Preliminary Draft

Lake Thunderbird TMDL Report

Prepared for
Oklahoma Department of Environmental Quality
Water Quality Division

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By

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PLEASE NOTE !

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Table of Contents

List of Figures

List of Tables

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 Waterbody
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	Nephelometric turbidity units
O.S.	Oklahoma Statutes
OAC	Oklahoma Administrative Code
OCC	Oklahoma Conservation Commission
ODAFF	Oklahoma Department of Agriculture, Food, and Forestry
OWRB	Oklahoma Water Resources Board

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
SDOX	Supersaturated Dissolved Oxygen
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

Lake Thunderbird is a 6,070-acre reservoir located 13 miles east of downtown Norman in Cleveland County, Oklahoma. The lake is located within a 256 square mile drainage area of the upper Little River watershed (HUC, 11090203). The lake, owned by the U.S. Bureau of Reclamation, was constructed to provide flood control, municipal water supply, recreation and wildlife habitat. Lake Thunderbird is a prime recreational lake for camping, fishing, swimming and boating for the growing population in and around the watershed. As of the 2010 census, the watershed population is estimated at 99,600. The lake serves as the primary public water supply for the cities of Norman, Midwest City, and Del City with water usage governed by the Central Oklahoma Master Conservancy District (COMCD). Lake Thunderbird is on Oklahoma's 2010 303(d) list for impaired beneficial uses of public/private water supply and warm water aquatic community.

This report documents the data and assessment methods used to establish total maximum daily loads (TMDL) for Lake Thunderbird (OK520810000020_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 oxygen levels in the lake to attain water quality targets to restore impaired beneficial uses and protect public health. TMDLs determine the pollutant loading that a waterbody, such as Lake Thunderbird, can assimilate without exceeding applicable 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 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 sources. The MOS is a percentage of the TMDL set aside to account for the lack of knowledge associated with natural processes in aquatic systems, model assumptions, and data limitations.

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 Lake Thunderbird are flood control, municipal water supply, recreation, and fish and wildlife propagation. Oklahoma DEQ has determined that Lake Thunderbird, designated as a Sensitive Water Supply (SWS) lake, is not supporting its designated uses for (a) Fish & Wildlife Propagation (FWP) for a Warm Water Aquatic Community because of excessive levels of turbidity and low dissolved oxygen; and (b) Public Water Supply because of excessive chlorophyll-a levels. High levels of both turbidity and chlorophyll-a can have deleterious effects on the 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 oxygen from the surface layer because of summer thermal stratification. The water quality targets established for Lake Thunderbird, based on statistics of the most recent 10 years of record, are defined as the long-term average in-lake surface concentration of 10 µg/L for chlorophyll-a and the 90^{th} percentile of the in-lake surface concentration of 25 NTU for turbidity. In addition, water quality standards for dissolved oxygen require that minimum surface DO of 6.0 mg/L for the spring and 5 mg/L for the summer and winter to be met and the anoxic volume of the lake not exceed 50% of the lake volume during the summer stratified season. The estimate of anoxic volume is based on a target oxygen concentration of 2 mg/L.

Pollutant Source Assessment. Water quality constituents that relate to impairments of Lake Thunderbird include suspended sediment, chlorophyll-a, phosphorus, nitrogen, and Carbonaceous biochemical oxygen demand (CBOD). The major contribution of pollutant sources from the watershed are derived from urban stormwater runoff from Moore, Norman and Oklahoma City,. A smaller contribution of pollutant loading is related to runoff from rural and unincorporated areas of the watershed. A waste load allocation (WLA) for point source discharges of urban stormwater from Moore, Norman and Oklahoma City, is determined for sediment, nutrients and CBOD. Urban stormwater discharges are regulated under the Clean Water Act by NPDES permits issued to the three cities as part of the MS4 Stormwater Program. A load allocation (LA) for nonpoint runoff of sediment, nutrients and ultimate CBOD is determined for the unincorporated area of the watershed not included within the boundaries of the three MS4 permits, along with the very small areas of the cities of Noble and Midwest City located in the watershed.

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 one year period from April 2008 to April 2009 with the public domain HSPF watershed model. Watershed model results were used to estimate the relative contributions of point and nonpoint sources of pollutant loading. As shown in Table ES- 1, the three cities of Moore, Norman and Oklahoma City accounted for the dominant share of total pollutant loading from the watershed. The EFDC model was developed to simulate water quality conditions in Lake Thunderbird 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 developed with water quality data collected at 8 locations in the lake during the one year period from April 2008 through April 2009. Model results were calibrated to observations for water level, water temperature, TSS, nitrogen, phosphorus, dissolved oxygen, organic carbon and algae biomass (chlorophyll-a). The Relative RMS Error performance targets of (a) 20% for water level and dissolved oxygen; (b) 50% for water temperature, nitrate and total organic phosphorus; and (c) 100% for chlorophyll-a were all attained with the model results for these constituents either much better than, or close to, the target criteria. The model results for TSS, total phosphorus, total phosphate, and total nitrogen were also good with the model performance statistics shown to be only 5-6% over the target criteria of 50%.

Table ES- 1 Relative Contribution of Point and Nonpoint Source Loading of Pollutants from the Lake Thunderbird Watershed (April 2008-April 2009)

	TN	TP	CBOD	Sediment
City Name	**%**	**%**	**%**	**%**
Moore	25.4	28.1	31.5	21.1
Norman	39.5	38.0	38.5	41.0
Oklahoma City	32.4	31.1	27.7	35.1
Other areas	2.6	2.8	2.3	2.7
Total	100	100	100	100

The calibrated lake model was used to evaluate the water quality response to reductions in watershed loading of sediment and nutrients and. Load reduction scenario model runs were performed to determine if water quality targets for turbidity and chlorophyll could be attained with watershed-based load reductions based on 35% removal of loading for sediment and nutrients. The long-term model results indicated that compliance with water quality criteria for turbidity, dissolved oxygen and chlorophyll could be achieved within a reasonable time frame. The calibrated model results thus supported the development of TMDLs for sediments, CBOD, TN and TP to achieve compliance with water quality standards for turbidity, chlorophyll and dissolved oxygen.

<u>TMDL, Waste Load Allocation, Load Allocation and Margin of Safety</u>. The linked watershed (HSPF) and lake (EFDC) model framework was used to calculate average annual suspended solids, CBOD, nitrogen and phosphorus loads (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, are expressed as daily loads (kg/day). The waste load allocation (WLA) for the TMDL for Lake Thunderbird is assigned to regulated NPDES point source discharges under three MS4 stormwater permits for Moore, Norman and Oklahoma City. The WLA, split among the three MS4 permits, includes pollutant discharges

regulated under NPDES stormwater permits for Construction Sites and Multi-Sector General Permit (MSGP) for various industrial facilities located within the MS4 areas of the watershed. The load allocation (LA) for the TMDL is assigned to the small land area of the watershed not included in the land area for the three MS4 permits and is set at the existing loading during the calibration period. Seasonal variation was accounted for in the TMDL determination for Lake Thunderbird by developing the watershed and lake models with hourly to sub-hourly time steps and over a full year of simulation with meteorological data representative of typical average hydrologic conditions in the watershed. The TMDL determined for Lake Thunderbird accounts for an implicit Margin of Safety (MOS) by decreasing the water quality targets for chlorophyll-a and turbidity by a factor of 10%. The decrease resulted in the target for turbidity lowered from 25 to 22.5 NTU and the target for chlorophyll-a from 10 to 9 µg/L.

The TMDL for Suspended Solids, TN and TP, determined from the lake model response to watershed load reductions, is based on the 35% reduction of the existing 2008-2009 watershed loads estimated with the HSPF model. Load reductions for these constituents are needed because the water quality criteria for turbidity and chlorophyll-a are not met under the existing loading conditions. For CBOD, however, the TMDL is based on the existing 2008-2009 ultimate CBOD loading from the HSPF watershed model since the water quality criterion for dissolved oxygen is met under existing loading conditions with reserved capacities. For example, the predicted volumetric anoxic volume for Lake Thunderbird is only about 30% (Figure 4-5) while the standards allows up to 50% anoxic volume. This reserved capacity will act as the implicit margin of safety. The total WLA for the three MS4 cities was computed from the Total Maximum Daily Load (TMDL) that was in turn derived from the long term average daily load (LTA) and the coefficient of variation (CV) estimated from HSPF loading data. The statistical methodology, documented in EPA (2007) "*Options for Expressing Daily Loads in TMDLs",* for computing the maximum daily load (MDL) limit is based on a long-term average load (LTA), temporal variability of the loading dataset expressed by the coefficient of variation (CV) and the Z-score statistic (1.645) for 95% probability of occurrence (Table ES-2). The load allocation (LA) is computed as the difference from the total maximum daily load (TMDL) and the total WLA load. The TMDL load is split between three WLA's for the three MS4 cities, the LA for the unincorporated area of the watershed and the implicit MOS as shown in Table ES-3.

Table ES- 2 Existing Loading and TMDL for Lake Thunderbird

	Units	TN	TP	CBOD	Suspended Solids
Existing 2008-2009 Load	kg/yr	116,138	21,775	232,487	11,231,882
Existing 2008-2009 Load	kg/day	318	60	637	30,772
Reduction Rate Required	Percent	35%	35%	0%	35%
Long Term Average Load	LTA, kg/day	207	39	637	20,002
Coefficient Variation	CV (n=376)	4.25	4.41	4.79	5.87
Total, Max Daily Load	TMDL, kg/day	798	149	2,441	75,119
Z-Score statistic =1.645 for 95% probability					

Table ES- 3 TMDL for Lake Thunderbird

Water Quality Constituent	TMDL	LA	WLA				MOS
			Total	Moore	Norman	OKC	
	(Kg/day)	(Kg/day)	(Kg/day)	(Kg/day)	(Kg/day)	(Kg/day)	(Kg/day)
Total Nitrogen (TN)	798	21	777	203	316	259	Implicit
Total Phosphorus (TP)	149	4	145	42	57	47	Implicit
CBOD	2,441	57	2,385	769	940	676	Implicit
Suspended_Solids (TSS)	75,119	2,020	73,100	15,850	30,844	26,406	Implicit

SECTION 1 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 Lake Thunderbird reservoir in Cleveland County, Oklahoma within the Little River drainage basin (Hydrologic Unit Code 11090203). High levels of turbidity reflect sediment loading from the watershed and elevated levels of chlorophyll-a in lakes reflect 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 levels typically indicate eutrophication of the lake as a result of excessive loading of the primary growth-limiting algal nutrients nitrogen and 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 and protecting public health in this waterbody. TMDLs determine the pollutant loading a waterbody can assimilate without exceeding applicable water quality standards (WQS). TMDLs also establish the pollutant load allocation 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, and includes 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 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.

Lake Thunderbird is on Oklahoma's 2010 303(d) list for impaired beneficial uses of public/private water supply and warm water aquatic community life. Causes of impairment have been identified as low oxygen levels, high levels of chlorophyll-a, and high turbidity (DEQ, 2010a). An important recreational lake for fishing and boating, Lake Thunderbird is designated by the Oklahoma Water Quality Standards (OWRB 2011) as a Sensitive Water Supply (SWS) since the lake serves as the primary public water supply source for the cities of Norman, Midwest City and Del City. With the three major municipalities of Moore, Norman and Oklahoma City in the watershed, this area is one of the fastest growing regions in Oklahoma. Urban development has been rapid over the past decade and continued urban development is forecast by local governments. There is clearly the need for appropriate mitigation of the ecological impact of point source and nonpoint sources of pollutant loading from the watershed to Lake Thunderbird.

Figure 1-1 shows a location map of Lake Thunderbird and the contributing sub-watersheds of the drainage basin to the lake. The map also displays the locations of the five (5) stream water quality monitoring (WQM) stations in the watershed and the eight (8) lake water quality monitoring stations used for this TMDL determination. Data obtained from the lake stations over the past 10 years were used as the basis for placement of Lake Thunderbird on the Oklahoma 303(d) list.

1.2 Watershed and Lake Thunderbird Description

Lake Thunderbird (OK Waterbody Identification Number OK520810000020_00) is a 6,070-acre reservoir located 13 miles east of downtown Norman in Cleveland County, Oklahoma at Longitude: 97° 13' 5" and Latitude: 35° 13' 15". The lake is located within a 256 square mile drainage area of the upper reaches of the Little River basin. The Little River basin is designated by the USGS with an identification code (11090203) known as the 8-digit level Hydrologic Unit Code (HUC) or catalog unit code. The lake, owned by the U.S. Bureau of Reclamation, was constructed in 1965 to provide flood control, municipal water supply, recreation and wildlife habitat by impounding the Little River and Hog Creek in northeast Cleveland County. Lake Thunderbird is an important recreational lake for camping, fishing and boating which is managed by the Oklahoma Tourism and Recreation Department (Lake Thunderbird State Park) (Bureau of Reclamation, 2009). The lake serves as a public water supply for the cities of Norman, Midwest City and Del City with water usage governed by the Central Oklahoma Master Conservancy District (COMCD). Lake Thunderbird is bordered by 86 miles of shoreline which is comprised of clay, sand and sandstone (OK Dept. Wildlife Conservation, 2008).

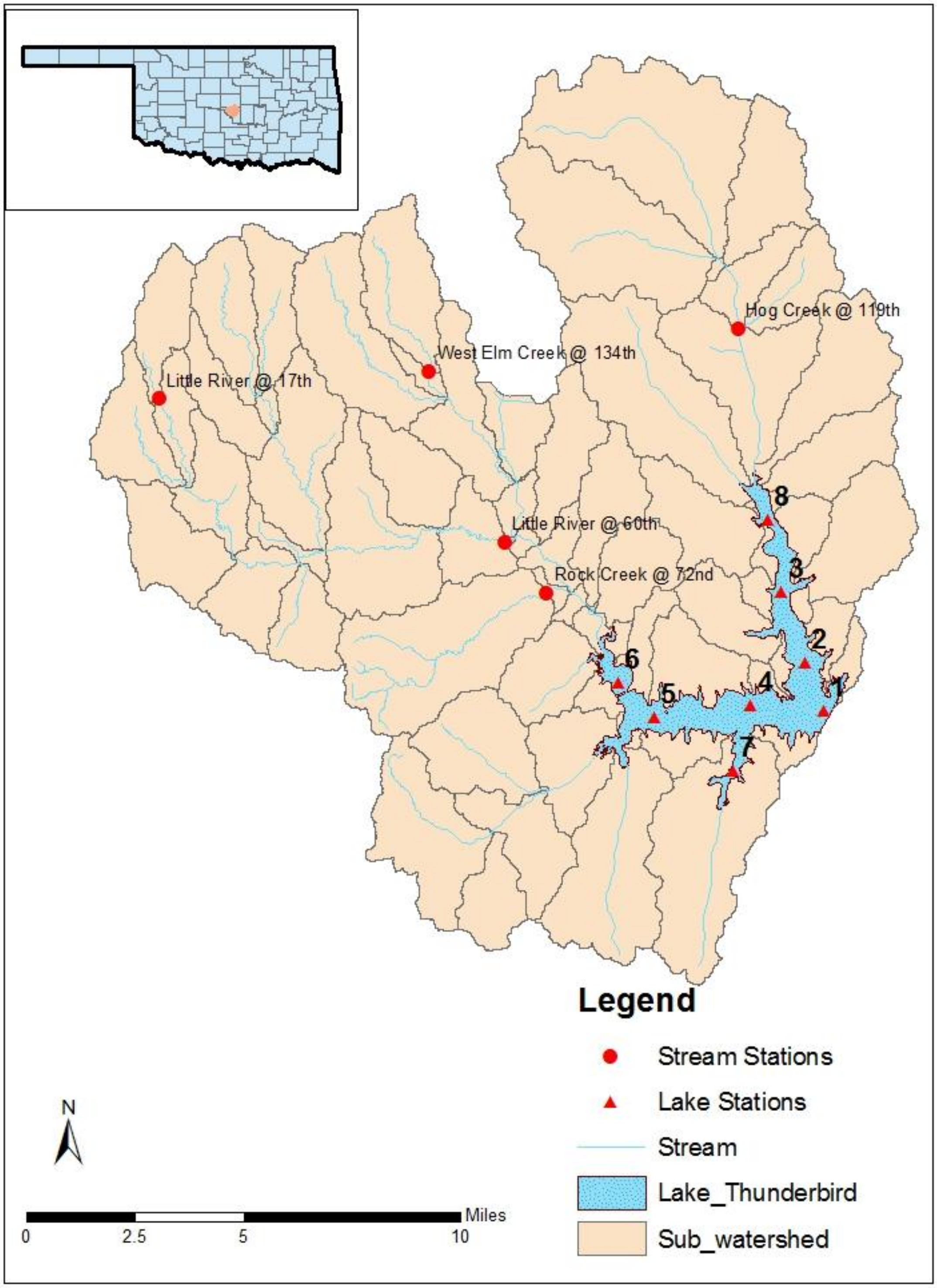

Figure 1-1 Lake Thunderbird Watershed

Table 1-1 presents general physical characteristics of Lake Thunderbird. Data sources include the U.S. Army Corps of Engineers, Tulsa District, Bureau of Reclamation, and the Oklahoma Department of Wildlife Conservation (2008).

Table 1-1 Physical Characteristics of Lake Thunderbird

Drainage Area	sq-miles	256
Surface Area @ Normal Pool Elevation[1]	acres	6,070
Normal Conservation Pool Elevation	ft, MSL[2]	1,039.0
Conservation Pool Storage Volume	acre-ft	119,600
Surface Area @ Flood Pool Elevation	acres	8,788
Flood Pool Elevation	ft, MSL	1,049.4
Flood Control Pool Storage Volume	acre-ft	196,260
Average Depth	ft	19.7
Maximum Depth	ft	57.6
Shoreline	miles	86.0

1. Elevation: vertical datum,NGVD29
2. MSL: mean sea level

Data Sources:
OK Dept Wildlife Conservation (2008)
Bureau of Reclamation (2009)
http://www.swt-wc.usace.army.mil/THUN.lakepage.html

The watershed occupies 256 square miles of residential, commercial and agricultural lands. The surrounding woodland habitat is comprised of Post and Blackjack oak in the Cross Timbers ecotype region of the Southern Plains. Table 1-2 summarizes the percentages and acres of land use categories for the contributing watersheds of the basin. The land use/land cover data were derived from the 2006 National Land Cover Database (NLCD) database (Fry et al., 2011).

Figure 1-2 shows the land use in the watershed draining to Lake Thunderbird. The most common land use category in the study area is Grassland/Herbaceous with 38% of the watershed area. In addition to Grassland/Herbaceous land use, a significant portion of the watershed is classified as Deciduous Forest with 35% of the watershed area. Urban developed land use categories account for16 % of the watershed area. Prevailing winds are out of the south-southeast most of the year at 5 to 20 mph (OK Dept. Wildlife Conservation, 2008). Average annual precipitation, derived from NOAA's NCDC statistical summary of air temperature and precipitation from 1971-2000, is 37.65 inches at the station located in Norman (ID=346386)(http://climate.ok.gov/data/public/climate/ok/archive/normals/ncdc/1971-2000/oknorm.pdf**)**.

Annual rainfall for Lake Thunderbird measured during the simulation period from 2008-2009 (36.9 inches) is comparable to the long term (1971-2000) average rainfall of 37.65 inches. This indicates that the 2008-2009 time period used for development of the model and analysis of loads for the TMDL represents "typical" hydrologic conditions for the watershed.

Based on 2010 census data (US Census Bureau, 2011), the population within this rapidly growing watershed is estimated at 99,600 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 5000-6999 persons per square mile corresponds to Oklahoma City and Moore in the urbanized northwest area of the watershed. The lowest population density (<100 persons per square mile) is characteristic of the more rural eastern area of the watershed and corresponds to the dominant land use categories of Grassland and Deciduous Forest. Table 1-3 presents population based on 2010 census data for Cleveland and Oklahoma counties that are located within the watershed. The table presents the total population of the county and the population of the county located within the watershed based on compilation of census tract data presented in Figure 1-3. Based on 2010 census tract data and a GIS map of populated areas served by public sewer systems in the watershed (Figure 1-4) estimates of the population served by public sewers (49%) and those not served (51%) in 2010 are presented in Table 1-4. The Census did not collect public sewer system data in its 2000 or 2010 census.

Table 1-2 Land Use Characteristics of the Watershed

Land Use	**Acres**	**Percent**
Open water	6,738	4.322%
Developed, open space	14,661	9.405%
Developed, low intensity	6,769	4.342%
Developed, medium intensity	3,102	1.990%
Developed, high intensity	661	0.424%
Barren Land	30	0.019%
Deciduous Forest	55,010	35.288%
Evergreen Forest	351	0.225%
Grassland/Herbaceous	59,765	38.338%
Pasture/Hay	5,452	3.498%
Cultivated Crops	3,341	2.143%
Emergent herbaceous wetlands	8	0.005%
Total Watershed	155,888	100%
Data Source: 2006 NLCD		

Table 1-3 County Population within the Watershed

County	Population Total	Population in Watershed
Cleveland	255,755	91,875
Oklahoma	718,633	7,725
Total	974,388	99,600
Data Source: 2010 US Census		

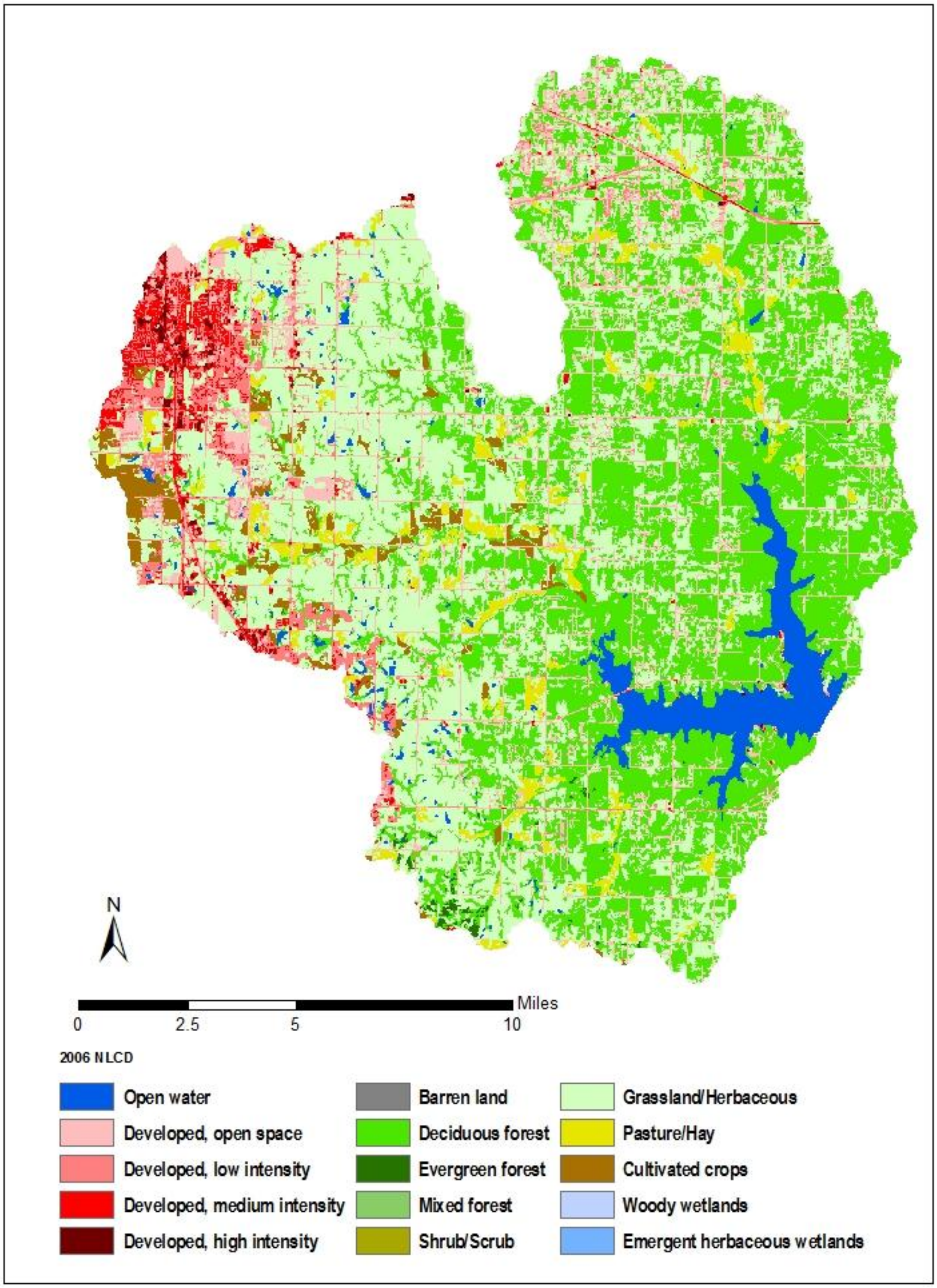

Figure 1-2 Land Use Distribution of the Watershed

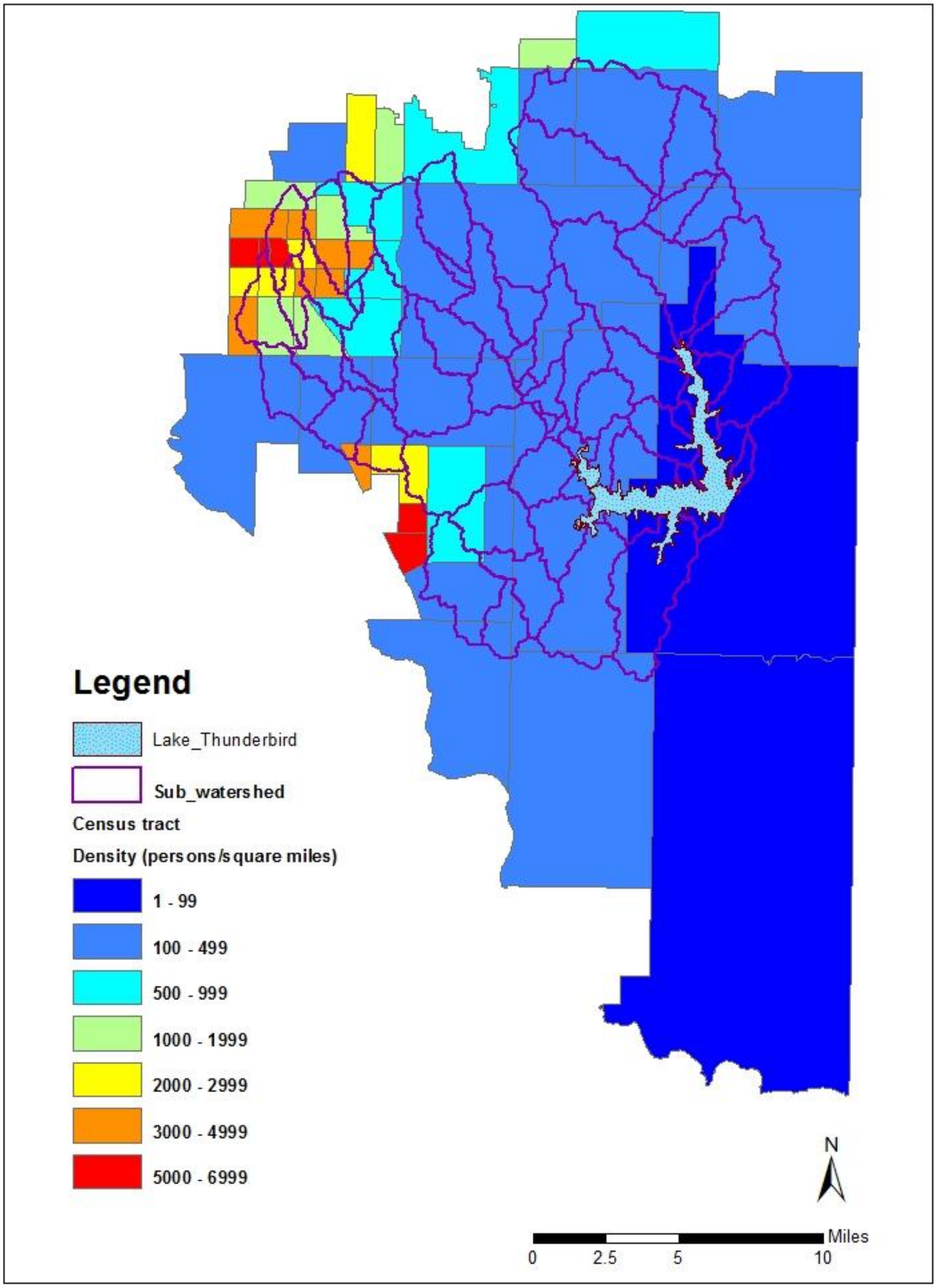

Figure 1-3 Population Density (persons per square mile) based on 2010 Census Tracts within the Lake Thunderbird Watershed

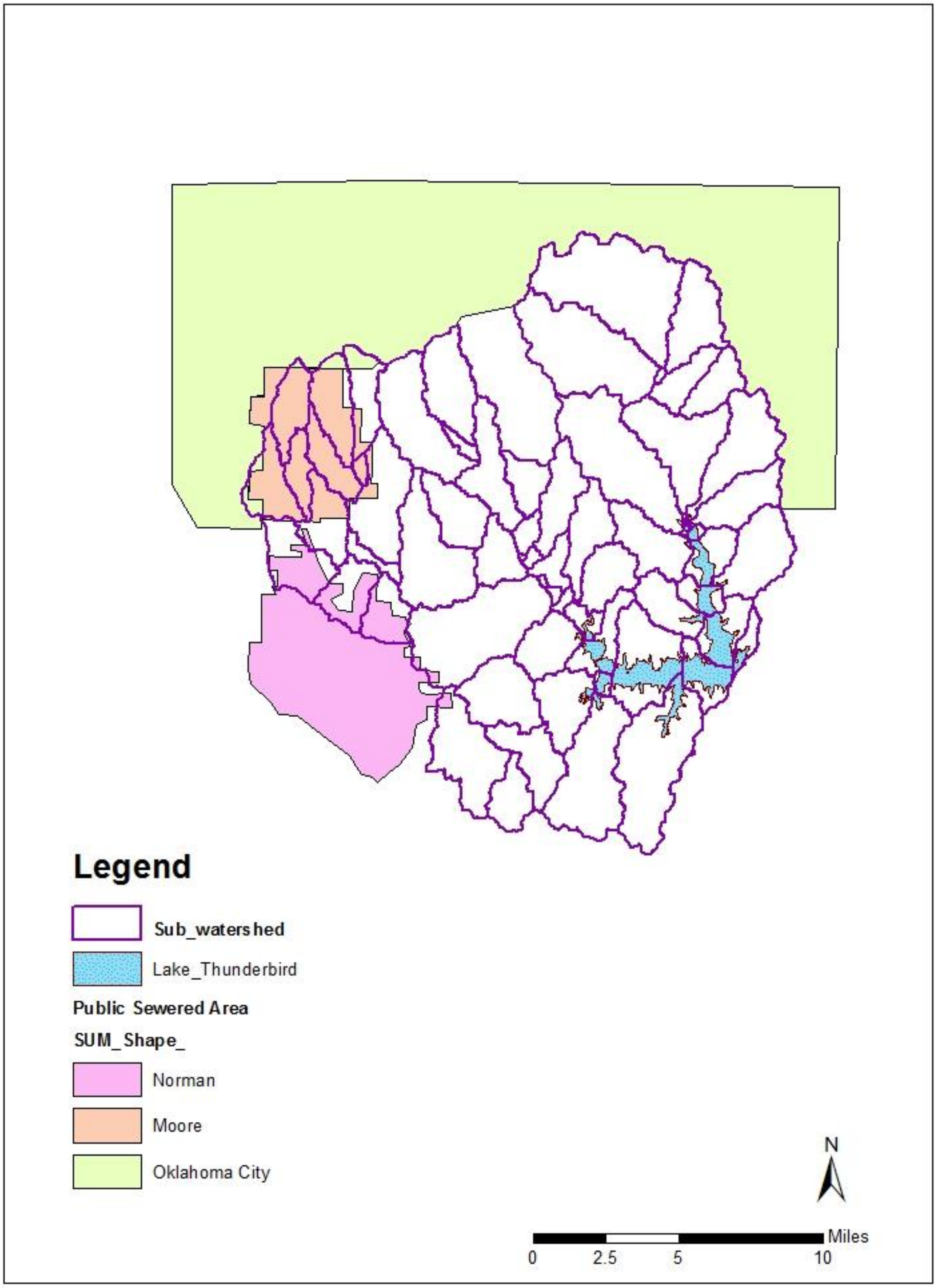

Figure 1-4 Public Sewer System Boundaries within the Lake Thunderbird Watershed

Table 1-4 2010 Population Served by Public Sewer Systems

2010	Population Total	Percent of Total
Sewered	48,920	49%
Unsewered	50,680	51%
Total	99,600	100%
Data Sources: 2010 US Census and GIS maps of public sewer systems		

1.3 Streamflow Characteristics

The magnitudes of annual, seasonal and daily variability of streamflow from the major streams in the watershed are essential data to characterize water and load inflows to a waterbody for a water quality management study such as this TMDL assessment of Lake Thunderbird. Although a USGS stream gage was historically located on the Little River at the present location near its lake inlet, the streamflow gage ceased operation in 1955 before the reservoir was constructed. At present there are only two gages recently installed and maintained by the USGS on the Little River upstream of Lake Thunderbird. The gage near Franklin Road in Norman (07229480) had records for gage height from March 30, 2012 to June 12, 2012 and the gage at Twelfth Ave NW in Norman (07229451) has records of both gage height and streamflow up to date since March 30, 2012. Stanley Draper Lake is a reservoir located in the Oklahoma City portion of the watershed that is upstream of Lake Thunderbird. Since the outflow from Stanley Draper Lake is exported outside of the watershed area draining to Lake Thunderbird, the contributing drainage area of 11.8 square miles to Stanley Draper Lake does not contribute to stream inflow to Lake Thunderbird. In the absence of historical and/or current streamflow measurements for the Lake Thunderbird watershed study area, flow estimates for the Little River, Hog Creek, Dave Blue Creek, Jim Blue Creek, Clear Creek and other smaller tributaries to the lake were developed using the HSPF watershed model. The development of the watershed model for the Lake Thunderbird study is summarized in Section 3.3 of this report and the complete technical report for the watershed model is presented in Appendix A.

SECTION 2 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, 2011). 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, an excerpt from the 2010 Integrated Report (DEQ, 2010), lists beneficial uses designated for Lake Thunderbird. The beneficial uses include:

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

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

Waterbody ID	Waterbody Name	AES	AG	FISH	WWAC	PBCR	PPWS	SWS
Lake Thunderbird	OK520810000020_00	I	F	X	N	F	N	X

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

Table 2-2 summarizes the impairment status for Lake Thunderbird. Lake Thunderbird 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 Lake Thunderbird

Waterbody ID	Waterbody Name	Size (acres)	TMDL Date	Priority	Turbidity	DO	Chl-a
OK520810000020_00	Lake Thunderbird	6,070	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, 2011).

(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. Because turbidity cannot be expressed as a mass load, total suspended solids (TSS) are used as a surrogate for the TMDLs in this report.

Dissolved Oxygen Standards for Lakes

The following excerpt from the Oklahoma WQS (OAC 785:45-5-12(f)(1)(D)) stipulates the dissolved oxygen numeric criterion for lakes to maintain and protect "Warm Water Aquatic Community" beneficial uses (OWRB, 2011):

(v) Support tests for WWAC lakes. The WWAC subcategory of the Fish and Wildlife Propagation beneficial use designated for a lake shall be deemed to be fully supported with respect to the DO criterion if both the Surface and Water Column criteria prescribed in (vi)(I) and (vii)(I) of this subparagraph (D) are satisfied. If either of the Surface or Water Column criteria prescribed in (vi)(II) or (vii)(II) produce a result of undetermined, then the WWAC subcategory of the Fish and Wildlife Propagation beneficial use designated for a lake shall be deemed to be undetermined with respect to the DO criterion; provided, if either of the Surface or Water Column criteria prescribed in (vi)(III) or (vii)(III) produce a result of not supported, then the WWAC subcategory of the Fish and Wildlife Propagation beneficial use designated for a lake shall be deemed to be not supported with respect to the DO criterion.

(vi) Surface criteria for WWAC lakes.

(I) The WWAC subcategory of the Fish and Wildlife Propagation beneficial use designated for a lake shall be deemed to be fully supported with respect to the DO criterion if 10% or less of the samples from the epilimnion during periods of thermal stratification, or the entire water column when no stratification is present, are less than 6.0 mg/L from April 1 through June 15 and less than 5.0 mg/L during the remainder of the year.

(II) The WWAC subcategory of the Fish and Wildlife Propagation beneficial use designated for a lake shall be deemed to be undetermined with respect to the DO criterion if more than 10% of the samples from the epilimnion during periods of thermal stratification, or the entire water column when no stratification is present, are less than 5.0 mg/L and 10% or less of the samples are less than 4 mg/L from June 16 through October 15, or more than 10% of the samples from the surface are less than 6.0 mg/L and 10% or less of the samples are less than 5.0 mg/L from April 1 through June 15.

(III) The WWAC subcategory of the Fish and Wildlife Propagation beneficial use designated for a lake shall be deemed to be not supported with respect to the DO criterion if more than

10% of the samples from the epilimnion during periods of thermal stratification, or the entire water column when no stratification is present, are less than 5.0 mg/L from April 1 through June 15 or less than 4.0 mg/L from June 16 through October 15, or less than 5.0 mg/L from October 16 through March 31, due to other than naturally occurring conditions.

(vii) Water Column criteria for WWAC lakes.

(I) The WWAC subcategory of the Fish and Wildlife Propagation beneficial use designated for a lake shall be deemed to be fully supported during periods of thermal stratification with respect to the DO criterion if less than 50% of the volume (if volumetric data is available) or 50% or less of the water column (if no volumetric data is available) of all sample sites in the lake are less than 2.0 mg/L.

(II) The WWAC subcategory of the Fish and Wildlife Propagation beneficial use designated for a lake shall be deemed to be undetermined during periods of thermal stratification with respect to the DO criterion if 50% or more, but not greater than 70%, of the water column at any given sample site in the lake is less than 2.0 mg/L due to other than naturally occurring conditions.

(III) The WWAC subcategory of the Fish and Wildlife Propagation beneficial use designated for a lake shall be deemed to be not supported during periods of thermal stratification with respect to the DO criterion if 50% or more of the water volume (if volumetric data is available) or more than 70% of the water column (if no volumetric data is available) at any given sample site is less than 2.0 mg/L.

(IV) If a lake specific study including historical analysis produces a support status which is contrary to an assessment obtained from the application of (I), (II) or (III) of (D)(vii) of this section, then that lake specific result will control.

<u>Chlorophyll-*a* Standards for SWS Lakes</u>

Lake Thunderbird is designated as a Sensitive Public and Private Water Supply (SWS) lake. The definition of SWS is summarized by the following excerpt from OAC 785:45-5-25(c)(4) of the Oklahoma WQS (OWRB 2011):

(A) Waters designated "SWS" are those waters of the state which constitute sensitive public and private water supplies as a result of their unique physical conditions and are listed in Appendix of this Chapter as "SWS" waters. These are waters (a) currently used as water supply lakes, (b) that generally possess a watershed of less than approximately 100 square miles or (c) as otherwise designated by the Board.

(B) New point source discharges of any pollutant after June 11, 1989, and increased load of any specified pollutant from any point source discharge existing as of June 11,1989, shall be prohibited in any waterbody or watershed designated in Appendix A of this Chapter with the limitation "SWS". Any discharge of any pollutant to a waterbody designated "SWS" which would, if it occurred, lower existing water quality shall be prohibited, provided however that new point source discharge(s) or increased load of specified pollutants described in 785:45-5-25(b) may

be approved by the permitting authority in those circumstances where the discharger demonstrates to the satisfaction of the permitting authority that a new point source discharge or increased load from an existing point source discharge will result in maintaining or improving the water quality of both the direct receiving water and any downstream waterbodies designated SWS.

The following excerpt from the Oklahoma WQS (OAC 785:45-5-10) stipulates the numeric criterion set for SWS lakes, including Lake Thunderbird (OWRB, 2011).

785:45-5-10. Public and private water supplies

The following criteria apply to surface waters of the state having the designated beneficial use of Public and Private Water Supplies:

(7) Chlorophyll-a numerical criterion for certain waters. The long term average concentration of chlorophyll-a at a depth of 0.5 meters below the surface shall not exceed 0.010 milligrams per liter in Wister Lake, Tenkiller Ferry Reservoir, nor any waterbody designated SWS in Appendix A of this Chapter. Wherever such criterion is exceeded, numerical phosphorus or nitrogen criteria or both may be promulgated.

In addition to the SWS designation of Lake Thunderbird, the lake watershed has also been assigned the designation of "Nutrient Limited Watershed" (NLW) in OAC 785:45-5-29. A NLW means a watershed of a waterbody with a designated beneficial use that is adversely affected by excess nutrients as determined by Carlson's (1977) Trophic State Index (TSI) (using chlorophyll-a) of 62 or greater, or is otherwise listed as "NLW" in Appendix A of Chapter 45 (OWRB 2010).

2.2 Overview of Water Quality Problems and Issues

Lake Thunderbird, located in central Oklahoma southeast of Oklahoma City, is a popular recreational lake in addition to its use as a water supply reservoir for the cities of Norman, Del City and Midwest City. Designated uses of the reservoir are flood control, municipal water supply, recreation, and fish and wildlife propagation. As a municipal water supply, Lake Thunderbird furnishes raw water for Del City, Midwest City, and the City of Norman under the authority of the Central Oklahoma Master Conservancy District (COMCD). Significant taste and odor problems, related to eutrophication, have led to numerous complaints from water supply customers (see OWRB, 2009 and OWRB, 2010). Based on an assessment of water quality monitoring data, Oklahoma DEQ has determined that Lake Thunderbird is not supporting its designated uses for (a) Fish & Wildlife Propagation (FWP) for a Warm Water Aquatic Community because of excessive levels of turbidity and low dissolved oxygen; and (b) Public Water Supply because of excessive chlorophyll-a levels. Excessive nutrient loading from the watershed, primarily from urban development, is thought to be causally related to the observed eutrophication of the lake. The Central Oklahoma Master Conservancy District (COMCD), in cooperation with OWRB, has been monitoring chlorophyll-a, nutrients, sediment, water temperature, organic matter and dissolved oxygen in the lake since 2000. In support of this TMDL study of Lake Thunderbird, OWRB and Oklahoma Conservation Commission (OCC) conducted a special monitoring program for the lake and its tributaries from April 2008 through April 2009 to supplement the monitoring program conducted as part of the routine COMCD-

OWRB surveys. Table 2-3 summarizes the site designation names, station numbers and locations of the water quality monitoring stations maintained by OWRB in Lake Thunderbird as a component of the Oklahoma Beneficial Use Monitoring Program (BUMP) network (OWRB, 2008). These stations are also used in the COMCD-OWRB surveys and the special monitoring for the TMDL study. Figure 2-1 shows the locations of the lake monitoring sites.

Table 2-3 OWRB Water Quality Monitoring Stations for Lake Thunderbird

Site	Station Number	Latitude	Longitude	Represents
1	520810000020-1sX	35.223333	-97.220833	Dam Site; Lacustrine
	520810000020-1-4X			
	520810000020-1-8X			
	520810000020-1-12X			
	520810000020-1bX			
2	520810000020-2X	35.238889	-97.228889	Lacustrine
	520810000020-2bX			
3	520810000020-3X	35.262222	-97.238889	Transition
4	520810000020-4X	35.224444	-97.250833	Lacustrine
	520810000020-4bX			
5	520810000020-5X	35.220278	-97.290556	Transition
6	520810000020-6X	35.231667	-97.305556	Riverine
7	520810000020-7X	35.203056	-97.258056	Riverine
8	520810000020-8X	35.286409	-97.244887	Riverine
11	520810000020-11X	35.212292	-97.302545	Riverine

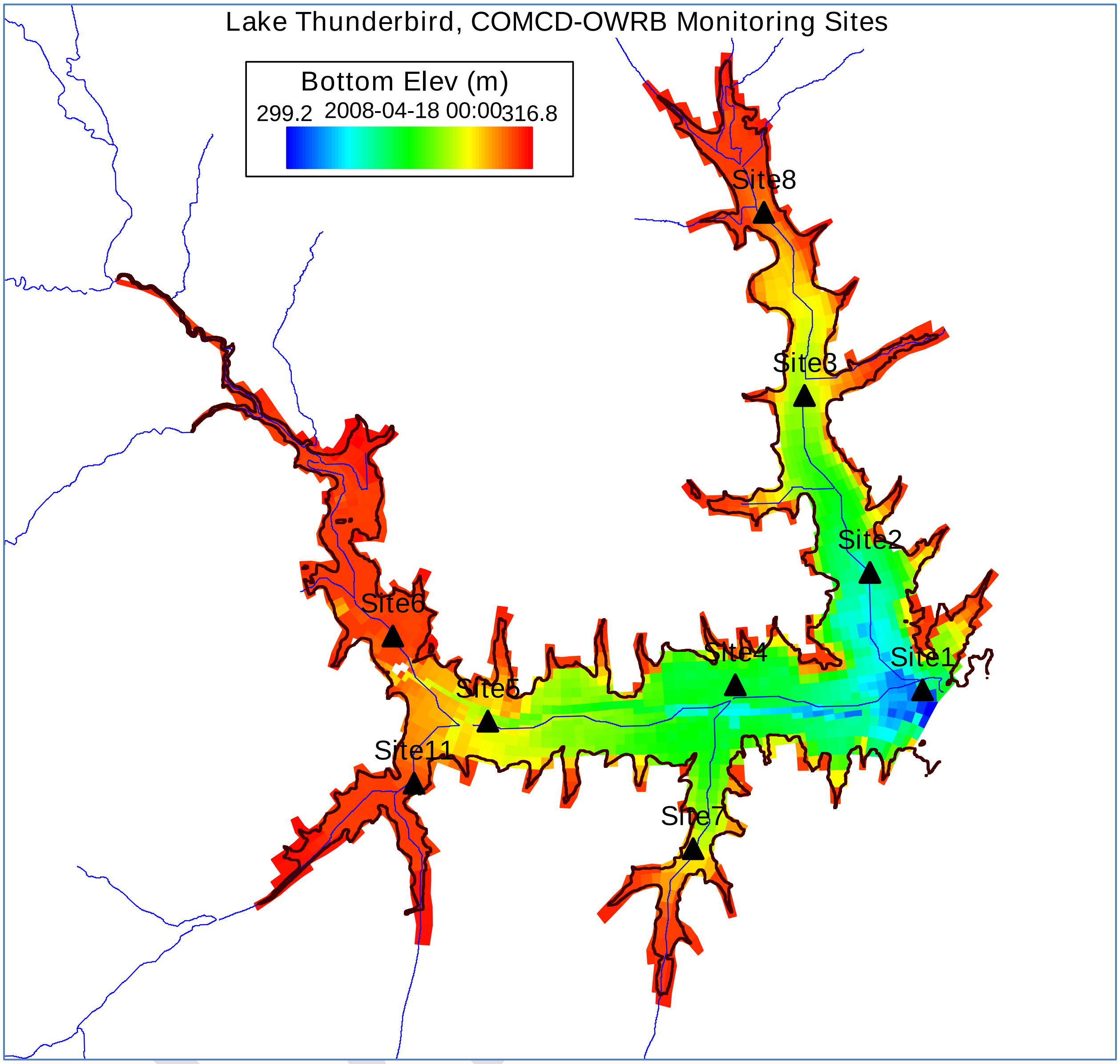

Figure 2-1 OWRB Water Quality Monitoring Stations for Lake Thunderbird

2.3 Water Quality Observations and Targets for Turbidity, Chlorophyll-a and Dissolved Oxygen

Oklahoma water quality standards for Lake Thunderbird turbidity, chlorophyll-a 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

- Chlorophyll-a: Average value of surface chlorophyll-a no greater than 10 µg/L based on long-term record of most recent 10 years.
- Dissolved Oxygen: Within the surface/epilimnion layer for protection of fish and wildlife propagation in warm water aquatic community (a) DO no less than 6 mg/L from April 1 to June 15 for early life stages; and (b) DO no less than 5 mg/L from June 16 to October 15 and October 16 to March 31 for protection of other life stages.
- Dissolved Oxygen: Anoxic volume of the lake, defined by a DO target level of 2 mg/L, shall not exceed 50% of the lake volume 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 is to be used as the basis for assessment of the water quality conditions and beneficial use support for a waterbody (OWRB, 2011a). Lake Thunderbird is listed as impaired based on an analysis of the most recent 10 years of records for chlorophyll-a, turbidity and DO.

Summary statistics presented in Table 2-4 are based on data collected by COMCD-OWRB from 2000 through 2009 used for the impaired listing of Lake Thunderbird. Observations for data collected from November 2000 through October 2009 for turbidity (Figure 2-2) and from July 2001 through October 2009 for chlorophyll-a (Figure 2-3) are used to compute the summary statistics for the monitoring sites listed in Table 2-3. The water quality data sets collected by COMCD-OWRB and OCC in 2008-2009 that was used to support the watershed and lake modeling studies developed for this TMDL are presented in Appendix D.

Table 2-4 Summary Statistics for Observed Turbidity and Chlorophyll-a in Lake Thunderbird, 2000-2009

Summary Statistic	Turbidity NTU	WQ Target NTU	Chlorophyll-a µg/L	WQ Target µg/L
Number of Records	307		770	
Start Date	11/2/2000		7/19/2001	
End Date	10/19/2009		10/19/2009	
Mean	22.8		**20.7**	**10**
10th Percentile	6.7		6.2	
25th Percentile	9.0		10.4	
50th Percentile	15.0		16.5	
75th Percentile	27.0		27.3	
90th Percentile	**53.2**	**25**	41.3	

As can be seen in the data presented in Table 2-4, the 90th percentile of 53.2 NTU for observed surface turbidity from 2000-2009 exceeds the water quality criteria target of 25 NTU. The 2001-2009 average for observed surface chlorophyll of 20.7 µg/L exceeds the water quality criteria target of 10 µg/L. The observed turbidity and chlorophyll-a data for 2000-2009 documents that conditions during this period did not support the Warm Water Aquatic Community use and the Public and Private Water Supply use of the lake as a SWS waterbody.

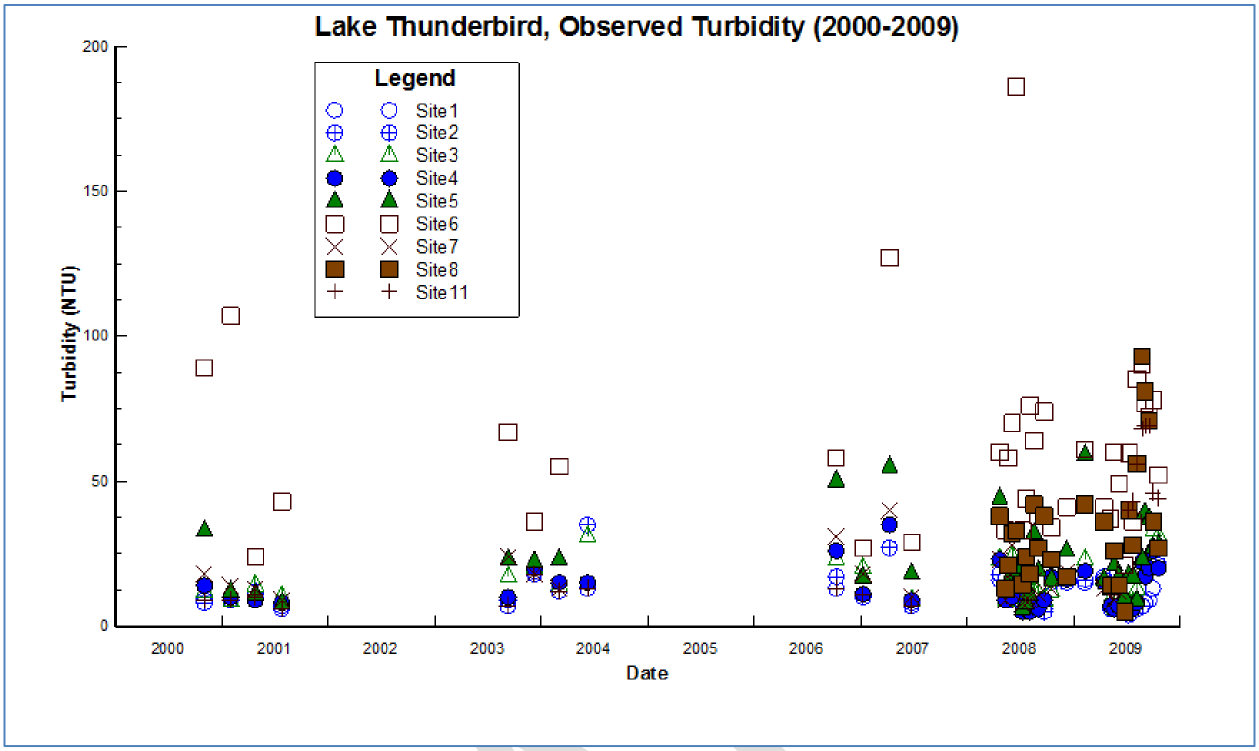

Figure 2-2 Observed Turbidity in Lake Thunderbird, 2000-2009

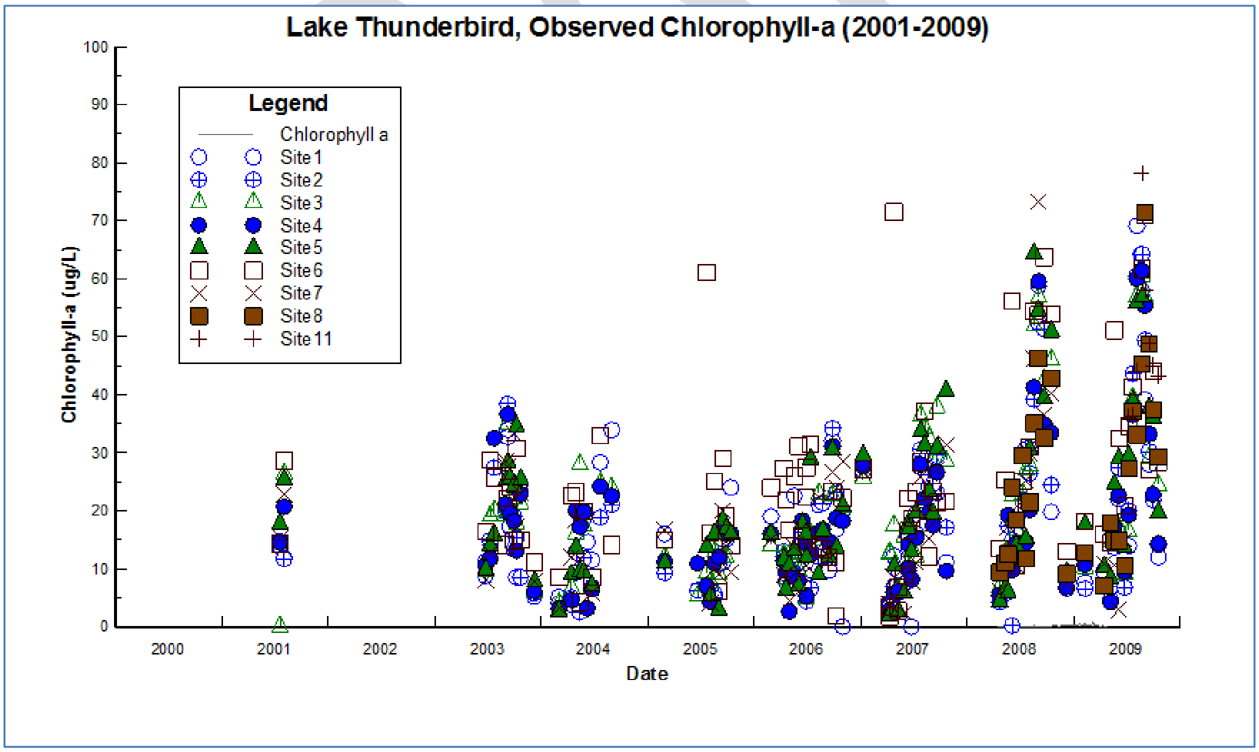

Figure 2-3 Observed Chlorophyll-a in Lake Thunderbird, 2001-2009

Based on an assessment of surface layer dissolved oxygen data, OWRB has determined that Lake Thunderbird is not fully supporting its beneficial uses for Fish and Wildlife Propagation as it relates to dissolved oxygen. As the result, Lake Thunderbird was listed for DO impairment in the 2010 303(d) list. Oklahoma Water Quality Standards for dissolved oxygen have been changed since the assessments for 2010 303(d) list were done. DEQ made a request to OWRB to perform a new DO assessment of Lake Thunderbird using the new surface and volumetric DO standards. It was determined that Lake Thunderbird is still impaired for dissolved oxygen. In 2003, for example, there were multiple instances recorded as early as May, where the dissolved oxygen was less than 5.0 mg/L throughout the entire water column. In addition to the evaluation of surface layer dissolved oxygen data, volumetric and water column analyses of dissolved oxygen station data showed that more than 50% of the lake volume was less than the 2 mg/L target for anoxia within the hypolimnion during summer stratified conditions.

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 Lake Thunderbird must demonstrate compliance with the numeric criteria prescribed for SWS lakes in the Oklahoma WQS (OWRB, 2011).

Water quality variables that relate to impairments of Lake Thunderbird for water clarity and turbidity include suspended sediment and algae biomass as chlorophyll-a. Water quality constituents that relate to impairments for chlorophyll-a 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 (chlorophyll-a), ultimate 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 loading analysis required for the TMDL determination. A 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 with the details presented in Appendix B.

SECTION 3 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 Lake Thunderbird. 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)

There are no municipal and industrial wastewater facilities or concentrated animal feeding operations (CAFO) located within the Lake Thunderbird watershed. The watershed does include a number of no-discharge WWTP facilities that do not discharge wastewater effluent to surface waters. For the purposes of this TMDL, no-discharge facilities are not considered a source of sediment, organic matter or nutrient loading to the lake.

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 Lake Thunderbird. MS4 permits have been issued for Midwest City, Moore, Noble, Norman, and Oklahoma City. 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 Lake Thunderbird 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

There are no municipal or industrial wastewater facilities located within the Lake Thunderbird watershed.

3.1.2 No-Discharge Wastewater Treatment Plants

A no-discharge WWTP facility does not discharge wastewater effluent to surface waters. For the purpose of this TMDL assessment, it is assumed that no-discharge wastewater facilities do not contribute TSS, organic matter or nutrient loading to watershed streams and Lake Thunderbird. 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. As shown in Figure 3-1 and

Table 3-1, there are 14 no-discharge facilities located within the watershed study area.

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 City of Moore in the Lake Thunderbird watershed there were 374 overflows reported during the years from 2000 to 2012. Of these, 130 events spilled more than 1000 gallons with a maximum bypass volume of 374,000 gallons. Within the City of Norman in the Lake Thunderbird watershed there were 28 overflows reported during the years from 2000 to 2008 that spilled more than1000 gallons with a maximum bypass volume of 20,000 gallons. Table 3-2 summarizes the SSO bypass occurrences in the Cities of Moore and Norman. Oklahoma City has a negligible publicly sewered area in the watershed. A detailed chronology of the bypass events for Moore and Norman is presented in Appendix F.

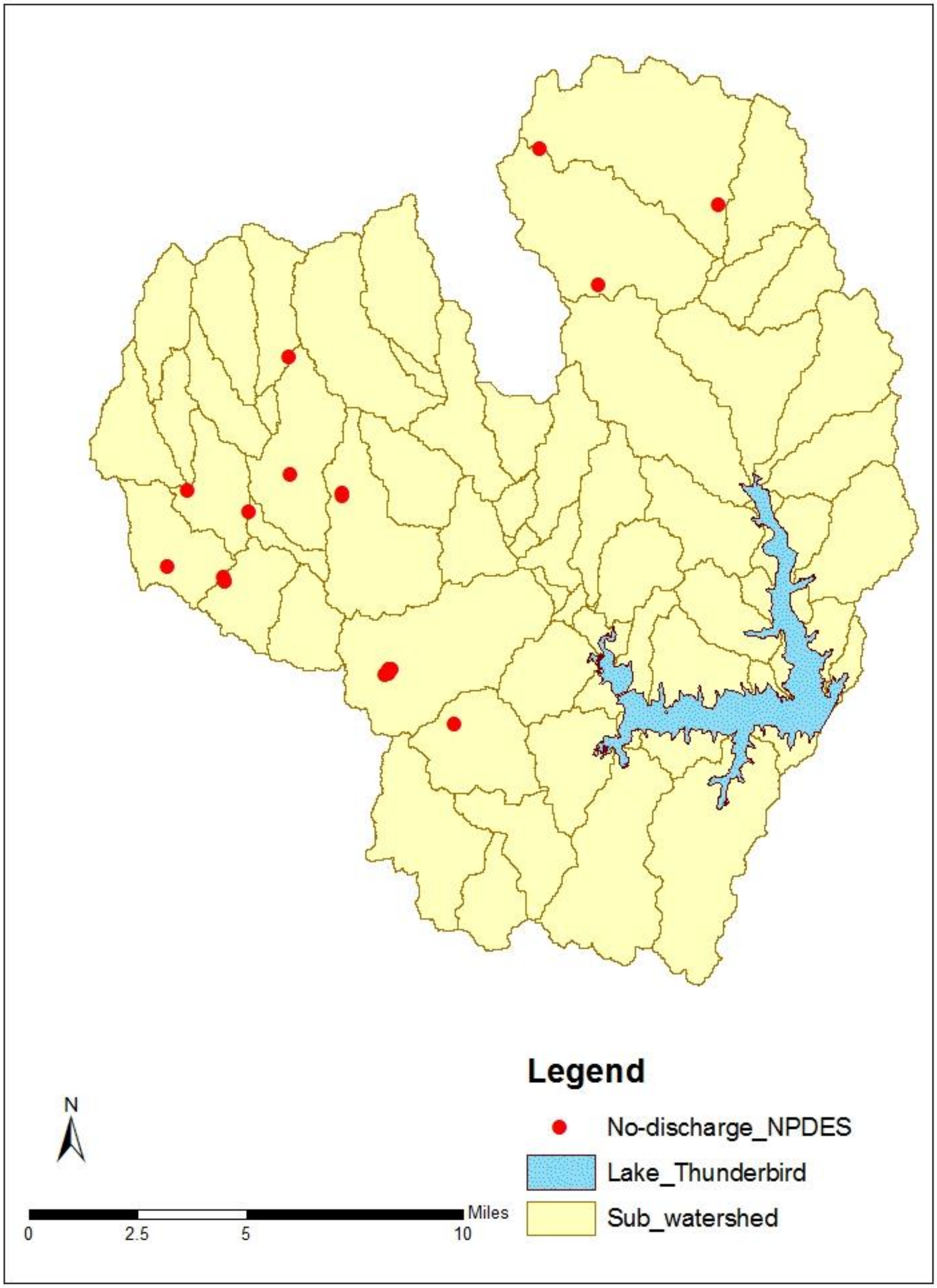

Figure 3-1 Location of NPDES No-Discharge WWTP Facilities in Lake Thunderbird Watershed

Table 3-1 NPDES No-Discharge Facilities in Lake Thunderbird Watershed

Facility Name	Facility Type	Facility No.	OWRB	County
All Saints Catholic School Lagoon	Lagoon (Total Retention)			Cleveland
BCM Oklahoma – Tecumseh Rd	Total Retention	OKG11T020	WD82-013	Cleveland
BCM Oklahoma – Norman North	Total Retention	OKG11T019		Cleveland
Control Flow	Total Retention		WD82-017	Cleveland
Dolese - North Norman	Total Retention	OKG11T031		Cleveland
Dolese - Moore	Total Retention	OKG11T082		Cleveland
Hall Park*	Lagoon (Total Retention)			Cleveland
Lakeside Church of God WWT	Lagoon (Total Retention)			Cleveland
Lucky Food Mart	Total Retention	OKG75T009		Cleveland
Miller's Acres WWT	Lagoon (Total Retention)			Cleveland
Ranch Estates MHP	Lagoon (Total Retention)			Cleveland
Barnes School	Lagoon (Total Retention)			Oklahoma
Schwartz School	Lagoon (Total Retention)			Oklahoma
Pro-Am	Lagoon (Total Retention)			Oklahoma

* No longer in use. Hall Park is connected to Norman sewer system.

Table 3-2 Summary of Sanitary Sewer Overflow (SSO) Bypass (> 1000 gallons) Occurrences in the Lake Thunderbird Watershed

City Name	Bypass Volume (gallons)	Number Events	Date Range		Max. Bypass Volume (gallons)
			From	To	
Moore	2,459,679	98	10/11/2000	3/20/2012	374,000
Norman	123,949	28	10/9/2000	11/6/2008	20,000

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 Lake Thunderbird there is one Phase I MS4 permit for Oklahoma City.

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/). The cities of Midwest City, Moore, Noble and Norman have Phase II MS4 permits for stormwater discharges and stormwater management (Figure 3-2). Because there are no numeric load limits for MS4 permits, Moore and Norman, along with Oklahoma City, will receive a separate WLA based on the proportional contribution of pollutant loading from each of the three cities relative to the total watershed load determined with the watershed model developed for this TMDL study. Midwest City and Noble have a very small contribution to the total watershed area so they will not be included as part of the WLA determined for the MS4 permits for the three larger cities in the watershed. These two smaller MS4 areas will, however, be accounted for by the Load Allocation (LA) for the portion of the watershed that is not included in the three MS4 urban areas. Table 3-3 lists the urban areas with Phase I or Phase II MS4 permits in the Lake Thunderbird watershed area. Table 3-3 lists the urban areas with Phase I or Phase II MS4 permits in the Lake Thunderbird watershed area.

Table 3-3 Urban Areas with MS4 Permits in the Lake Thunderbird Watershed

City Name	Permit-ID	MS4 Phase	Date Issued
Oklahoma City	OKS000101	Phase I	01/19/2007
Moore	OKR040012	Phase II	12/1/2005
Norman	OKR040015	Phase II	11/29/2005
Noble	OKR040037	Phase II	1/5/2006
Midwest City	OKR040011	Phase II	11/7/2005

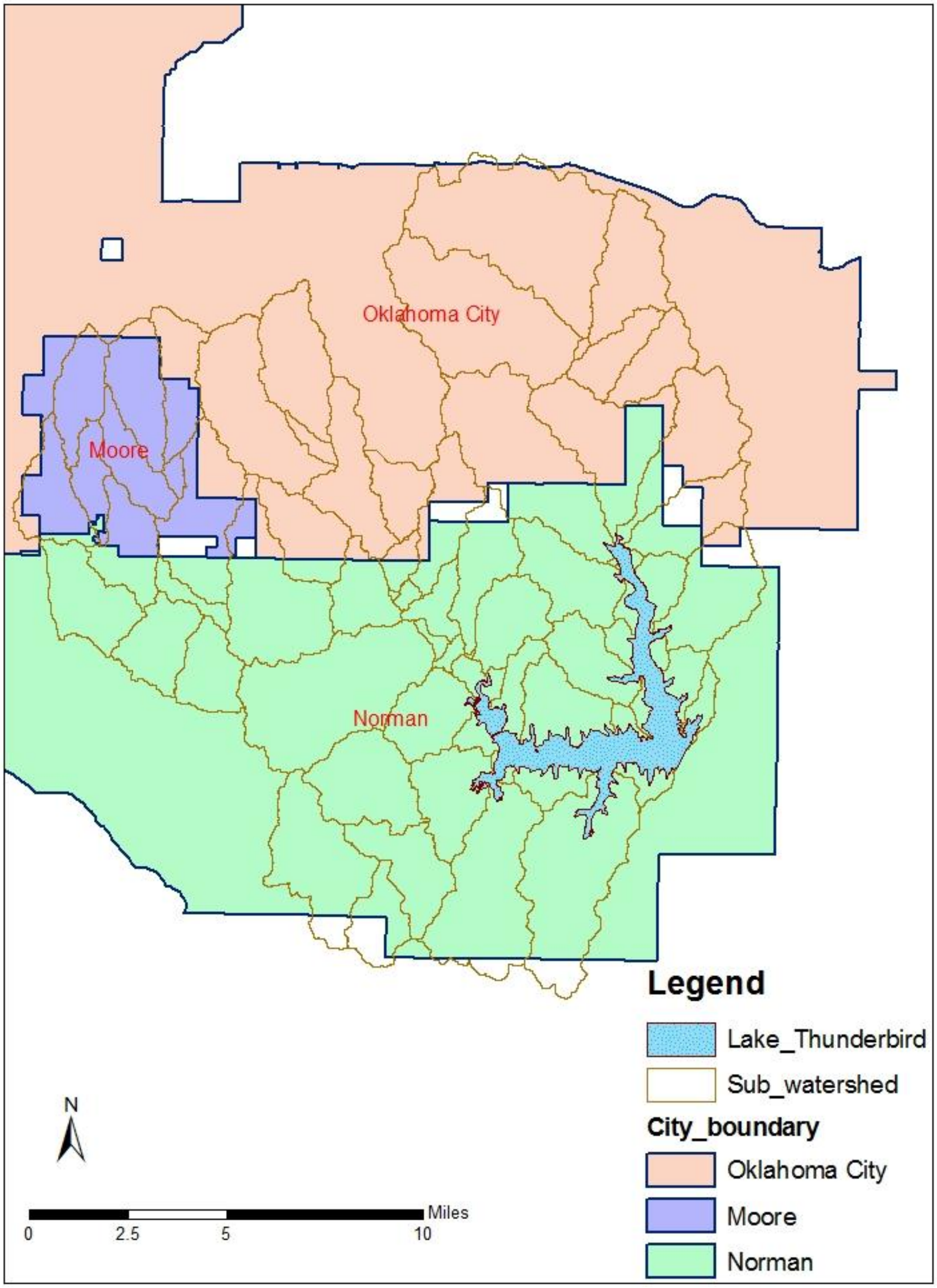
Oklahoma City
Moore
Norman
Legend
Lake_Thunderbird
Sub_watershed
City_boundary
Oklahoma City
Moore
Norman
N
0
2.5
5
10
Miles

Figure 3-2 MS4 City Boundaries for Moore, Norman and Oklahoma City in the Lake Thunderbird 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 243 construction site permits issued within the Lake Thunderbird watershed are shown in Figure 3-3. Table 3-4 summarizes the number of construction site permits issued for each year from 2007 through 2012 where the issue date of the permit was available.

Table 3-4 Construction Site Permits Issued in the Lake Thunderbird Watershed

Year	Number of Permits
2007	15
2008	52
2009	26
2010	15
2011	20
2012	26
Unknown	89
Total	**243**

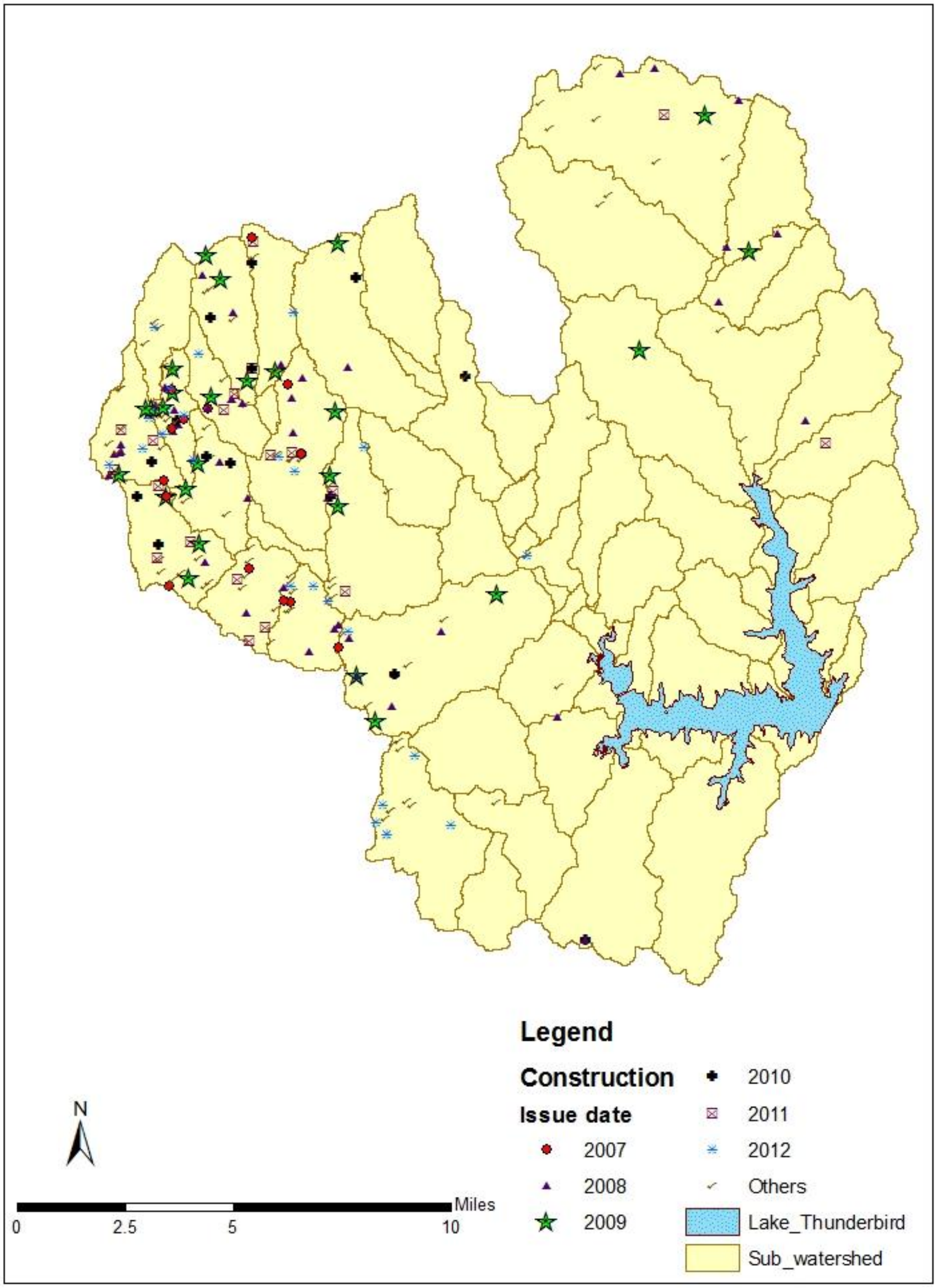

Figure 3-3 Construction Site Permits Issued in the Lake Thunderbird Watershed (2007-2012)

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. The locations of the 14 industrial site MSGP permits issued within the Lake Thunderbird watershed are shown in Figure 3-4. Table 3-5, organized by SIC type description and the permit identification numbers, summarizes the MSGP industrial site permits issued in the watershed.

Table 3-5 Industrial Site MSGP Permits Issued in Lake Thunderbird Watershed

Company Name	SIC Type	County	Permit-ID	Date Issued	Receiving Water
Silver Star	Asphalt Paving Mixtures And Blocks	Cleveland	OKR050570	2/23/2012	Little River
Vaughan Foods	Food Preparations	Cleveland	OKR051641	2/29/2012	Moore Creek
E & S Equipment, Inc.	Industrial Valves	Cleveland	OKR051761	3/15/2012	Little River, N Fork
Milligan Materials	Local Trucking, Without Storage	Cleveland	OKR052433		Little River
Southwestern Wire, Inc.	Miscellaneous Fabricated Wire Products	Cleveland	OKR051014	5/30/2012	Little River
Oklahoma Foreign Parts, Inc.	Motor Vehicle Parts, Used	Cleveland	OKR050246	3/12/2012	Little River
Ruppert Enterprises, Inc.	Motor Vehicle Parts, Used	Cleveland	OKR050252	3/28/2012	Little River
Frecks Truck Parts, Oklahoma Truck Parts, Inc.	Motor Vehicle Parts, Used	Cleveland	OKR051032	3/28/2012	Little River
Pat Spaulding	Motor Vehicle Parts, Used	Cleveland	OKR051422	3/1/2012	Little River
Windmill LLC	Motor Vehicle Parts, Used; Scrap And Waste Materials	Cleveland	OKR051320	2/14/2012	Little River
Sand Express Inc.	Nonmetallic Minerals Services	Cleveland	OKR051916	7/15/2009	Little River, N Fork
Sooner Redi Mix LLC	Ready-Mixed Concrete	Oklahoma	OKR051754	8/13/2008	Little River, N Fork
Van Eaton Ready Mix	Ready-Mixed Concrete	Cleveland	OKR051978	3/2/2012	Little River, N Fork
Johnson Controls, Inc.	Refrigeration And Heating Equipment	Cleveland	OKR050347	3/13/2012	Little River

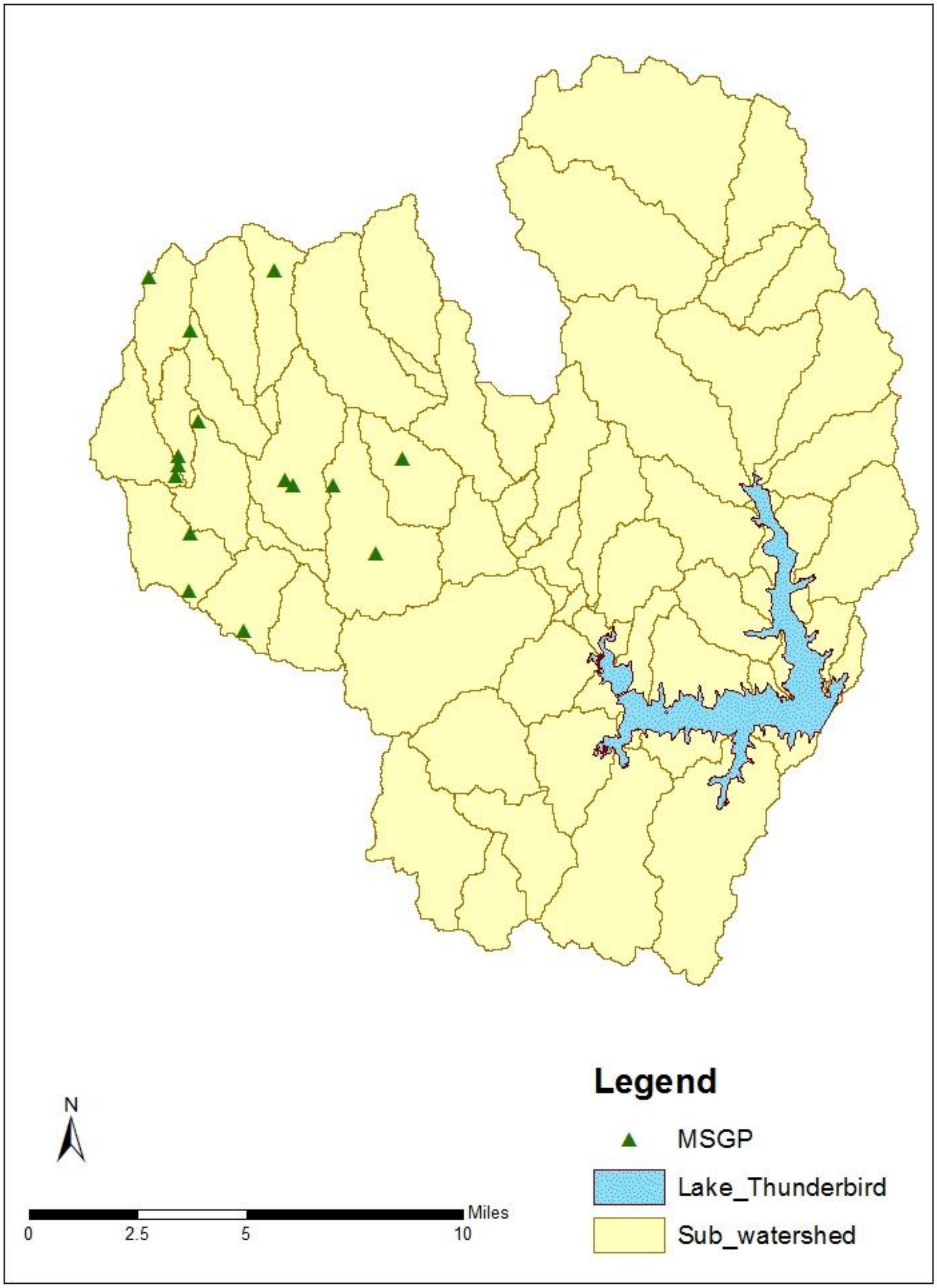

Figure 3-4 Multi-Sector General Permits (MSGP) Issued in the Lake Thunderbird Watershed for Industrial Sites

3.1.6 NPDES Animal CAFO's

There are no concentrated animal feeding operations (CAFO) located within the Lake Thunderbird watershed.

3.2 Assessment of Pollutant Sources

3.2.1 Atmospheric Deposition of Nutrients

In many coastal and inland watersheds, atmospheric deposition of nitrogen, derived primarily from burning fossil fuels, can account for 25-30 percent, or more, of the total nitrogen loading to a waterbody. Atmospheric deposition of nitrogen is therefore a potentially significant component of the budget for nitrogen loading to a waterbody. This source is considered to be an uncontrollable source term for the TMDL determination. Nevertheless, lake water quality models that simulate the nutrient balance of the lake must account for 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 Lake Thunderbird, wet and dry deposition data was estimated as the average of annual data from 2008-2009 for ammonia and nitrate from the National Atmospheric Deposition Program (NADP) for Station OK17 (Kessler Farm Field Laboratory, Lat 34.98; Lon -97.5214) and the Clean Air Status and Trends Network (CASTNET) Station CHE185 (Cherokee Nation, Lat 35.7507, Lon -94.67). 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.

3.2.2 Watershed Loading of Nutrients and Sediment

External loading of nutrients and sediments from the watershed to the lake 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 budget for 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 Little River drainage basin into Lake Thunderbird 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 Lake Thunderbird project is presented in Section 3.3 of this report with a complete description of the model given in Appendix A of this report.

3.2.3 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 budget for the lake and stimulate algal production. Particulate organic matter in the water column and sediment bed of Lake Thunderbird is derived from both external watershed runoff loading (non-living detritus) and internal biological production of living organic matter. Particulate organic matter settles out of the water column, accumulates within the sediment bed, and undergoes decomposition processes. During the summer stratified months from mid-May 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 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.

Site-specific measurements of nutrient release from the sediment bed under aerobic and anoxic conditions in Lake Thunderbird are not presently 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); Eucha Lake (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 set of 17 lakes/reservoirs in the Central Plains (Dzialowski and Carter, 2011) that can be used to estimate internal loading rates of nutrients for Lake Thunderbird. Benthic phosphate release rates, characteristic of mesotrophic lakes and reservoirs, have also been estimated by OWRB (2011b) for Lake Thunderbird using an empirical methodology developed by Nurnberg (1984).

3.3 HSPF Watershed Model

3.3.1 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-watersheds (Bicknell et al., 2001). The internal stream model routes flow and water quality constituents through a network of river reaches for each sub-watershed of the watershed. The HSPF hydrologic sub-model provides for simulation of water balances in each sub-watershed 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-watershed land use through model calibration to simulate the water balance and pollutant loading from a sub-watershed. 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 is considered a Level 3 Complex or Advanced Model. The URL for HSPF is http://www.epa.gov/ceampubl/swater/hspf /index.htm.

3.3.2 Model Setup and Data Sources

The HSPF model was initially setup using EPA's BASINS watershed modeling platform. The sub-watershed boundaries were delineated based on USGS's NHD flow line and the National Elevation Dataset (NED). The 2001 NLCD land use data were used in the Lake Thunderbird watershed model. An intensive one-year stream monitoring was conducted by the Oklahoma Conservation Commission (OCC) with support from DEQ from April 2008 to April 2009. Five monitoring stations were set up in the lake watershed on major tributaries with programmable automatic samplers (autosamplers) and rain gages. The information of these stations is given in Table 3-6 and Figure 3-5. Five-minute rainfall data from these five stations and the MESONET station at the Max Westheimer Airport (Figure 3-5) were used as boundary forcing in the Thunderbird model. All the other meteorological data were obtained from the MESONET station at the Westheimer Airport.

Table 3-6 Information of the OCC observation stations

Station ID	Site Name	Description	Latitude	Longitude
OK520810-00-0080W	L17	Little River @ 17th St.	35.32350	-97.49630
OK520810-00-0140P	Elm	West Elm Creek @ 134th St.	35.33400	-97.38540
OK520810-00-0080H	L60	Little River @ 60th Ave.	35.27763	-97.35321
OK520810-00-0090C	Rock	Rock Creek @ 72nd Ave.	35.26100	-97.33550
OK520810-00-0030G	Hog	Hog Creek @ 119th Ave.	35.34957	-97.25816

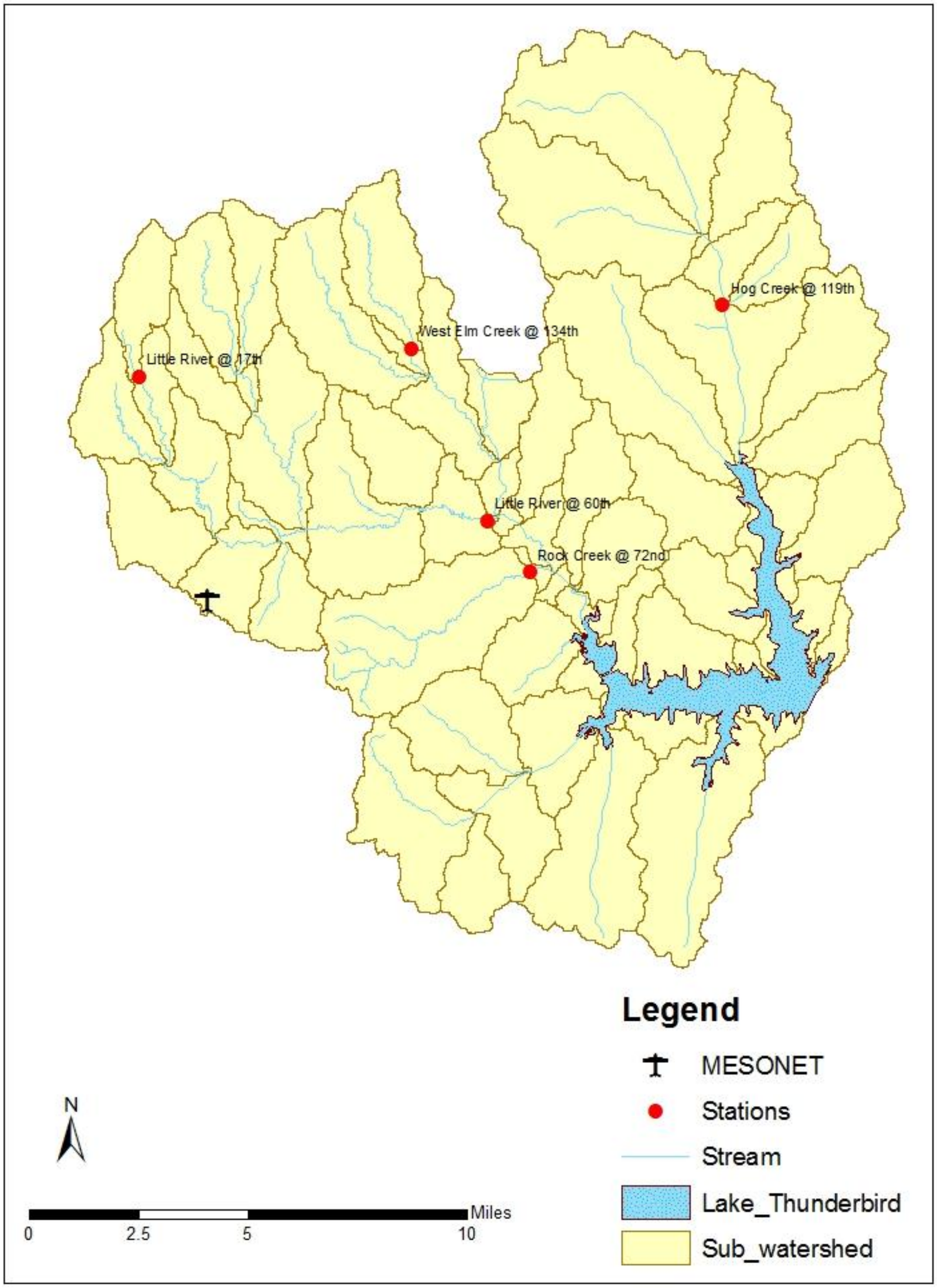

Figure 3-5 Sub-watershed delineation for the Lake Thunderbird watershed

3.3.3 Model domain and discretization for sub-watershed representation

The model breaks the Lake Thunderbird watershed into 66 sub-watershed/stream reaches based on the stream network in the watershed as described by USGS's NHD database and flow path calculations based on the NED dataset (Figure 3-5). These sub-watersheds were further assigned to 6 groups based on the precipitation data used for each of these groups. All other meteorological data (e.g., air temperature and solar radiation) were shared by all sub-watersheds as reported by the MESONET station at the Westheimer Airport. The MESONET station is located just outside the watershed in Norman while the airport is partially in the watershed.

3.3.4 Observed OCC 2008-2009 stream data for model calibration

Stream discharge and water quality data from the five OCC stations were used for model calibration (Table 3-6 and Figure 3-5). Stream discharge rating curves based on water depth were initially developed for the monitoring stations using stream survey data, limited number of discharge measurements, and Manning's equation. As more stream discharge measurements with a wider range of discharge rates became available well into the monitoring period, the rating curves were refined and updated. They were finalized after the monitoring work was completed and the discharge record was revised retrospectively. This affected the flow-weighted sampling for total phosphorus (TP) and total Kjeldahl nitrogen (TKN) as they required accurate discharge rate for correct flow weighting. The model calibration process accounted for this inconsistency by simulating water depth at the monitoring sites and using the initial rating curves to simulate the concentrations of TP and TKN of the flow-weighted composite samples.

3.3.5 HSPF Model Calibration

The HSPF model covered the period where stream discharge and water quality data were measured for the watershed: April 17, 2008 through April 26, 2009. The time step for the HSPF model simulation was set at one hour.

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 analysis are conducted to evaluate model performance.

In this study, observed stream discharge and water quality parameters were plotted on the same graphs with model simulated time series of these same parameters. 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 model simulation matched observed data. Statistics for comparing the observed data and the model simulation were calculated as shown in Table 3-7.

Figure 3-6 through Figure 3-9 showed the time series comparison plots at one of the five monitoring stations.

Table 3-7 Calculated statistics at calibration station L17 (Little River at 17th Street, Moore).

Parameter	Units	Observed Data average	HSPF Average	% Difference	r^2	Nash-Sutcliffe coefficient
Flow	cfs	7.6	6.2	-18%	0.92	0.66
Temperature	Degrees-C	16.3	16.3	0%	0.72	0.71
TSS	mg/L	19.0	20.7	8.9%	0.63	-0.56
TP	mg/L	0.215	0.25	5.5%	0.0	-1.54
TKN	mg/L	1.35	1.56	9.1%	0.09	-1.56
DO	mg/L	8.5	8.0	-6.2%	0.71	0.71

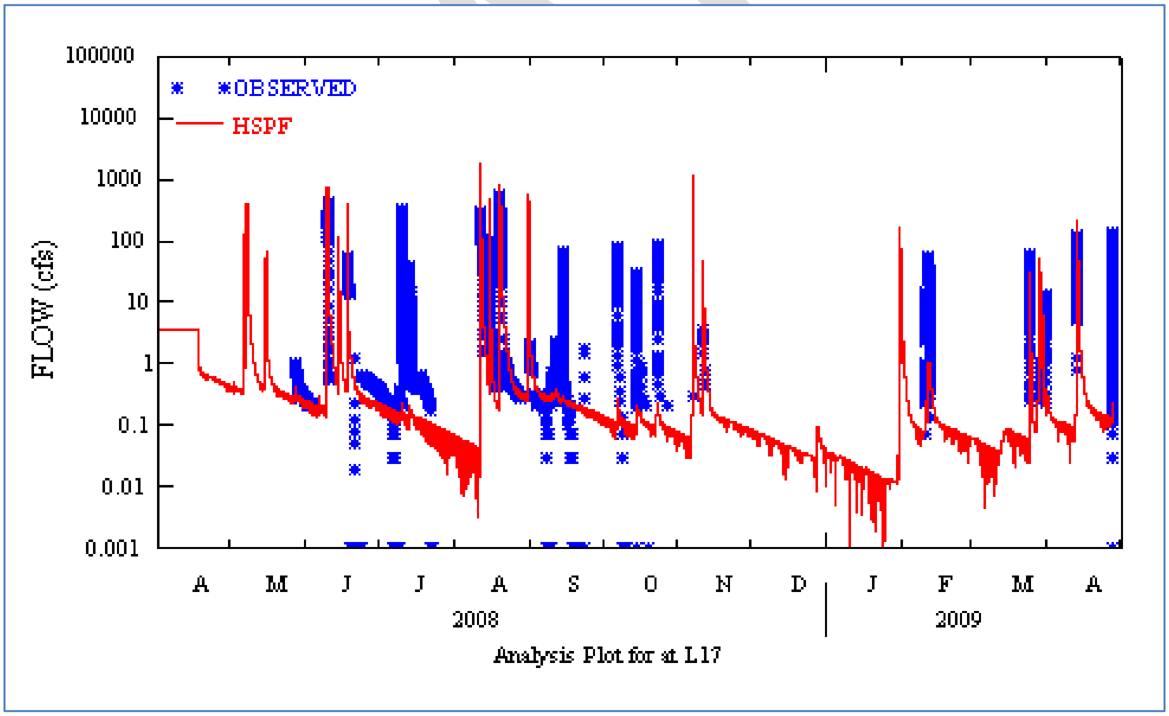

Figure 3-6 Flow calibration plot at station L17 (observed data are not continuous)

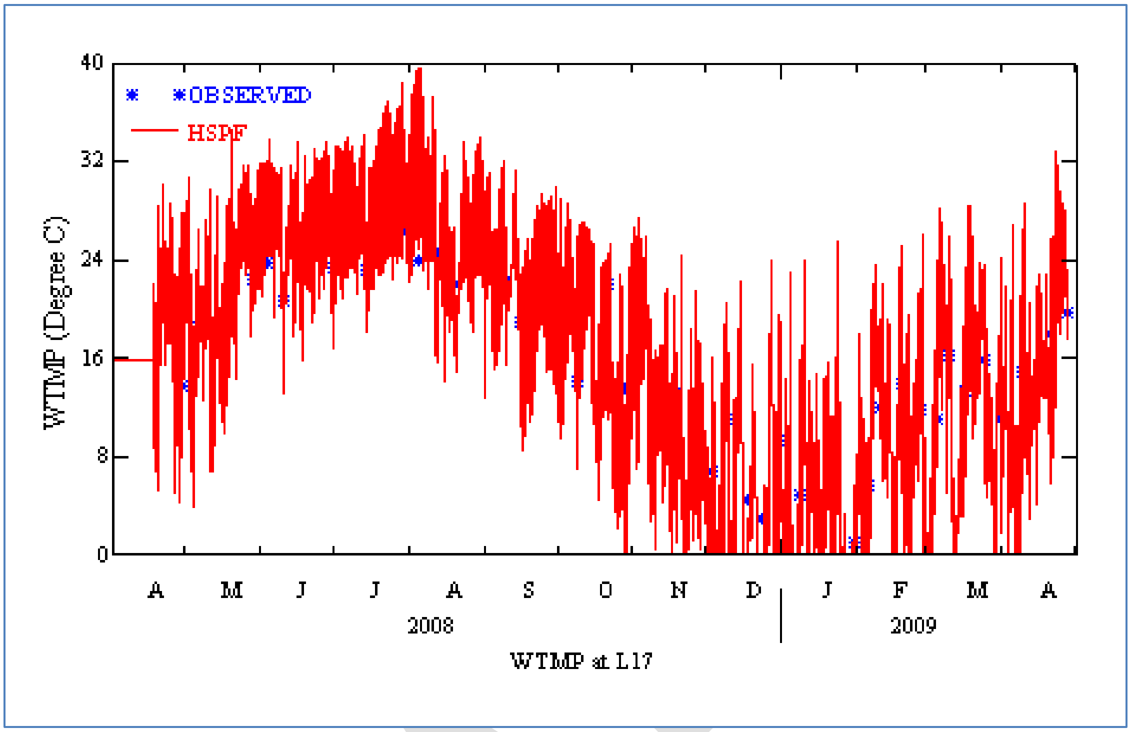

Figure 3-7 Water temperature calibration plot at station L17

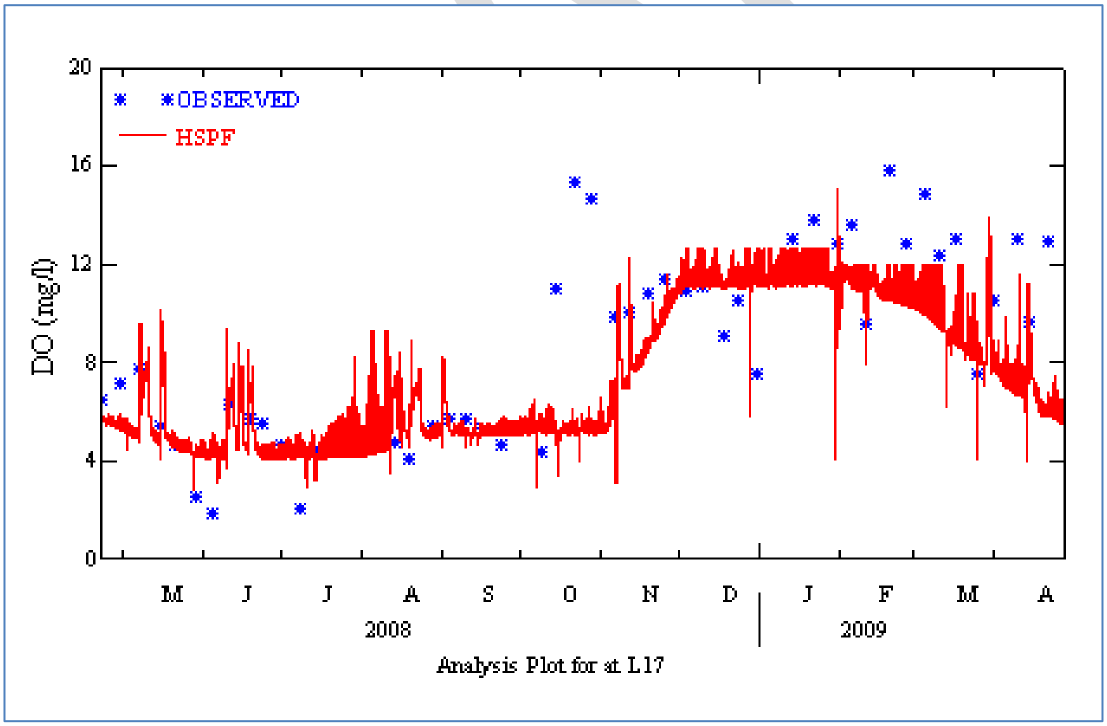

Figure 3-8 DO calibration plot at station L17

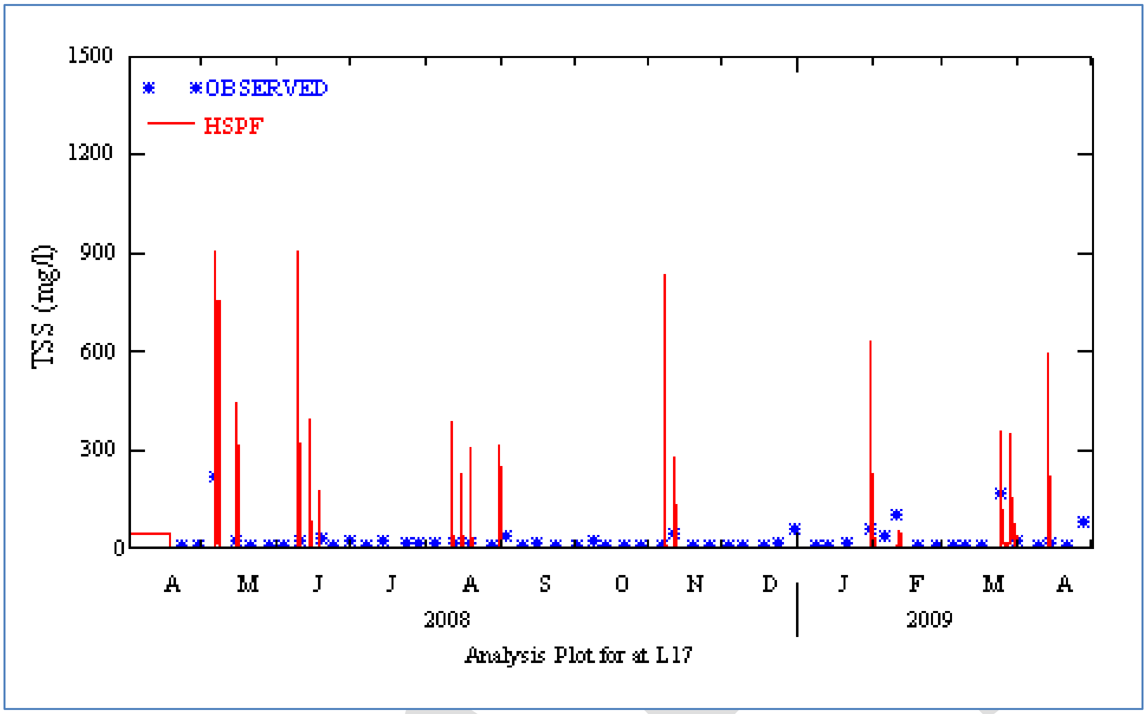

Figure 3-9 TSS calibration plot at station L17

3.3.6 HSPF Load budget for TSS, TN, TP and CBOD loads for existing calibration conditions

The HSPF model framework consists of a network of sub-watersheds that generate flow and pollutant loading from runoff over the land uses of sub-watersheds defined within a larger watershed domain for a project. 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 reach that is defined by length, volume, surface area, depth and hydraulic residence time. In this study, sub-watersheds that drain into Lake Thunderbird via a tributary generate flow and water quality concentrations at specific downstream outlet locations at the lake. Sub-watersheds that are adjacent to and drain directly into Lake Thunderbird generate water volume and loads from distributed runoff over the entire sub-watershed. By aggregating the pollutant loading from all the tributary and distributed runoff sub-watersheds, the annual pollutant budget derived from the HSPF model is given in Table 3-8. The pollutant loadings normalized on a per acre per year basis for each sub-watershed are given in Figure 3-10 through Figure 3-14.

Table 3-8 HSPF Load Budget

Total HSPF watershed Loads: 4/27/2008-4/26/2009					
Watershed Load	TN	TP	CBOD	Sediment	TOC
	1000 lb/yr	1000 lb/yr	1000 lb/yr	1000 lb/yr	1000 lb/yr
Tributary	268.943	57.001	818.460	28,503.2	1,369.796
Distributed	17.045	0.593	49.656	1,544.4	88.209
Total	285.988	57.595	868.116	30,047.6	1,458.005

Total HSPF watershed Loads: 4/27/2008-4/26/2009					
Watershed	TN	TP	CBOD	Sediment	TOC
Load	kg/day	kg/day	kg/day	kg/day	kg/day
Tributary	334.2	70.8	1,017.1	35,422.0	1,702.3
Distributed	21.2	0.7	61.7	1,919.3	109.6
Total	355.4	71.6	1,078.8	37,341.3	1,811.9

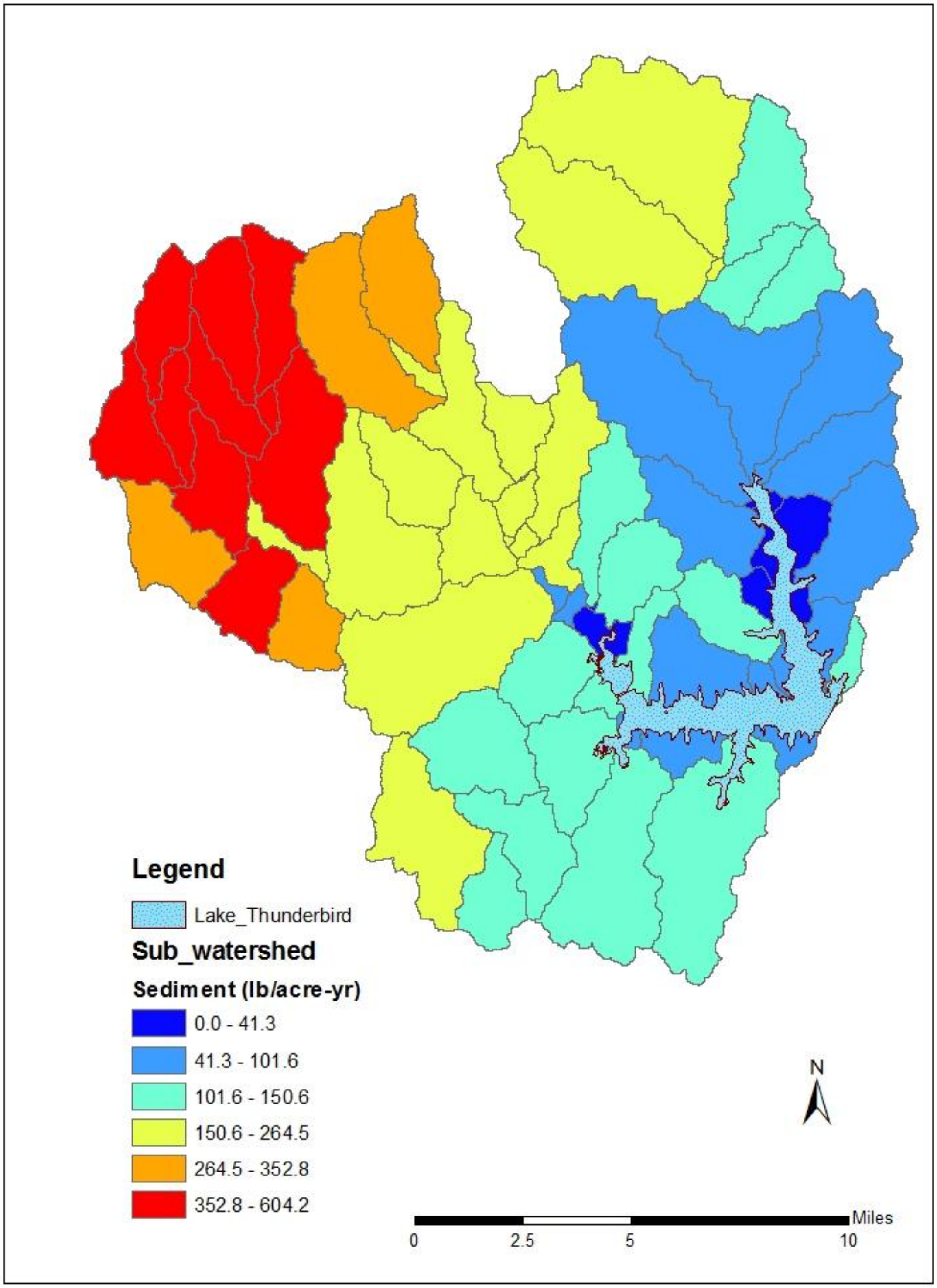

Figure 3-10 Calculated sub-watershed sediment loadings by HSPF model

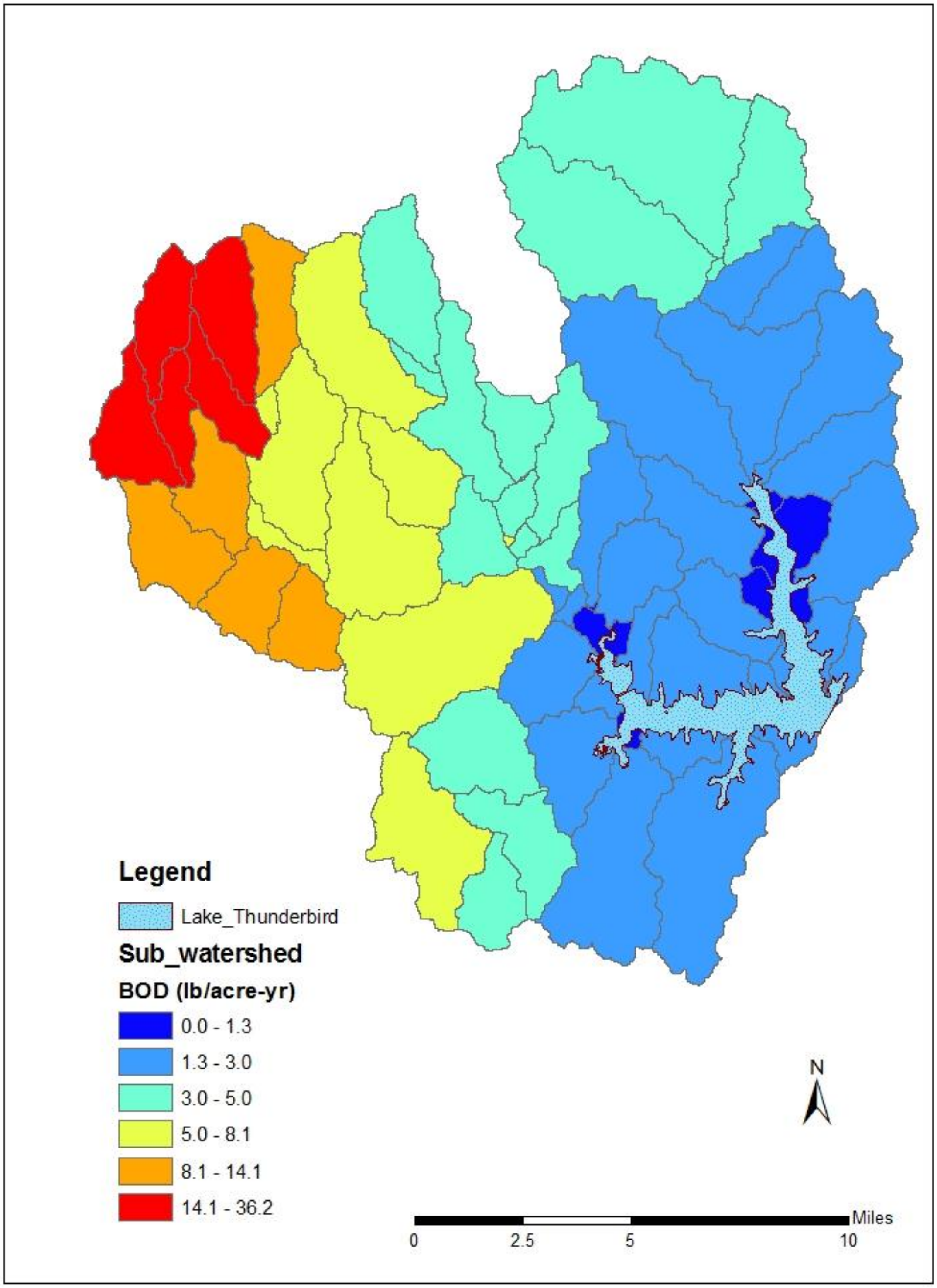

Figure 3-11 Calculated sub-watershed CBOD loadings by HSPF model

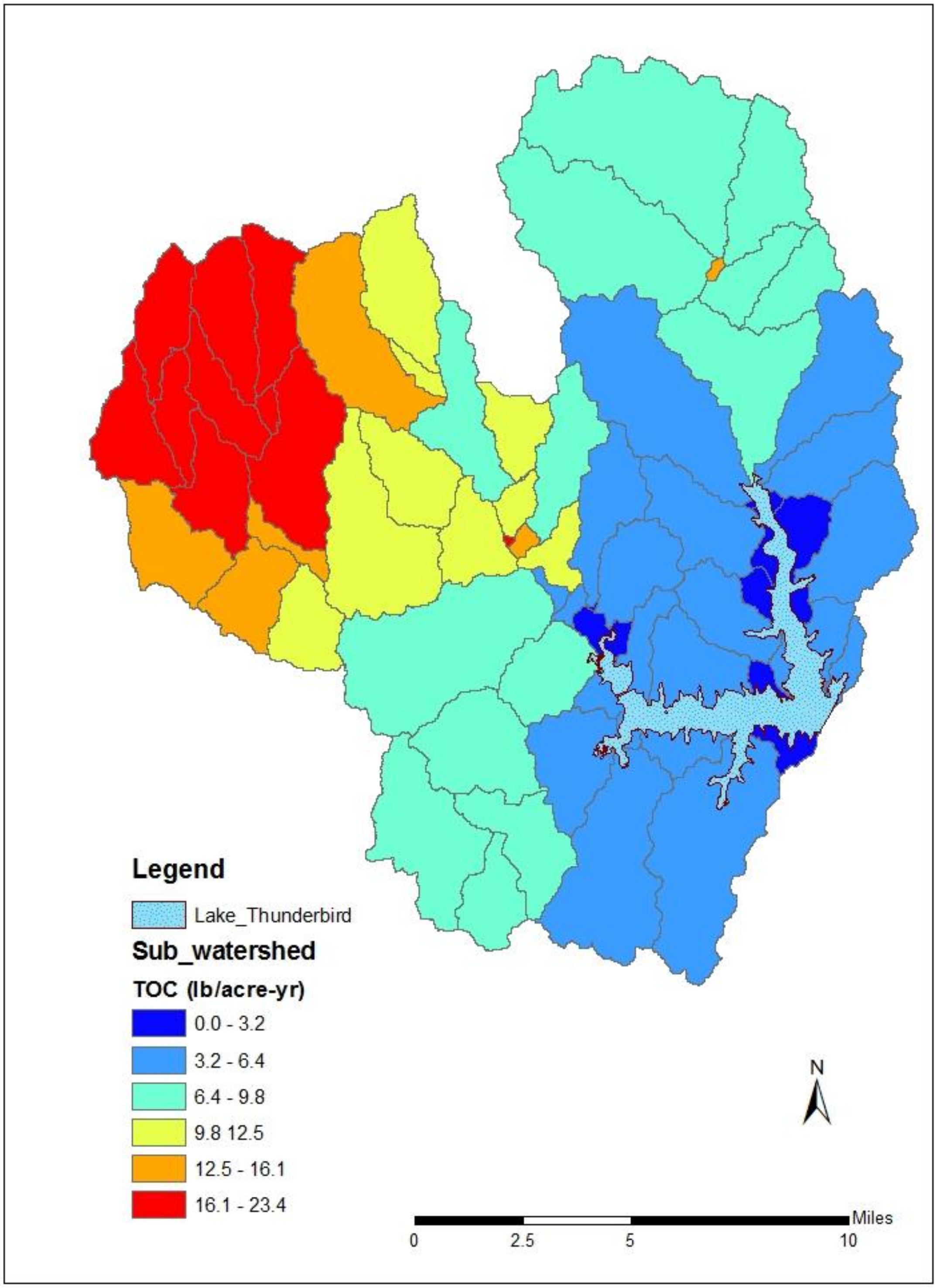

Figure 3-12 Calculated sub-watershed TOC loadings by HSPF model

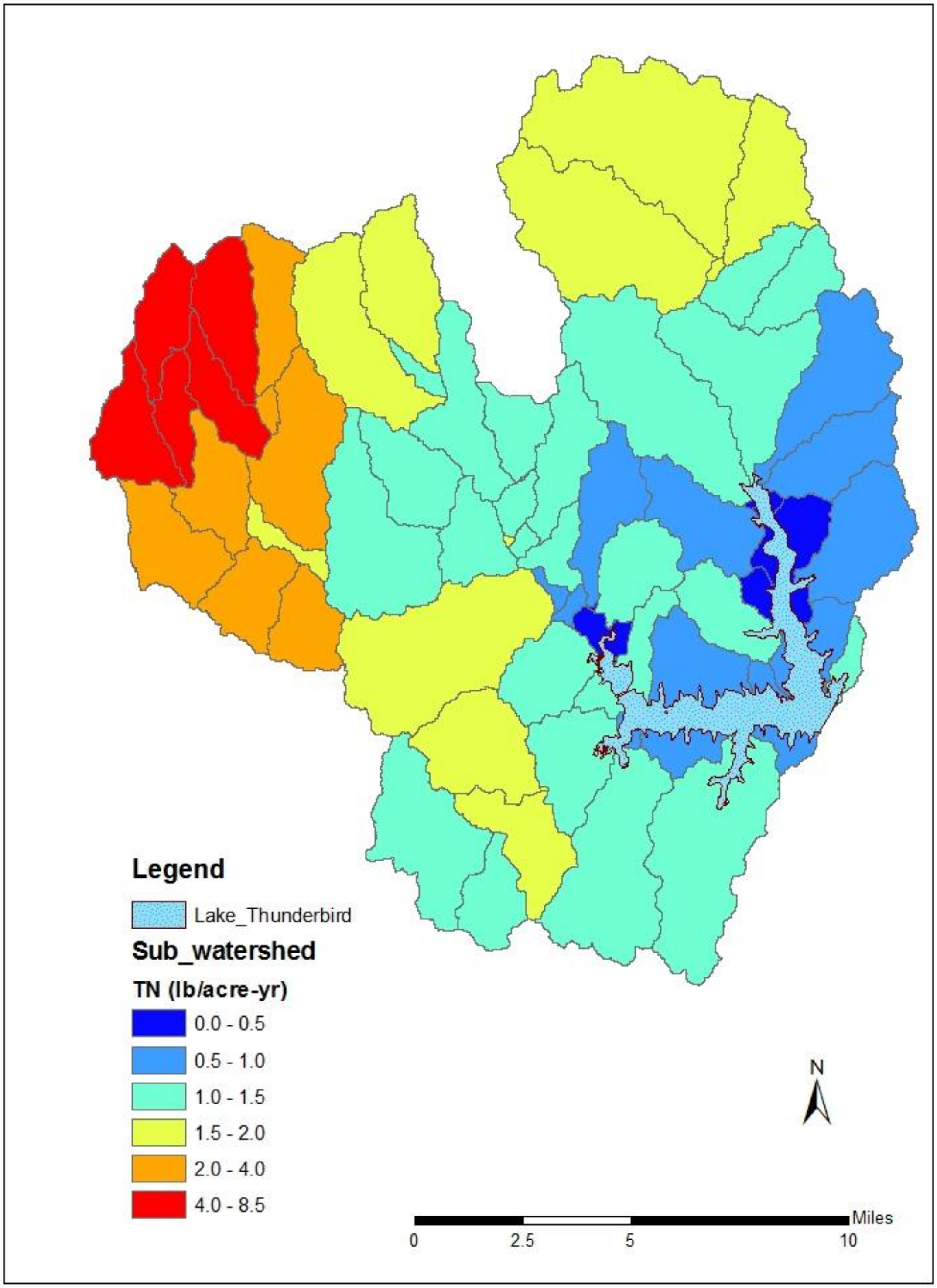

Figure 3-13 Calculated sub-watershed TN loadings by HSPF model

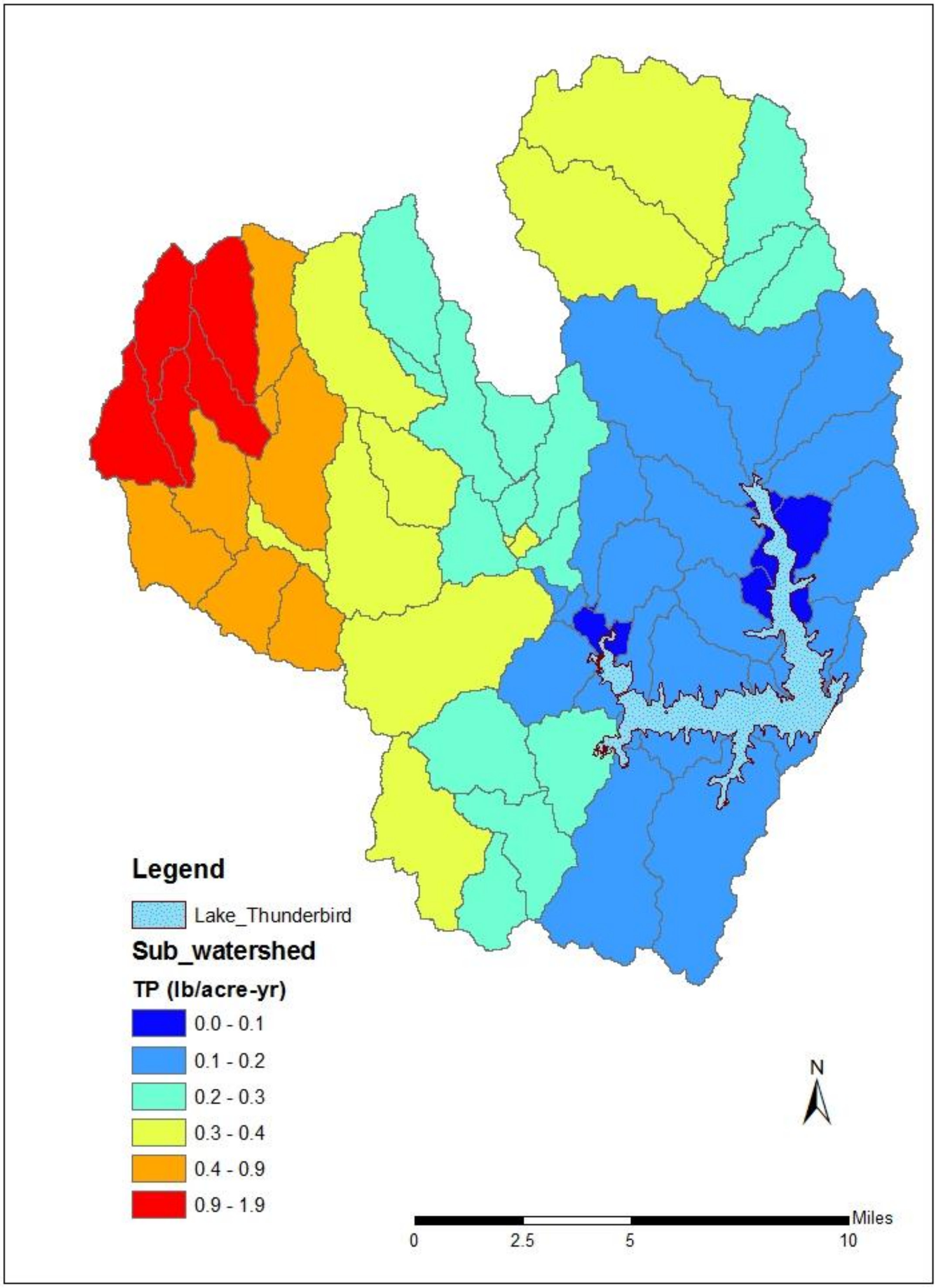

Figure 3-14 Calculated sub-watershed TP loadings by HSPF model

SECTION 4 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 Lake Thunderbird and HSPF watershed pollutant loading. Appendix B of this TMDL report presents a description of the EFDC model, setup of the model, data sources, model results for current 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, 2008). 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 model included routine lake and tributary monitoring by Oklahoma Water Resources Board (OWRB) and the Oklahoma Conservation Commission (OCC); lake level and storage volume monitoring by the USGS and the U.S. Army Corps of Engineers (COE); and meteorological data from rain gages co-located with tributary sampling sites and the Oklahoma MESONET network. Data was collected by OWRB in 2001 with an Acoustic Doppler Continuous Profiler (ADCP) to map bathymetry of Lake Thunderbird. The Central Oklahoma Master Conservancy District (COMCD), in cooperation with OWRB, has been monitoring chlorophyll-a, nutrients, sediment, water temperature, organic matter and dissolved oxygen in the lake since 2000. In support of this TMDL study of Lake Thunderbird, OWRB and OCC conducted a special monitoring program from April 2008 through April 2009 to collect samples in watershed tributaries and to

supplement the monitoring program conducted as part of the routine COMCD-OWRB surveys of Lake Thunderbird. Sediment bed data was also collected by OWRB at five stations in the lake in 2008 to provide sediment bed data needed for the sediment diagenesis model. The data collected by OWRB and OCC was used for development and calibration of the EFDC hydrodynamic, sediment transport, water quality, and sediment diagenesis models. Tables of observed water quality data used for lake model calibration are presented in Appendix D of this report.

EFDC Model Domain. The EFDC model allows for the physical representation of the lake with either coarse or fine resolution grid blocks. For this study, a fine resolution mesh of grid cells was developed to obtain a good representation of the effect of lake geometry, particularly the remnant river channels of the Little River and Hog Creek, and river inflow on circulation in the lake (Figure 4-1). The computational grid developed to map the geometry of Lake Thunderbird consisted of 1,660 horizontal cells. Depth of the water column was represented with 6 layers to account for the effects of seasonal stratification. The shoreline of the lake is defined by the normal pool elevation of 1039.0 ft (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 4-1). The causeway across the southwestern area of the Little River arm of the lake was represented in the model grid as a barrier to flow by removing selected model grid cells to force flow to be transported around the roadway.

Boundary Conditions. The EFDC lake model requires the specification of external boundary data to describe: (1) flow and pollutant loading from the watershed; (2) withdrawals from water supply intakes and releases at the dam; (3) meteorological and wind forcing; and (4) atmospheric deposition of nutrients. As described in Section 3.3, flow and pollutant loading from the watershed was provided by the HSPF model as hourly time series data for 18 tributaries and 18 distributed flow areas. Tributary inflows included the Little River, Elm Creek, Rock Creek, Hog Creek, Dave Blue Creek, Jim Blue Creek, Clear Creek, Willow Branch and a number of unnamed streams. Although HSPF and EFDC both model sediments, nutrients, organic matter, algae and dissolved oxygen, the model results for some HSPF state variables require stoichiometric transformations, as described in Appendix B, for linkage to the EFDC state variables.

A flow boundary was assigned to represent water supply withdrawals at a common intake location from the reservoir for the municipalities of Norman, Midwest City and Del City. Water supply withdrawal data was provided by COMCD. A flow boundary was assigned to account for release flow at the dam (designated by the U.S. Army Corps of Engineers as Station NRM02) with flow data provided by the Army Corps of Engineers. The only sources of water inflow to the lake model are from the simulated HSPF flows and precipitation and the only withdrawals of water are assigned from water supply withdrawals, release flow at the dam and evaporation.

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 Station NRMN. 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 to existing conditions (2008-2009) 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 Lake Thunderbird, wet and dry deposition data for nitrogen, presented in Appendix B, was estimated as the average of annual data from 2008-2009 for ammonia and nitrate from the National Atmospheric Deposition Program (NADP) for Station OK17 (Kessler Farm Field Laboratory) and the Clean Air Status and Trends Network (CASTNET) Station CHE185. Wet deposition loading of ammonia and nitrate was estimated from annual rainfall (36.9 inches) measured during the period from April 2008-April 2009. 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).

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 mid-April 2008. The spatial distribution of initial conditions for the model is based on simulated conditions at the end of the 1-year model simulation period. Restart conditions, written for all state variables of the model at the end of a preliminary model run, were used to assign a simulated set of initial conditions that accounted for spatial variability of conditions in the water column and sediment bed.

4.3 EFDC Model Calibration to Existing Conditions

The EFDC lake model was setup for a 375 day period from April 17, 2008 through April 26, 2009. Model results were calibrated against observed data collected at 8 water quality monitoring sites shown in Figure 2-1. Model results were calibrated to observations for water level, water temperature, TSS, nitrogen, phosphorus, dissolved oxygen, organic carbon and algae biomass (chlorophyll). 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 only provides a brief description of lake model calibration. For more details, please refer to Appendix B of this report.

TSS and Turbidity. Water clarity is an issue for impairment in Lake Thunderbird and turbidity is the parameter used to determine if the lake fully supports designated uses. Since the EFDC model does not simulate turbidity directly as a state variable, comparison of EFDC results with the water quality criteria for turbidity required the development of a regression relationship of TSS vs. turbidity based on site-specific paired data for Lake Thunderbird. The TSS vs. turbidity relationship developed for Lake Thunderbird, presented in Appendix B, was used to transform modeled TSS to modeled turbidity for comparison to the water quality criteria for turbidity of 25 NTU. Based on summary statistics computed for turbidity for all 8 stations, the 90th percentile for observed 2008-2009 turbidity (29.7 NTU) is seen to exceed the water quality target of 25 NTU. The 90th percentile of the calibrated model results for turbidity (27.6 NTU) computed for the 8 stations also shows non-compliance with the target of 25 NTU.

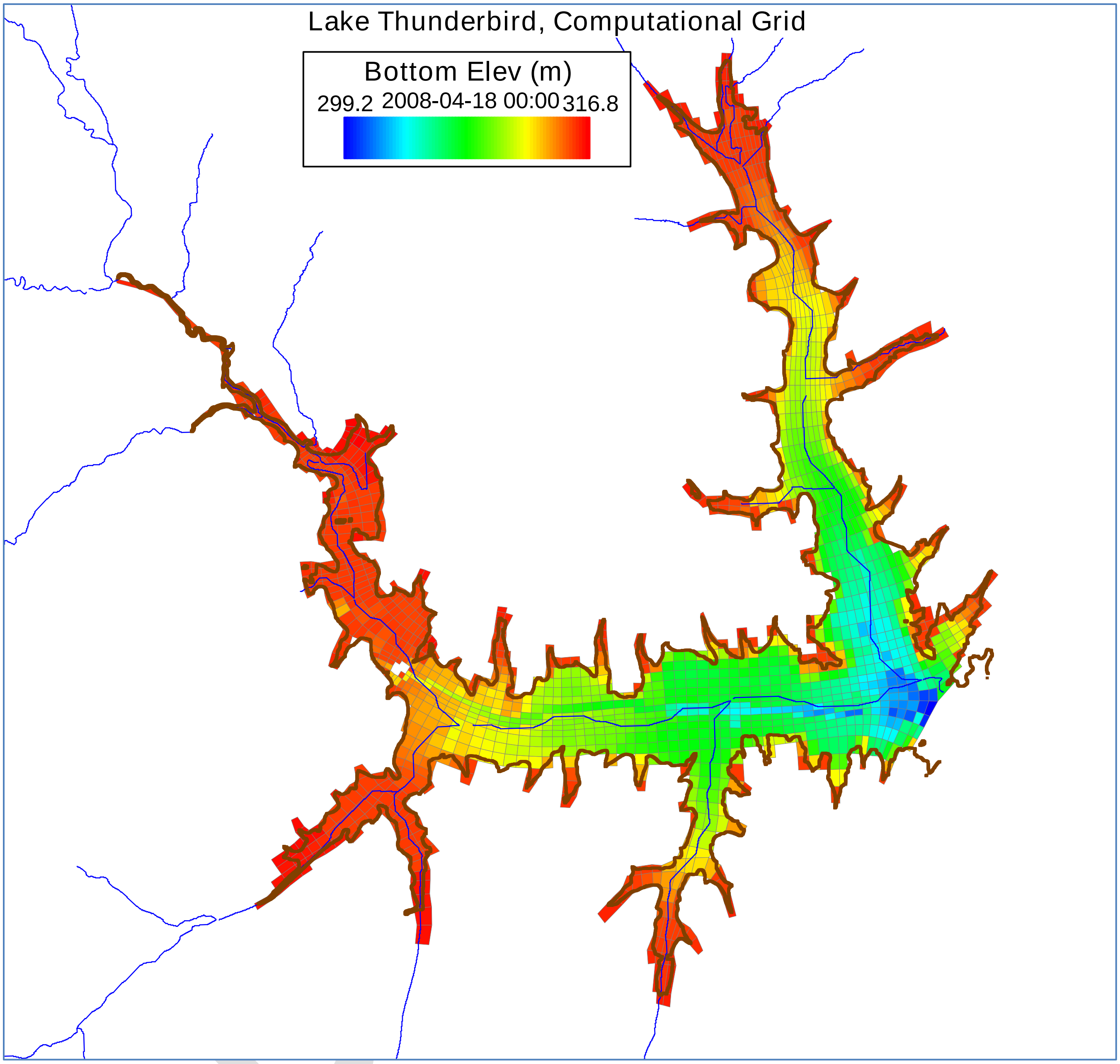

Figure 4-1 Lake Thunderbird Computational Grid and Bottom Elevation

Chlorophyll-a. Water quality criteria targets for chlorophyll-a and dissolved oxygen are directly compared to model results for chlorophyll and dissolved oxygen. Model results for chlorophyll-a, in general, show good agreement with the observed seasonal trend of chlorophyll for most of the simulation period of 2008-2009. The observed seasonal progression of algae biomass is controlled by water temperature, the availability of phosphate and adequate light for growth. Observed TN:TP ratios and model results both indicate that phosphorus is the limiting factor for algal growth in Lake Thunderbird. Based on summary statistics computed for all 8 stations, the 2008-2009 average for observed surface chlorophyll (24.8 µg/L) exceeds the target criteria for SWS lakes of 10 µg/L. The average value for the calibrated model results for chlorophyll of 21.5 µg/L also shows non-compliance with the SWS target criteria.

Dissolved Oxygen. Oklahoma water quality standards for dissolved oxygen for Lake Thunderbird are specified in relation to (a) the surface layer/epilimnion and (b) the anoxic volume of the lake within the hypolimnion. Within the surface layer/epilimnion, dissolved oxygen shall be no less than 6 mg/L from April 1 to June 15 for protection of early life stages and no less than 5 mg/L from June 16 to March 31 for protection of other life stages of a warm water aquatic community. 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 stratification from mid-May through October 1. Model results for dissolved oxygen at the deep lacustrine sites (1, 2 and 4) show good agreement with the observed seasonal trend of both surface layer oxygen levels and bottom layer oxygen depletion where the observed anoxic conditions are controlled by the onset and erosion of lake stratification. Model results for dissolved oxygen for each grid cell are post-processed to derive a composite time series to compute the percentage of the whole lake volume defined as anoxic by the cutoff target DO level of 2 mg/L. On a whole lake basis, the maximum percentage of the lake volume defined by the target oxygen level of 2 mg/L for 2008-2009 is estimated at ~30% in early August just prior to the two large storm events of August 2008. Since the maximum anoxic volume estimated for the whole lake is ~30%, the water quality anoxic volume target of no more than 50% of the lake volume less than 2 mg/L during stratification is attained for the 2008-2009 calibration period.

Benthic Flux of Phosphate. Model results are also analyzed to evaluate benthic flux rates of phosphate and sediment oxygen demand simulated with the sediment diagenesis model since these coupled water column-sediment bed processes are critical for model results for chlorophyll-a and dissolved oxygen. Since observed measurements of the benthic flux of phosphate are not available for Lake Thunderbird, mean values of modeled benthic phosphate fluxes are computed for the summer stratified anoxic period from May 15 through October 1, 2008 for the lacustrine monitoring stations (Site 1, 2 and 4) for comparison to literature data for other lakes and reservoirs. The mean benthic flux rates for phosphate, computed as 3.6, 2.7 and 5.2 mg P/m^2-day for Site 1, 2 and 4, respectively, are thus consistent with the 10th to 90th percentile range of anoxic phosphate fluxes of ~1.7 to 7.4 mg P/m^2-day measured by Dzialowski and Carter (2011).in mesotrophic reservoirs in Missouri and Kansas.

Model-Data Performance. The Relative RMS Error performance targets, defined as a composite statistic derived from pooled model-observed data pairs from all stations, are consistent with model performance targets recommended for surface water models (Donigian, 2000). As presented in Appendix B, the model performance targets for water level and dissolved oxygen (20%), water temperature, nitrate and total organic phosphorus (50%), and chlorophyll (100%) are all attained with the model results for these variables much better than, or close to, the target criteria. The model results for TSS, total phosphorus, total phosphate, and total nitrogen are also good with the model performance statistics shown to be only 5-6% over the target criteria of 50%. The exceptions to the overall good results achieved with the model are for Total Organic Carbon and Total Organic Nitrogen where the Relative RMS Errors exceed the target criteria of 50% by over 25%.

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 Lake Thunderbird. The Relative RMS Errors are used as targets for performance evaluation of the calibration of the 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.

4.4 Pollutant Load Budget: Existing Model Calibration (2008-2009)

Using data developed for calibration of the watershed model and the lake model to 2008-2009 conditions, a mass balance budget for sediment, nutrients and CBOD is compiled to identify the relative magnitude of the external and internal sources of pollutant loading to the lake. External sources include tributary 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. Mass balance loading rates (as kg/day) are compiled for the 375 day simulation period from April 2008-April 2009.

Table 4-1 presents a summary of the mass balance budget for the existing 2008-2009 calibration conditions for HSPF watershed loads. Table 4-2 presents a summary, and comparison, of the external and internal benthic flux loading rates for the existing 2008-2009 calibration conditions. Table 4-3 presents the percentage contributions of watershed, atmospheric deposition and benthic flux loading to the total inorganic nutrient load. As shown in Table 4-3, internal benthic flux of phosphate accounts for 89% of the total phosphate loading to the lake on an annual basis. Atmospheric deposition of the sum of nitrate and ammonia (DIN) accounts for 46% of the inorganic nitrogen input while benthic flux of DIN accounts for 38% of the total DIN loading to the lake. Accounting for one-third or more of the total inorganic nitrogen loading, atmospheric deposition and benthic flux both represent significant contributions to the total load for inorganic nitrogen.

Table 4-1 Annual Watershed Loading of Nutrients, CBOD and Sediment for Existing Calibration Conditions (2008-2009) Delivered to Lake Thunderbird

Model Calibration	Annual
Source	Watershed HSPF
Existing 2008-2009	kg/day
Total Nitrogen (TN)	318.2
Total Phosphorus (TP)	59.7
CBOD	636.9
Suspended_Solids	30,772.3

Table 4-2 Comparison of Annual Watershed Loading, Atmospheric Deposition and Sediment Flux of Inorganic Nutrients for Existing Calibration Conditions (2008-2009)

Model Calibration	Annual	Annual	Annual	Annual
Source	Watershed HSPF	AtmDep	SedFlux	Total
Existing 2008-2009	kg/day	kg/day	kg/day	kg/day
Phosphate(PO4)	7.8	0.5	68.6	76.8
Nitrate (NO3)	30.5	79.5	61.0	171.0
Ammonia (NH4)	7.6	32.6	32.6	72.9
DIN (NO3+NH4)	38.1	112.1	93.6	243.8

Table 4-3 Percentage Contribution of Annual Watershed Loading, Atmospheric Deposition and Sediment Flux of Inorganic Nutrients for Existing Calibration Conditions (2008-2009)

Model Calibration	Annual	Annual	Annual	Annual
Source	Watershed HSPF	AtmDep	SedFlux	Total
Existing 2008-2009	%	%	%	%
Phosphate(PO4)	10.1	0.7	89.2	100
Nitrate (NO3)	17.8	46.5	35.7	100
Ammonia (NH4)	10.5	44.7	44.8	100
DIN (NO3+NH4)	15.6	46.0	38.4	100

4.5 Water Quality Response to Modeled Load Reduction Scenarios

The calibrated lake model was used to evaluate the water quality response to reductions in watershed loading of sediment, nutrients and CBOD. Load reduction scenario simulation runs were performed to determine if water quality targets for turbidity, chlorophyll and dissolved oxygen could be attained with watershed-based load reductions of 25%, 35%, 50%, and 75%. Based on an evaluation of the load reduction scenario results the 35% removal alternative was selected for a detailed “spin-up” analysis of the long-term water quality response of the lake to changes in watershed loads. The 35% removal scenario was used to simulate 8 years of sequential “spin-up” runs to evaluate the long-term response of water quality conditions in the lake to the 35% 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 8 spin-up years. The results derived from the 8 years of spin-up simulations did not, therefore, account for any projected, or future, conditions of hydrologic variability within the watershed.

The 35% pollutant removal scenario identified for the TMDL for Lake Thunderbird is based on a simple uniform reduction of all sediment, CBOD, TN and TP loads contributed by all tributaries, stormwater point sources and distributed runoff from the watershed to represent the reduction of pollutant loads to Lake Thunderbird. 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 35% 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.

<u>Turbidity and Chlorophyll-a</u>. As discussed in Section 2 of this report, Oklahoma water quality standards for Lake Thunderbird turbidity and chlorophyll-a are as follows:

- *Turbidity*: no more than 10% of turbidity samples greater than 25 NTU based on compilation of records of most recent 10 years
- *Chlorophyll-a*: Average value of surface chlorophyll-a no greater than 10 µg/L based on long-term historical record of most recent 10 years

Table 4-4 summarizes the annual statistics for turbidity and chlorophyll-a for (a) the observed data collected in 2008-2009 used for model calibration, (b) the calibrated model results and the results generated with (c) eight years of spin-up runs for the 35% removal scenario, respectively. Summary statistics are computed from model results for all 8 sites for the annual simulation period from April 2008-April 2009. The chlorophyll-a statistic is computed as the average of the model results for all 8 sites. The turbidity statistic is computed as the 90th percentile of the model results for all 8 sites. The number of simulation records for the model statistics (N=17,856) is based on 2,232 records per site for 8 sites.

As can be seen in the data presented in Table 4-4, the 90th percentile for observed turbidity (29.7 NTU) exceeds the target of 25 NTU. The calibrated model results for surface turbidity (27.6 NTU) also show non-compliance with the target of 25 NTU. Each of the spin-up runs for the 35% management scenario show a gradual improvement in turbidity with respect to compliance with the target of 25 NTU. Figure 4-2 presents the long-term trends for the turbidity data presented in Table 4-4 for the 35% removal scenario.

As shown in Table 4-4, the 2008-2009 average for observed surface chlorophyll-a (24.8 µg/L) exceeds the target criteria for SWS lakes of 10 µg/L. The calibrated model results for chlorophyll-a (21.5 µg/L) also show non-compliance with the SWS target criteria. Figure 4-3 shows the spin-up trend for the chlorophyll data presented in Table 4-4 for the 35% removal scenario. Algae biomass increases for Year 0 and Year 1 of the 35% removal scenario because turbidity is reduced, water clarity is improved and primary productivity increases with increased light availability for algae growth. After Year 1, chlorophyll-a progressively declines each year until the SWS water quality criteria of 10 µg/L is attained by Year 5 under the 35% removal scenario. Chlorophyll-a gradually declines after the first spin-up year because the supply of phosphorus available to support primary production in the euphotic zone diminishes as internal phosphorus loading from benthic phosphate flux is reduced (see Figure 4-4). The largest contribution of internal loading of phosphate to the lake, controlled by hypoxic bottom water oxygen conditions, occurs during the summer stratified period from mid-May to early October. As can be seen in Figure 4-4 the whole lake seasonal benthic phosphate flux declines from 5.4 mg P/m^2-day for the initial year (Year 0) to 1.7 mg P/m^2-day after 8 years of model spin-up as the coupled interaction of the sediment-water system attains a new equilibrium condition.

Table 4-4 Summary Statistics for Chlorophyll-a and Turbidity for observed data, model calibration and 8 years (YR1-YR8) of spin-up runs of the 35% removal scenario. Observed data and model results are aggregated over the whole lake for the simulation period (2008-2009).

35%R	8 SITES	8 SITES	8 SITES	8 SITES
	CHL	TURBIDITY	CHL	TURBIDITY
	(µg/L)	(NTU)	(µg/L)	(NTU)
ANNUAL	AVERAGE	90%ile	Pct_Chng	Pct_Chng
Target	10	25		
Observed	24.8	29.7		
Calibration	21.5	27.6		
Yr0	23.0	19.3		
Yr1	24.5	18.5	6.6%	-3.8%
Yr2	20.5	18.4	-16.4%	-0.6%
Yr3	15.6	18.0	-23.9%	-2.5%
Yr4	11.8	17.7	-24.3%	-1.4%
Yr5	10.0	17.6	-15.2%	-0.6%
Yr6	9.3	17.4	-7.6%	-1.1%
Yr7	8.9	17.3	-3.4%	-0.7%
Yr8	8.9	17.3	-0.9%	0.0%

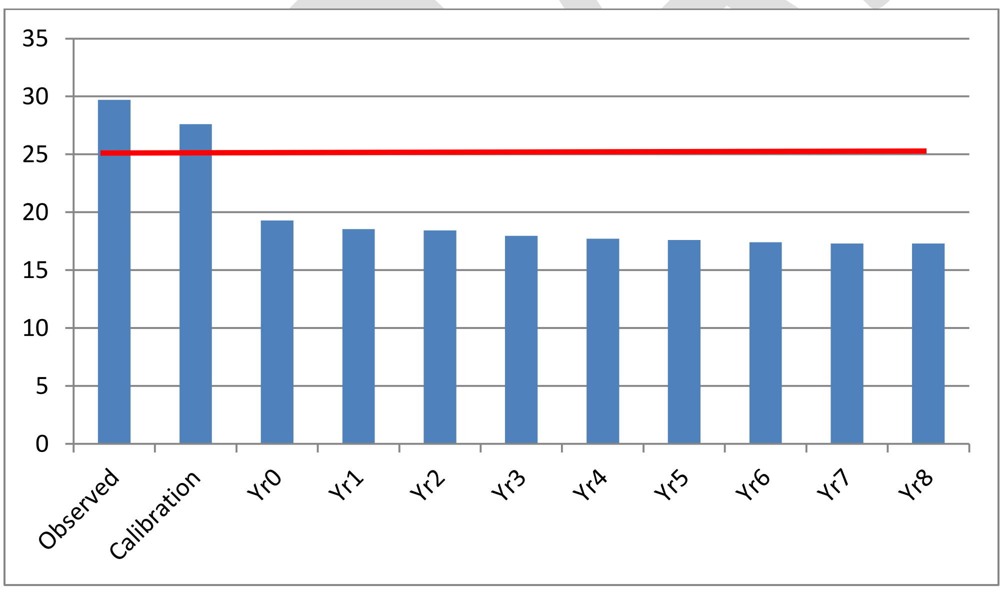

Figure 4-2 Surface Turbidity (NTU): Spin-Up Model Results for 35% Removal, Annual 90th Percentile of all 8 Sites

The spin-up simulation analysis of the coupled water column-sediment bed response to the 35% reduction in watershed loading of sediment and nutrients indicates that compliance with the SWS target for chlorophyll-a of 10 µg/L can be attained within a reasonable time frame. **It is**

important to emphasize that the model spin-up results are <u>not</u> a prediction of the number of years required for lake recovery because of the idealized spin-up conditions of a precisely maintained watershed load reduction level and repeated climatic and hydrologic conditions of 2008-2009. The model results, do, however, provide technically credible evidence that future conditions can be in compliance with SWS water quality criteria for chlorophyll-a within a reasonable time frame if watershed loads are reduced as recommended and the reduction is sustained.

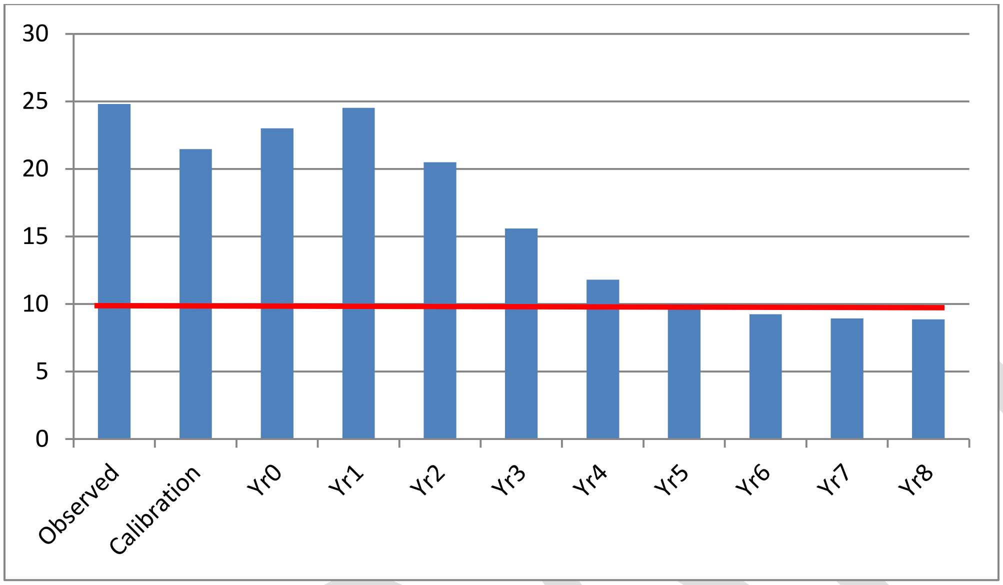

Figure 4-3 Surface chlorophyll-a (µg/L): Spin-Up Model Results for 35% Removal, Annual Average of all 8 Sites

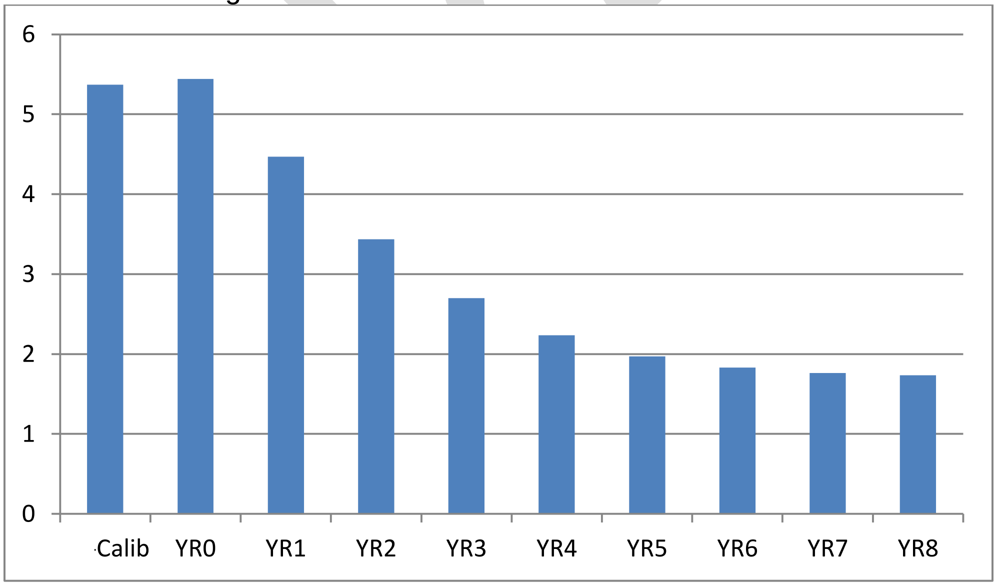

Figure 4-4 Sediment Flux PO4 (mg P/m^2-day), whole lake average for seasonal stratified period from May 15-Oct 1, 2008 for the 35% removal scenario

Dissolved Oxygen and Sediment Oxygen Demand. Oklahoma water quality standards for dissolved oxygen for Lake Thunderbird are specified in relation to (a) the surface layer and (b) the anoxic volume of the lake within the hypolimnion. Within the surface layer/epilimnion, dissolved oxygen shall be no less than 6 mg/L from April 1 to June 15 and no less than 5 mg/L during the remainder of the year based on long-term records of the most recent 10 years. Within the hypolimnion, the anoxic volume of the lake shall not exceed 50% of the lake volume during the period of seasonal stratification from mid-May through October 1. Model results for surface layer dissolved oxygen are in compliance with the water quality criteria for surface DO levels. The results of the computations of anoxic volume, based on a target oxygen level of 2 mg/L, are presented as time series of anoxic volume of the whole lake in Figure 4-5 for the 35% removal scenario with a comparison shown to the anoxic volume results for the existing calibration conditions. As can be seen by comparison of the model calibration to the progression of spin-up years, the anoxic volume gradually decreases with each spin-up year from the 35% reduction of watershed loading.

The anoxic volume of the lake gradually decreases because the whole lake sediment oxygen demand (SOD) is reduced with each spin-up year of the 35% removal scenario (Figure 4-6). SOD gradually declines from ~0.78 g O_2/m^2-day for the initial year (Year 0) to 0.2 g O_2/m^2-day after 4 years and ~0.12 g O_2/m^2-day after 8 years of spin-up for the 35% removal scenario. The gradual decline in SOD reflects the response of the coupled water column and sediment bed of the lake to new equilibrium conditions for particulate organic matter deposition to the sediment bed based on the effectiveness of the load reduction scenario for 35% removal of sediments and nutrients from watershed loading.

As a management alternative in response to the repeated occurrence of hypolimnetic anoxia during summer stratified conditions, an oxygen injection system has been installed in Lake Thunderbird (Cadenhead, 2012). COMCD received an American Recovery and Reinvestment Act of 2009 grant (ARRA) to install and operate a Supersaturated Dissolved Oxygen (SDOX) system and in 2010, the COMCD partnered with the OWRB, to design, install, and monitor the SDOX pump at the lake's deepest area near the dam. This energy-efficient pump uses the latest technology to prevent the lakes hypolimnion from going anoxic throughout the summer months without disrupting the lake's natural thermocline. As discussed in Section 4.3.2, seasonal anoxia exacerbates eutrophic conditions in the lake by triggering the benthic release of nutrients as an internal load to the water column. Eutrophic conditions that favor bluegreen algae (cyanobacteria) blooms contribute to taste and odor problems in drinking water. Operation of the SDOX device is targeted to improve oxygen levels in the lake to support the warm water fishery but also to reduce the treatment cost for drinking water. Since the SDOX system became operational after the study period of 2008-2009, the effects of the oxygen injection system are not represented in either calibration of the model to existing conditions or to the projection of the water quality impact of the 35% removal scenario.

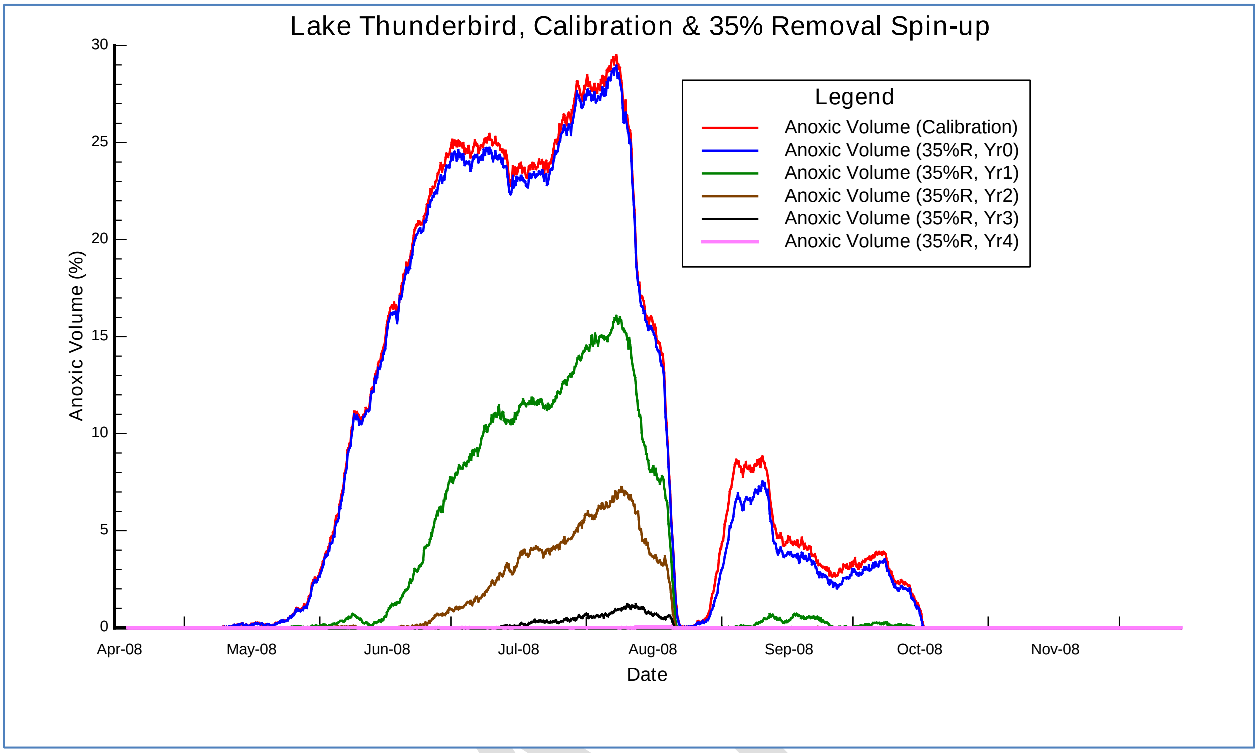

Figure 4-5 Time series of anoxic volume of whole lake for 35% Removal Management Scenario. Model calibration results are shown as red line. Percentage of anoxic volume is based on aggregation of all grid cells in the lake.

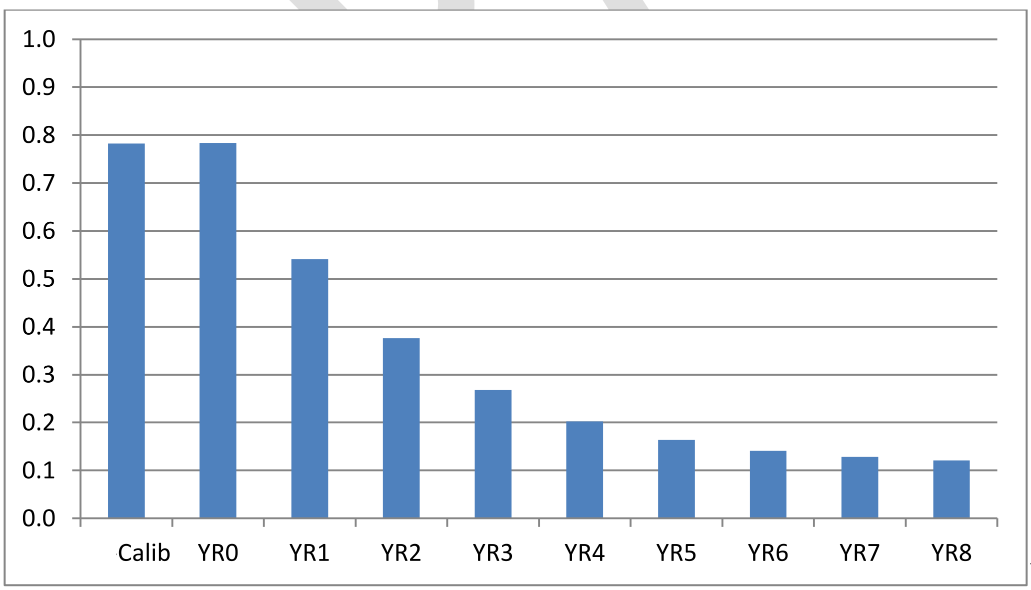

Figure 4-6 Sediment Oxygen Demand (g O_2/m^2-day), whole lake average for seasonal stratified period from May 15-Oct 1, 2008 for the 35% removal scenario

4.6 Pollutant Load Budget: 35% Removal Scenario

Table 4-5 presents a summary of the April 2008-April 2009 mass balance budget for the 35% removal scenario for HSPF watershed loads. Table 4-6 presents a summary, and comparison, of the external and internal benthic flux loading rates for the 35% removal scenario. Table 4-7 presents the percentage contributions of watershed, atmospheric deposition and benthic flux loading to the total inorganic nutrient load for the 35% removal scenario. As shown in Table 4-7, the contribution of the internal benthic flux of phosphate to the total phosphate load decreases from 89% for the existing calibration condition (see Table 4-3) to 80% for the 35% removal case after a spin-up period of 8 years.

In contrast to the existing conditions for model calibration where the sediment bed is a significant source of inorganic nitrogen (DIN) to the lake (see Table 4-2), the model spin-up results after 8 years suggest that the sediment bed may be a sink for DIN. The results of the spin-up after 8 years for the 35% removal scenario indicates that DIN may be lost from the water column to the sediment bed under the simulated conditions for the bed. As shown in Table 4-6, a negative sediment flux load for ammonia and nitrate represents a loss of inorganic nitrogen from the water column to the sediment bed. With reduced external watershed loading and organic matter deposition from the water column, organic matter in the sediment bed is slowly decomposed and DIN concentrations in porewater decline. Benthic release rates gradually decrease over time until conditions exist where the DIN concentration in the sediment bed is lower than the DIN concentration in the overlying water column; and DIN is transported by diffusion from the water column to the sediment bed.

As shown in Table 4-6 for the 35% removal scenario, the external input of nitrate from the watershed (~20 kg/day) is approximately equivalent to the internal loss of nitrate from the water column to the bed (~21 kg/day). The internal loss of ammonia from the water column to the sediment bed (~14 kg/day) is almost three times the external input of ammonia from the watershed (5 kg/day). Overall, the total estimated benthic input of phosphate is decreased by 37% with the phosphate load declining from 76.8 kg/day for the existing calibration case (Table 4-2) to 28.6 kg/day (Table 4-6) for the 35% removal scenario. Similarly, the total estimated input of inorganic nitrogen is decreased by 42% with the sum of the nitrate and ammonia (DIN) load declining from 243.9 kg/day for the existing calibration case (Table 4-2) to 101.8 kg/day (Table 4-6) for the 35% removal scenario.

Table 4-5 Annual Watershed Loading of Nutrients, CBOD and Suspended Solids for 35% Removal Scenario

Model 35% Removal	Annual
Source	HSPF
	kg/day
Total Nitrogen (TN)	206.8
Total Phosphorus (TP)	38.8
CBOD	414.9
Suspended_Solids	20,002.0

Table 4-6 Comparison of Annual Watershed Loading, Atmospheric Deposition and Sediment Flux of Inorganic Nutrients for 35% Removal Scenario

Model 35% Removal	Annual	Annual	Annual	Annual
Source	HSPF	AtmDep	SedFlux	Total
	kg/day	kg/day	kg/day	kg/day
Phosphate(PO_4)	5.1	0.5	23.1	28.6
Nitrate (NO_3)	19.8	79.5	-21.4	77.9
Ammonia (NH_4)	5.0	32.6	-13.7	23.9
DIN(NO_3+NH_4)	24.8	112.1	-35.1	101.8

Table 4-7 Percentage Contribution of Annual Watershed Loading, Atmospheric Deposition and Sediment Flux of Inorganic Nutrients for 35% Removal Scenario

Model 35% Removal	Annual	Annual	Annual	Annual
Source	HSPF	AtmDep	SedFlux	Total
	%	%	%	%
Phosphate(PO_4)	17.7	1.7	80.6	100
Nitrate (NO_3)	25.4	102.1	-27.5	100
Ammonia (NH_4)	20.8	136.4	-57.2	100
DIN(NO_3+NH_4)	24.3	110.2	-34.5	100

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. Lake Thunderbird, 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, calibrated to 2008-2009 data, accounts for the cause-effect interactions of water clarity, nutrient cycling, algal production, organic matter deposition, sediment decay, and sediment-water fluxes of nutrients and oxygen.

The spin-up results for the 35% removal scenario suggest that chlorophyll-a may increase initially because of the availability of nutrients combined with the reduction of turbidity and improvement in water clarity, all favorable conditions for algae growth. Over time, however, the sediment bed reservoir of nutrients will diminish, benthic release of nutrients to the lake will be reduced and the pool of nutrients available to support algal production will be reduced. The model results demonstrate a gradual reduction in internal loading of nutrients from the sediment bed and an improvement in water quality conditions over the years based on the spin-up runs for the 35% removal scenario.

The model indicates that water quality conditions are expected to be in compliance with the SWS water quality criteria for chlorophyll-a of 10 µg/L within a reasonable timeframe. It is important to note, however, that the spin-up results for the 35% 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 because of the idealized spin-up conditions of a precisely maintained watershed load reduction level and repeated climatic conditions of a past year. The model, does however, provide a technically credible framework that clearly shows that water quality improvements can be achieved in Lake Thunderbird within a reasonable time frame to support the desired beneficial uses if watershed loading can be controlled and sustained to a level based on 35% reduction of the existing loading conditions. Attainment of water quality standards will occur, however, only over a period of time and only after full implementation of source controls and BMPs considered necessary to achieve an overall 35% removal of sediment and nutrients from the watershed.

Although the model demonstrates that internal loading of phosphate is a significant controlling factor for eutrophication in the lake, loading from the watershed is a direct factor in the deterioration of water quality conditions and ultimately the accumulation in the lake sediment of excessive nutrients and organic matter from the watershed over the past 5 decades is the source of the internal loading. Reductions in watershed loading are therefore required to achieve improvements in lake water quality. The model results suggest that compliance with water quality criteria for turbidity, dissolved oxygen and chlorophyll-a can be achieved with a 35% 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 sediments, CBOD, TN and TP to achieve compliance with water quality standards for turbidity, chlorophyll-a and dissolved oxygen. The calibrated HSPF watershed runoff model and the EFDC hydrodynamic and water quality model of Lake Thunderbird provides DEQ with a scientifically defensible surface water model framework to support development of TMDLs and water quality management plans for Lake Thunderbird.

SECTION 5 TMDLS AND LOAD ALLOCATIONS

The linked watershed (HSPF) and lake (EFDC) models were used to calculate average annual sediment, CBOD, 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 Lake Thunderbird as daily maximum loads (as kg/day).

5.1 Wasteload Allocation (WLA)

The waste load allocation for the TMDL for Lake Thunderbird will be assigned to regulated NPDES point source facilities located within the watershed as described below.

5.1.1 NPDES Municipal and Industrial Wastewater Facilities

There are no municipal and industrial wastewater facilities located within the Lake Thunderbird watershed.

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 Lake Thunderbird. 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. As discussed in Section 3, 12 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 since bypass overflows are not allowed.

5.1.3 NPDES Municipal Separate Storm Sewer System (MS4)

The waste load allocation for the TMDL for Lake Thunderbird will be assigned to point sources accounted for by MS4 stormwater permits. Within the watershed area for Lake Thunderbird are the Phase I MS4 permit issued to Oklahoma City and the Phase II permits to Moore and Norman. Since there are no numeric load limits for MS4 permits, each of these three MS4 cities receives a separate WLA where the TMDL calculations are based on the proportional contribution of the existing pollutant loading from each of the three cities relative to the total watershed pollutant load determined by the HSPF watershed model. A pollutant load budget derived from the HSPF watershed model for the existing 2008-2009 conditions is presented in Section 3.3.6 of this report.

As discussed in Section 3, cities of Noble and Midwest City also have Phase II MS4 permits for stormwater discharges and stormwater management. Only partially located in the Lake Thunderbird watershed, Noble and Midwest City urban areas account for, however, a very small contribution to the total watershed area. These two MS4 cities, therefore, are not included as part of the WLA determined for the MS4 areas for the three larger cities in the watershed. The small portion of the watershed accounted for by the MS4 areas for Noble and Midwest City, however, are included in the Load Allocation (LA) for the part of the watershed that is not included in the area covered by the three MS4 permits for Moore, Norman and Oklahoma City.

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 of this report, a total of 243 construction site permits have been issued within the Lake Thunderbird watershed by September 2012. Sediment and nutrient loading from construction site permit activities will be accounted for, as part of the overall WLA determined for each of the three MS4 permits for Moore, Norman and Oklahoma City.

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 Lake Thunderbird watershed, 14 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 3-5. The MSGP permits will be accounted for in this TMDL as part of the overall WLA for the three MS4 permits for Moore, Norman and Oklahoma City.

5.1.6 NPDES Animal CAFO's

There are no concentrated animal feeding operations (CAFO) located within the Lake Thunderbird watershed.

5.2 Load Allocation (LA)

5.2.1 Nonpoint Sources

The area of the watershed that is covered by the three MS4 permits for Moore, Norman and Oklahoma City accounts for a very large percentage of the watershed. The Load Allocation for the TMDL for Lake Thunderbird will, therefore, be assigned in proportion to the small land area of the watershed that is not included in the land area for the three MS4 permits. The area covered by the two MS4 permits for Noble and Midwest City and the remaining small unincorporated areas of the watershed and the city of Slaughterville are too small to be separated and are included in the Load Allocation for the TMDL. The LA for the unincorporated areas may be converted at some time in the future to a WLA if the unincorporated areas are annexed by any of the three MS4 cities of Moore, Norman and Oklahoma City. The Load Allocation of the watershed is based on the watershed loads for sediment and nutrients estimated with the watershed model for the existing 2008-2009 conditions rather than the load for this small area that would be based on 35% removal of the existing load.

5.3 Seasonal Variability

Federal regulations (40 CFR §130.7(c)(1))require that TMDLs account for seasonal variation in watershed hydrologic conditions and pollutant loading. Seasonal variation was accounted for in the TMDL determination for Lake Thunderbird by using one full year of water quality data collected as part of a special study of Lake Thunderbird from April 2008-April 2009. Water quality data collected during 2008-2009 for this TMDL study is considered to be representative of typical average 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 one year study period from April 2008 through April 2009. The models thus included hydrologic and limnological conditions for a full cycle 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 WQSs are attained. 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 are used in the TMDL calculations, the MOS is implicit. When a specific percentage of the TMDL is set aside to account for the lack of knowledge, then the MOS is considered explicit.

The TMDL determined for Lake Thunderbird accounts for an implicit MOS. The implicit MOS is incorporated in the TMDL determination by decreasing the water quality targets for chlorophyll-a and turbidity by 10%. Using a 10% MOS for the water quality targets, the target for turbidity is decreased from 25 to 22.5 NTU and the target for chlorophyll-a is decreased from 10 to 9 µg/L. TMDL for ultimate CBOD was set the same as the load at the calibration condition because DO standards were met at the calibration condition with reserved capacities. As shown in Figure 4-5, the predicted volumetric anoxic volume for Lake Thunderbird is only about 30% while the standards allows up to 50% anoxic volume. This reserved capacity will act as the implicit margin of safety for dissolved oxygen.

5.5 TMDL Calculations

A TMDL is expressed as the sum of all WLAs (point source loads), LAs (nonpoint source loads), and an appropriate MOS. This definition 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, CBOD, 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 Lake Thunderbird. Given that mass transport, assimilation, and dynamics of suspended solids, CBOD, and nutrients vary both temporally and spatially, pollutant loading to Lake Thunderbird 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 Lake Thunderbird 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.

Two documents available from EPA provide a statistical basis for the 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".* These documents provide the statistical method for identifying a maximum daily limit based on a long-term average and considering temporal variability in the load time series dataset. The methodology for calculating the Maximum Daily Load (MDL) from the Long Term Average (LTA) load is based on the characterization of flow, stream concentration and watershed loading data as lognormal distributions rather than as normal distributions. The methodology for the MDL is based on calculations of the (a) long-term average load (LTA) of untransformed loading data calculated by the watershed (HSPF) model; and (b) an estimation of the statistical variability of the time series for loading based on calculations of the mean, standard deviation (σ), variance (σ^2) and the coefficient of variation (CV). Based on the long-term average annual loading rate (LTA) required to attain compliance with water quality standards, the maximum daily load (MDL) is determined to represent the allowable upper limit of loading data that is consistent with the long-term average load (LTA) determined by the TMDL study. The allowable upper limit takes into account temporal variability of the watershed loading data, the desired confidence interval of the upper bound for the MDL determination and the lognormal characteristics of the loading data. The maximum daily load (MDL) is computed from the LTA and the statistics of the loading data by the following equations for a lognormal distribution:

$$MDL = LTA * \exp(Z\sigma - 0.5\sigma^2)$$

$$\sigma^2 = \ln(1 + CV^2)$$

Where:

MDL = Maximum daily load limit (as kg/day)
LTA = Long-term average load with required reduction scenario (as kg/day)
Z = Z-score statistic for the probability of occurrence for upper percentile limit
CV = Coefficient of Variation = Standard Deviation/Mean
σ = Standard Deviation
σ^2 = Variance

Time series derived from the sum of all the daily loads contributed by each of the 18 tributaries and 18 distributed runoff catchments included in the HSPF watershed model were used to compute the mean, standard deviation and the coefficient of variation (CV) of the loads for suspended solids, TN, TP and CBOD. The variability of the total loading data simulated by the HSPF model was determined using the CV computed for the total load accounted for by the HSPF locations. Loads from each tributary and distributed runoff catchment were summed to integrate the total mass loading over the 375 day simulation period (April 17, 2008 through April

26, 2009). The annual average loading rate (LTA) for a 365 day year was then computed from the integrated mass load for 375 days prorated to 365 days with a multiplier of 0.9733 (365/375). For the Lake Thunderbird TMDL calculations, a 95% probability level of occurrence was used with the Z-score statistic assigned a value of Z=1.645.

The WLA and LA for Suspended Solids, TN and TP, determined from the lake model response to watershed load reductions, is based on 35% reduction of the existing 2008-2009 watershed loads estimated with the HSPF model. A load reduction from the watershed is needed because the criteria for turbidity and chlorophyll-a are not satisfied under the existing loading conditions. For CBOD, however, the WLA and LA is based on the existing 2008-2009 ultimate CBOD loading from the HSPF watershed model to the lake since the water quality criteria for dissolved oxygen is satisfied under existing loading conditions for both surface layer/epilimnion dissolved oxygen levels and the anoxic volume of the hypolimnion. For monitoring purposes, 20-day CBOD is considered to be ultimate CBOD.

Table 5-1 presents the watershed loads as the long term average (LTA) load for the existing conditions and for the projected 35% removal management scenario. The LTA load and the coefficient of variation (CV) of the HSPF time series load data is used to compute the MDL for Suspended Solids, TN, TP and ultimate CBOD given in Table 5-2. Table 5-3 presents the load-based percentages of the existing 2008-2009 loads for the three MS4 cities area derived from the total existing watershed load that is accounted for by the loads contributed by each of the three MS4 Cities and the remaining unincorporated land area of the watershed. The percentage splits for the unincorporated area given in Table 5-3 were used to compute the LA (as kg/day) based on the existing loads given in Table 5-1 after conversion of the annual load to daily load.

The total WLA load for the three MS4 cities was computed from the MDL load given in Table 5-2 and the LA loading rate computed from the total existing loading and the small percentage of the watershed load that is accounted for by the unincorporated areas. The total TMDL load is split between the WLA for the three MS4 cities and the LA for the unincorporated area of the watershed as shown in the following equations:

TMDL = WLA + LA+ Implicit MOS

Where

LA= Existing Load from Unincorporated Area
TMDL = MDL load given in Table 5-2
WLA=WLA (3 Cities) = TMDL – LA
WLA (City) = WLA (3 Cities) * % Load of each City given in Table 5-4

Table 5-4 gives the percentage of the existing load contributed by each MS4 city to the total existing load for the three MS4 cities. The percentage splits for each MS4 city given in Table 5-4 were then used with the MDL given in Table 5-2 and the calculation of the total WLA loads from the relationships given above to determine the WLA for each of the three MS4 cities. Table 5-5 presents the WLA for the three MS4 cities of Moore, Norman and Oklahoma City and the LAs for the unincorporated areas of the watershed and the small areas in Noble and Midwest City that are not included in the MS4 boundaries for the three cities. The small differences between the percentage values in Table 5-3 and Table 5-4 are due to the fact that no load reduction is given to the LA portion of the TMDL. Consequently, WLA to the MS4 cities were reduced beyond the 35% by a small fraction to compensate for the required overall watershed reduction. Table 5-5 gives the final TMDL appropriations for all sources and pollutants.

Table 5-1 Long Term Average (LTA) Load for Suspended Solids, TN, TP, and BOD: Existing Conditions and 35% Removal in Lake Thunderbird

Water Quality Constituent	LTA Existing Annual Load	Load Reduction Rate	LTA Reduced Annual Load	LTA Reduced Daily Load
	kg/yr	Percent	kg/yr	kg/day
Total Nitrogen (TN)	116,138	35%	75,490	207
Total Phosphorus (TP)	21,775	35%	14,154	39
CBOD	232,486	0%	232,486	637
Suspended Solids	11,231,882	35%	7,300,723	20,002

LTA- Long Term Average Load

Table 5-2 Maximum Daily Load (MDL) for Suspended Solids, TN, TP, and CBOD to Meet Water Quality Targets for Turbidity, Chlorophyll-a and Dissolved Oxygen in Lake Thunderbird

Water Quality Constituent	LTA Reduced Daily Load	HSPF CV	MDL (TMDL) Load
	kg/day	N=375	kg/day
Total Nitrogen (TN)	207	4.25	798
Total Phosphorus (TP)	39	4.41	149
CBOD	637	4.79	2,441
Suspended Solids	20,002	5.87	75,119

LTA- Long Term Average Load

MDL- Maximum Daily Load

CV- Coefficient of Variation

Z-Score =1.645 for 95% probability

Table 5-3 Percentage of Total TMDL for Three MS4 Cities (WLA) and Unincorporated Areas (LA)

Existing Load %	TOTAL	TOTAL	TOTAL	Moore	Norman	OKC
WQ_Variable	WLA(3-City)	LA	WLA+LA	WLA	WLA	WLA
	%	%	%	%	%	%
Total Nitrogen (TN)	97.36	2.64	100	25.40	39.54	32.42
Total Phosphorus (TP)	97.23	2.77	100	28.10	37.95	31.17
CBOD	97.68	2.32	100	31.49	38.52	27.67
Suspended Solids	97.31	2.69	100	21.10	41.06	35.15
WLA% (City)= Existing[City Load/Total Watershed Load] WLA% (3-Cities)= Existing[3-City Load/Total Watershed Load] LA% = Existing[Unincorporated Area/Total Watershed Load]						

Table 5-4 Percentage of Total WLA for Three MS4 Cities (WLA)

Existing Load%	Moore	Norman	OKC	TOTAL
WQ_Variable (Splits)	WLA	WLA	WLA	WLA
	%	%	%	%
Total Nitrogen (TN)	26.09	40.62	33.30	100
Total Phosphorus (TP)	28.91	39.03	32.06	100
CBOD	32.24	39.43	28.33	100
Suspended_Solids	21.68	42.19	36.12	100
City WLA% = Existing City Load/Total 3 City Load				

Table 5-5 TMDL for Lake Thunderbird

Water Quality Constituent	**TMDL**	**LA**	**WLA**				**MOS**
			Total	**Moore**	**Norman**	**OKC**	
	(Kg/day)	**(Kg/day)**	**(Kg/day)**	**(Kg/day)**	**(Kg/day)**	**(Kg/day)**	**(Kg/day)**
Total Nitrogen (TN)	798	21	777	203	316	259	Implicit
Total Phosphorus (TP)	149	4	145	42	57	47	Implicit
CBOD	2,441	57	2,385	769	940	676	Implicit
Suspended_Solids (TSS)	75,119	2,020	73,100	15,850	30,844	26,406	Implicit

5.6 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 5-6 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 5-6 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

5.6.1 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 the report, urban stormwater related discharges are the main sources of controllable pollutants to Lake Thunderbird. The three main municipalities in the watershed will therefore be required to undertake certain pollutant reduction 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 WLAs of 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 US 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 Lake Thunderbird watershed. Appendix E outlines these requirements.

This TMDL does not specify a WLA for industrial stormwater. However, industrial stormwater permittees in the Lake Thunderbird 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 Lake Thunderbird 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 Lake Thunderbird 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.

5.6.2 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 Lake Thunderbird watershed.

Although most of the watershed is covered by MS4 permits, the majority of the watershed land use is rural and consequently, pollution associated with stormwater runoff from these areas are nonpoint sources in nature. Measures to control and reduce loading from these sources should be considered by the MS4 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.

Specifically, there are loading control practices that have the potential to improve water quality in Lake Thunderbird in the near term before watershed pollutant loading can be reduced to the TMDL required levels. For example, COMCD should consider continuing or expanding the hypolimnetic oxygen injection program currently being evaluated. This could prove effective in retarding lake internal loading of nutrients and lowering lake bottom oxygen demand. Another potential project that would require COMCD involvement is the establishment of treatment wetlands on the Little River arm of the lake above the Alameda Drive bridge/causeway, where natural sedimentation and resuspension has made this particularly shallow part of the lake not suitable for most of the designated uses of the lake.

SECTION 6 PUBLIC PARTICIPATION

This draft report is submitted to EPA for technical review. After the technical approval, a public notice will be circulated to the local newspapers and/or other publications in the area affected by the TMDLs in this Study Area. The public will have opportunities to review the TMDL report and make written comments during a public comment period that lasts 45 days. Depending on the interest and responses from the public, a public meeting may be held within the watershed affected by the TMDLs in this report. If a public meeting is held, the public will also have opportunities to ask questions and make formal oral comments at the meeting and/or to submit written comments at the public meeting.

All written comments received during the public notice period become a part of the record of these TMDLs. All comments will be considered and the TMDL report will be revised according to the comments, if necessary, prior to the ultimate completion of these TMDLs for submission to EPA for final approval.

After EPA's final approval, each TMDL will be adopted into the Water Quality Management Plan (WQMP). These TMDLs provide a mathematical solution to meet ambient water quality criterion with a given set of facts. The adoption of these TMDLs into the WQMP provides a mechanism to recalculate acceptable loads when information changes in the future. Updates to the WQMP demonstrate compliance with the water quality criterion. The updates to the WQMP are also useful when the water quality criterion changes and the loading scenario is reviewed to ensure that the instream criterion is predicted to be met.

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