1,384.50**	**703.1**	**2,087.6**	Implicit
NPDES Wastewater						
OK0043907 (S)	3.5	0.31%	0	6.5	6.5	Implicit
OKG380001 (S)	0.3	0.03%	0	0.5	0.5	Implicit
OK0033791 (S)	0.2	0.02%	0	0.4	0.4	Implicit
OK34568-006 (L)	364.7	32.11%	0	670.3	670.3	Implicit
OK0000272 (L)	1.8	0.16%	0	3.3	3.3	Implicit
OK0035149 (L)	12.0	1.06%	0	22.1	22.1	Implicit
Lake Hudson Inflow	Delta lognormal distribution					
Watershed HSPF	Lognormal distribution					
Small WWTP	Lognormal distribution					
Large WWTP	Lognormal distribution					

Table 5-2 Maximum Daily Load (MDL) for Total Nitrogen to Meet Water Quality Targets for Turbidity, TSI and Dissolved Oxygen in Fort Gibson Lake

Fort Gibson Lake Total-Nitrogen			% R= TMDL=	45% 16,711.0	kg/day	
Source	Existing E(X) Mean	Existing % Share	LA kg/day	WLA kg/day	LA+WLA kg/day	Margin of Safety
Lake Hudson Inflow	5,012.2	68.0%	11,361.0	0.0	11,361.0	Implicit
Watershed HSPF	1,663.9	22.6%	3,771.5	0.0	3,771.5	Implicit
Small WWTP	29.0	0.4%	0.0	65.6	65.6	Implicit
Large WWTP	667.4	9.1%	0.0	1,512.9	1,512.9	Implicit
Total	**7,372.5**	**100.0%**	**15,132.5**	**1,578.5**	**16,711.0**	Implicit
NPDES Wastewater						
OK0043907 (S)	10.53	0.14%	0	23.9	23.9	Implicit
OKG380001 (S)	10.55	0.14%	0	23.9	23.9	Implicit
OK0033791 (S)	7.87	0.11%	0	17.8	17.8	Implicit
OK34568-006 (L)	570.46	7.74%	0	1,293.0	1,293.0	Implicit
OK0000272 (L)	17.12	0.23%	0	38.8	38.8	Implicit
OK0035149 (L)	80.22	1.09%	0	181.8	181.8	Implicit
Lake Hudson Inflow	Delta lognormal distribution					
Watershed HSPF	Lognormal distribution					
Small WWTP	Lognormal distribution					
Large WWTP	Lognormal distribution					

Table 5-3 Maximum Daily Load (MDL) for Total Organic Carbon to Meet Water Quality Targets for Turbidity, TSI and Dissolved Oxygen in Fort Gibson Lake

Fort Gibson Lake Total Organic Carbon (TOC)			% R= TMDL=	45% 63,109.4	 kg/day	
Source	Existing E(X) Mean	Existing % Share	LA kg/day	WLA kg/day	LA+WLA kg/day	Margin of Safety
Lake Hudson Inflow	9,211.8	26.6%	16,800.3	0.0	16,800.3	Implicit
Watershed HSPF	23,794.4	68.8%	43,395.9	0.0	43,395.9	Implicit
Small WWTP	37.6	0.1%	0.0	68.6	68.6	Implicit
Large WWTP	1,559.8	4.5%	0.0	2,844.7	2,844.7	Implicit
Total	**34,603.6**	**100.0%**	**60,196.2**	**2,913.3**	**63,109.4**	Implicit
NPDES Wastewater						
OK0043907 (S)	30.2	0.09%	0.0	55.1	55.1	Implicit
OKG380001 (S)	4.3	0.01%	0.0	7.8	7.8	Implicit
OK0033791 (S)	3.2	0.01%	0.0	5.8	5.8	Implicit
OK34568-006 (L)	899.3	2.60%	0.0	1,640.1	1,640.1	Implicit
OK0000272 (L)	387.5	1.12%	0.0	706.8	706.8	Implicit
OK0035149 (L)	281.0	0.81%	0.0	512.5	512.5	Implicit
Lake Hudson Inflow	Delta lognormal distribution					
Watershed HSPF	Lognormal distribution					
Small WWTP	Lognormal distribution					
Large WWTP	Lognormal distribution					

Table 5-4 Maximum Daily Load (MDL) for TSS to Meet Water Quality Targets for Turbidity, TSI and Dissolved Oxygen in Fort Gibson Lake

Fort Gibson Lake Total Suspended Solids (TSS)			% R= TMDL=	45% 117,188.5	kg/day	
Source	Existing E(X) Mean	Existing % Share	LA kg/day	WLA kg/day	LA+WLA kg/day	Margin of Safety
Lake Hudson Inflow	27,556.7	15.7%	18,402.3	0.0	18,402.3	Implicit
Watershed HSPF	147,275.7	83.9%	94,242.5	0.0	94,242.5	Implicit
Small WWTP	10.5	0.0%	0.0	264.0	264.0	
Large WWTP	642.2	0.4%	0.0	4,279.7	4,279.7	
Total	**175,485.2**	**100.0%**	**116,752.6**	**4,543.7**	**117,188.5**	Implicit
NPDES Wastewater						
OK0043907 (S)	5.3	0.00%	0	227.1	227.1	
OKG380001 (S)	2.6	0.00%	0	34.1	34.1	
OK0033791 (S)	2.7	0.00%	0	2.8	2.8	
OK34568-006 (L)	438.9	0.25%	0	969.8	969.8	
OK0000272 (L)	103.0	0.06%	0	1,095.4	1,095.4	
OK0035149 (L)	103.4	0.06%	0	2,214.5	2,214.5	
Lake Hudson Inflow	Delta lognormal distribution					
Watershed HSPF	Delta lognormal distribution					
Small WWTP	Permit limit					
Large WWTP	Permit limit					

5.7 Strengths and Weaknesses of Watershed-Lake Modeling Approach

Strengths. A mass balance-based surface water model framework was developed to establish the cause-effect linkage between external pollutant loading from the Neosho River watershed and hydrodynamic and water quality conditions in Fort Gibson Lake. The watershed (HSPF) and lake (EFDC) models are dynamic models that represent time-variable conditions as continuous simulations. HSPF is a public-domain lumped parameter watershed model that represents runoff, streamflow and loading of water quality constituents including sediment, nutrients and organic matter within a watershed network of catchments. EFDC is a public-domain 3-dimensional model that includes hydrodynamics, sediment transport and biogeochemical processes for water quality and eutrophication. EFDC is unique among advanced surface water models because the hydrodynamic model is internally coupled within a single source code to the sediment transport and water quality/eutrophication modules. The HSPF-EFDC model framework for Fort Gibson Lake has been successfully applied for numerous TMDL studies including applications in Oklahoma for Tenkiller Ferry Lake, Lake Thunderbird and Oologah Lake.

EFDC is designed to link external flow and point/nonpoint source loading with hydrodynamics, seasonal stratification, eutrophication and internal coupling of organic matter deposition to the sediment bed with decomposition processes in the bed that, in turn, produce benthic fluxes of nutrients and sediment oxygen demand across the sediment-water interface. The EFDC model of Fort Gibson Lake accounts for the cause-effect interactions of external loading with water clarity, nutrient cycling, algal production, organic matter deposition, decay in the sediment bed, and internally generated benthic fluxes of nutrients and sediment oxygen demand. These are critical capabilities of the EFDC model because Fort Gibson Lake, like many reservoirs in Oklahoma, is characterized by seasonal thermal stratification, hypoxia and internal benthic loading of nutrients that is triggered, in part, by low dissolved oxygen conditions in the hypolimnion.

Model performance statistics for the calibration and validation periods, computed from a comparison of paired observed/simulated data, demonstrated that the watershed and lake model results were either better than, or close to, the target criteria specified for the model framework. Maximum Daily Loads (MDL) computed for the TMDL determinations are based on 95% confidence interval statistics of lognormal and delta lognormal distributions of pollutant loading with 45% removal of existing NPDES point source and nonpoint source watershed loads. As Water Year 2006 was characterized by extreme drought conditions that affected flow in the Lower Neosho River watershed and other areas of Oklahoma (Tortorelli, 2008; Sandbo et al., 2008), the delta lognormal distribution was used to represent inflow and loading from Lake Hudson as well as watershed loading of suspended solids (TSS). The watershed-lake model of HSPF and EFDC thus provides DEQ with a scientifically defensible surface water model framework to support determination of TMDLs and development of water quality management plans for Fort Gibson Lake.

Weaknesses. As a lumped parameter watershed model, HSPF is not based on a physical representation of the landscape (i.e., 3-dimensional grid) based on topography, land uses, soil and upper/lower zones for groundwater. HSPF, instead, represents a watershed as a network of delineated catchments characterized by similar topography, soil type and land uses. Surface and subsurface hydrologic processes within catchments are then described by empirical formulations that are often considered to be overparameterized with numerous coefficients required for calibration and validation of HSPF mass balance-based hydrologic, stream routing and pollutant loading processes (Borah et al., 2019).

Watershed and lake model performance is evaluated to determine the endpoints for model calibration using a “weight of evidence” approach that has been adopted for many surface water modeling studies. The “weight of evidence” approach for evaluation of model vs. observed data includes visual inspection of model-data plots and calculation of model performance statistics. The “weight of evidence” approach recognizes that, as an approximation of a waterbody, perfect agreement between observed data and model results is not expected and is not specified as a performance criterion for success of model calibration. Model performance statistics, although determined in this study to be better than, or close to, target criteria for the watershed and lake models, have been used only as targets, but not as rigid criteria for rejection or acceptance of watershed or lake model results. The “weight of evidence” approach thus acknowledges that no surface water model is perfect, that all models are approximations of physical and biogeochemical processes in a watershed or lake and that there is inherent uncertainty in both input data and observed data used to develop the models.

TMDL guidance from EPA (2002b) includes the requirement that "*TMDLs must take into account critical conditions for stream flow, loading, and water quality parameters as part of the analysis of loading capacity*". Zhang and Padmanabhan (2019) note that consistent methodologies for defining critical conditions are typically not used for TMDL studies and that there is no guarantee that critical, or worst-case, conditions will either (a) occur or (b) be accurately simulated during a hydrologic period selected for development of a continuous time-variable model. Although Water Year 2006 was characterized by extreme drought conditions that affected the Lower Neosho River watershed and other areas of Oklahoma (Tortorelli, 2008; Sandbo et al., 2008), a potential weakness of the approach used for the Fort Gibson Lake watershed-lake model could be that the selection of representative dry, average and wet years in 2005-2008 might not have fully satisfied the very rigorous worst-case combination of pollutant loading and streamflow that cause violations of water quality standards (Zhang and Padmanabhan, 2019).

The EFDC lake model was applied to simulate ten (10) years of sequential "spin-up" runs to evaluate the long-term response of water quality conditions in the lake to a simple uniform 45% removal change in external loading from the watershed. As new sediment bed conditions in Fort Gibson Lake need to equilibrate in response to the 45% removal scenario for external loading, watershed flow and reduced pollutant loading data generated by the HSPF model for 2006 were repeated for each spin-up year. Model results derived from the spin-up runs did not, therefore, attempt to account for any hydrologic variability of projected, or future, conditions within the Neosho River watershed nor did the methodology attempt to represent implementation of either site-specific BMPs or reductions from NPDES point source dischargers to tributaries of the Neosho River watershed. The 45% removal spin-up scenario results, therefore, should not be taken as absolute projections of future water quality conditions and attainment with water quality targets in Fort Gibson Lake by some future calendar date. The lake model results demonstrate expected compliance with water quality targets as a response to idealized spin-up conditions of the precisely maintained watershed flow and simple load reduction scenario derived from repeating hydrologic conditions of 2006.

5.8 TMDL Implementation

DEQ will collaborate with a host of other state agencies and local governments working within the boundaries of state and local regulations to target available funding and technical assistance to support implementation of pollution controls and management measures. Various water quality management programs and funding sources will be utilized so that the pollutant reductions as required by these TMDLs can be achieved and water quality can be restored to maintain designated uses. DEQ's Continuing Planning Process (CPP), required by the CWA §303(e)(3) and 40 CFR 130.5, summarizes Oklahoma's commitments and programs aimed at restoring and protecting water quality throughout the State (DEQ 2006). The CPP can be viewed from DEQ's website at

http://www.deq.state.ok.us/wqdnew/pubs/2006_CPP_final.pdf.

Table 5-5 provides a partial list of the state partner agencies DEQ will collaborate with to address point and nonpoint source reduction goals established by TMDLs.

Table 5-5 Partial List of Oklahoma Water Quality Management Agencies

Agency	Web Link
Oklahoma Conservation Commission	http://www.ok.gov/conservation/Agency_Divisions/Water_Quality_Division
Oklahoma Department of Wildlife Conservation	http://www.wildlifedepartment.com/wildlifemgmt.htm
Oklahoma Department of Agriculture, Food, and Forestry	http://www.ag.ok.gov/aems
Oklahoma Water Resources Board	http://www.owrb.state.ok.us/quality/index.php

5.8.1 Point sources

As authorized by Section 402 of the CWA, the DEQ has delegation of the NPDES Program in Oklahoma, except for certain jurisdictional areas related to agriculture (retained by State Department of Agriculture), and the oil and gas industry (retained by Oklahoma Corporation Commission), for which the EPA has retained permitting authority. The NPDES Program in Oklahoma, in accordance with an agreement between DEQ and EPA relating to administration and enforcement of the delegated NPDES Program, is implemented via the Oklahoma Pollutant Discharge Elimination System (OPDES) Act [Title 252, Chapter 606 (http://www.deq.state.ok.us/rules/611.pdf)].

As shown in Section 3 of this report, NPDES wastewater discharges, and watershed runoff, are the main sources of controllable pollutants to Fort Gibson Lake. In addition, as described in Section 4, the outflow from Lake Hudson to the Neosho River is also a controllable external source of pollutants at the upstream boundary of Fort Gibson Lake. The pollutant contributions from the Phase II MS4 permitted areas for the County of Wagoner and Tahlequah, as described in Section 3.1.3, are very small and will be considered as part of the Load Allocation (LA) for the watershed.

The County of Wagoner and Tahlequah will be required to undertake certain pollutant reduction the measures within the terms of their MS4 permits under the OPDES system. These measures must be designed to achieve progress toward meeting the reduction goals established in the TMDL in order to comply with the LAs established for this TMDL. These stormwater best management practices (BMPs) based requirements are addressed in Appendix E of this report. MS4 permittees will review the adequacy of their Storm Water Management Program (SWMP) against these requirements. The SWMP must be modified in accordance with Appendix E within 24 months after the TMDL is approved by the EPA.

In addition to the specific requirements for a TMDL Compliance Plan outlined in Appendix E, some general strategies are recommended here as examples of what the MS4s in the watershed could do to improve the management of stormwater runoff and reduce its associated pollutant loading:

- Improve control of sanitary sewer overflows (SSOs);
- Implement enhanced oversight and controls to improve performance of on-site wastewater treatment systems (septic tanks); and
- Establish a stakeholder/citizen advisory committee to involve the public in designing and implementing pollutant load reduction strategies.

Although this TMDL does not specify a WLA for construction stormwater activities, permittees are required to meet the conditions of the Stormwater Construction General Permit (OKR10) issued by the DEQ and properly select, install and maintain all BMPs required under the permit, including applicable additional BMPs required in Appendix E, and meet local construction stormwater requirements if they are more restrictive. After EPA approval of this TMDL, specific stormwater construction permit requirements pertaining to this TMDL will be included as site-specific requirements in authorizations issued under permit OKR10 by the DEQ for construction activities located in the Fort Gibson Lake watershed. Appendix E outlines these requirements.

This TMDL does not specify a WLA for industrial stormwater. However, industrial stormwater permittees in the Fort Gibson Lake watershed are required to meet the conditions of the industrial stormwater general permit (the Multi-Sector General Permit [MSGP, OKR05]) and properly select, install and maintain all BMPs required by the permit, including applicable additional BMPs required in Appendix E, for sediment and nutrient control. Existing permittees within the sectors specified in Appendix E located in the Fort Gibson Lake watershed must update their SWP3 to comply with the requirements in this TMDL within 12 months of EPA approval of the TMDL. Future MSGP permits proposed within the Fort Gibson Lake watershed will be evaluated on a case-by-case basis for additional requirements if it is determined that sediment and nutrients are potential pollutants in the stormwater discharge. Appendix E outlines these requirements.

5.8.2 Nonpoint Sources

Nonpoint source pollution in Oklahoma is managed by the Oklahoma Conservation Commission. The Oklahoma Conservation Commission works with state partners such as Oklahoma Department of Agriculture, Food, and Forestry (ODAFF) and federal partners such as the EPA and the National Resources Conservation Service of the USDA, to address water quality problems similar to those seen in the Fort Gibson Lake watershed.

As described in Section 1.2, the majority of the watershed land use is agricultural and rural and consequently, pollution associated with runoff from these areas is nonpoint source in nature. Measures to control and reduce land use-dependent loading should be considered by the counties, local municipalities and, when appropriate, in cooperation with the OCC. The primary mechanisms used for management of nonpoint source pollution are incentive-based programs that support the installation of BMPs and public education and outreach.

5.8.3 Reasonable Assurances

EPA guidance about Reasonable Assurance for development of TMDLs states that: *A discussion of your reasonable assurances, as defined at 40 CFR § 130.2(p), that wasteload allocations and load allocations will be implemented. http://water.epa.gov/lawsregs/lawsguidance/cwa/tmdl/TMDL-ch3.cfm*

Reasonable assurance is required by the EPA guidance for a TMDL to be approvable only when a waterbody is impaired by both point and nonpoint sources and where a point source is given a less stringent wasteload allocation based on an assumption that NPS load reductions will occur. In such a case, "reasonable assurance" that the NPS load reductions will actually occur must be demonstrated. In this report, both point and non-point sources are given the same amount of load reduction except TSS. Since point sources are to be regulated, this ensures that impairments to the waterbodies in this report will not be caused by point sources. Although nonpoint source pollution in Oklahoma is managed by the Oklahoma Conservation Commission (OCC), DEQ will work in conjunction with OCC and other state partners such as Oklahoma Department of Agriculture, Food, and Forestry (ODAFF) and other federal partners such as the EPA and stakeholders within the watershed to design and develop programs to help non-point sources meet the load reduction goals contained in this report. Appendix E of this report of this report includes BMPs that can be used to curb water quality problems seen in the Fort Gibson Lake watershed.

As shown in Table 5-1, NPDES point source wastewater discharges account for 33.7% of all point and nonpoint source Total Phosphorus loading to Fort Gibson Lake for the 1-year period from January through December 2006. One wastewater facility (OK0034568, Oklahoma Ordnance Works Authority [OOWA]) accounts for 32% of the total loading of Total Phosphorus loading to the lake and this one facility accounts for 95% of the Total Phosphorus loading contributed by the six (6) NPDES point source wastewater dischargers. Observed monthly average Discharge Monitoring Report (DMR) records from 2004-2008 were used to assign effluent flow and effluent loading of BOD, TSS, DO, nitrogen, and phosphorus from this facility's discharge to the Neosho River. The facility is located at Pryor in the upper reaches of the Fort Gibson Lake model (see Table 3-1 and Figure 3-1). Estimates of effluent flow, sediment, nutrients, and BOD loads from the OOWA wastewater facility are very accurate as monthly DMR operating records were used to assign effluent data for this flow boundary condition.

The remaining 66% of Total Phosphorus loading to Fort Gibson Lake is accounted for by local watershed drainage represented by the HSPF model (16.5%) and the outflow from Lake Hudson (49.8%). The outflow from Lake Hudson, in turn, is directly influenced by the outflow from the Eucha-Spavinaw watershed (392 square-mile drainage area) and the outflow from the Grand Lake watershed (10,300 square-mile drainage area) (see Figure 4-1).

In this report, uniform 45% nutrient load reduction from point and nonpoint sources is recommended. However, the percent reduction goal to meet Water Quality Standards may be determined by the stakeholders at a later date. WLA will be implemented through Oklahoma NPDES permits that may contain special conditions for additional monitoring, special studies, BMPs, and compliance schedules. Reasonable assurance that nonpoint sources will meet the Load Allocation in the TMDL is dependent upon the availability and implementation of nonpoint source pollutant reduction plans, controls, or BMPs within the watershed. The Oklahoma Conservation Commission (OCC) is responsible for the state's nonpoint source program as defined in Section 319 of the CWA. Oklahoma DEQ will work in conjunction with OCC and other federal, state, and local partners within the respective Eucha-Spavinaw and Grand Lake watersheds to ensure that the load reduction goals for nonpoint sources are attained. All waterbodies are ranked and prioritized as part of the Unified Watershed Assessment and that priority ranking will determine the likelihood of implementation of projects in the Eucha-Spavinaw and Grand Lake watersheds.

As the State of Oklahoma must provide "reasonable assurance" that nonpoint source Load Allocations from local watershed drainage (16.5% of the total load of TP) and from the outflow of Lake Hudson (49.8% of the total load of TP load) will be achieved, Oklahoma DEQ will work closely with OCC to establish the strategic plans that are being considered, or are being implemented, for watershed management control actions in the Eucha-Spavinaw and Grand Lake watersheds. As the Grand Lake watershed covers 10,300 square miles over 4 states and 2 EPA regions, "reasonable assurance" that the Load Allocation for Fort Gibson Lake will be achieved is contingent on the success of non-regulatory, regulatory, and incentive-based watershed management programs and control actions that have been, or will be, implemented within the very large Grand Lake watershed.

Eucha-Spavinaw Watershed. An EPA approved TMDL for phosphorus was developed for Eucha Lake and Spavinaw Lake in September 2009 (USEPA and ODEQ, 2009). Phosphorus reduction goals were established for each of the two lakes. The Eucha-Spavinaw watershed contains two wastewater dischargers located in Arkansas. NPDES permit limits for these point sources were established through a court settlement between the City of Tulsa and poultry producers in the watershed. The remainder of the load reduction for the TMDL was assigned to nonpoint sources within the watershed. The effectiveness of implementation of nonpoint source BMPs are currently being evaluated.

Grand Lake Watershed. A watershed management strategy document for the Grand Lake watershed is currently under development through a cooperative agreement between Oklahoma DEQ, Grand River Dam Authority, and the Grand Lake Watershed Alliance Foundation (GWLAF). The plan is expected to be completed by the Fall of 2019. Implementation of the nonpoint source reduction strategies recommended in the plan will be coordinated by OCC and the Grand Lake Watershed Alliance Foundation, in cooperation with other state and local agencies.

6.0 PUBLIC PARTICIPATION

This report was preliminary reviewed by EPA. After EPA reviewed this draft TMDL report, DEQ was given approval to submit this Report for Public Notice. The public notice was sent to local newspapers, to stakeholders in the Study Area affected by these draft TMDLs, and to stakeholders who requested all copies of TMDL public notices. The public notice was also posted at the DEQ website: https://www.deq.ok.gov/water-quality-division/watershed-planning/tmdl/

The public comment period lasted 45 days from April 7, 2023 to May 22, 2023. During that time, the public had the opportunity to review the TMDL report and make written comments. Written comments received during the public notice period are a part of the public record of these TMDLs and can be found in Appendix J. One public comment was received and no revisions were made to the final Fort Gibson Lake TMDL Report.

The public meeting was held on Thursday, May 11, 2023. In-person and online meeting options were offered, but there was no public participation. After EPA's final approval, the TMDLs and 208 Factsheet will be adopted into the WQMP.

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