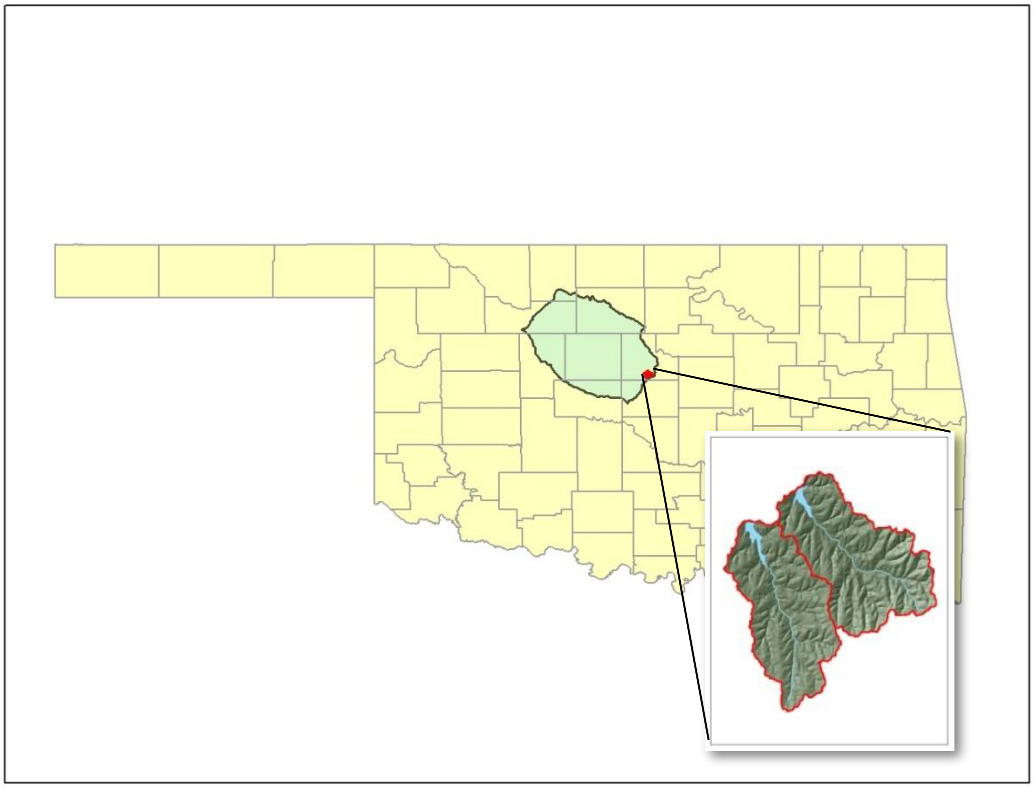
FINAL

CHLOROPHYLL-*a* TOTAL MAXIMUM DAILY LOADS FOR GUTHRIE LAKE (OK620910040060_00) AND LIBERTY LAKE (OK620910040080_00)



Prepared for:

OKLAHOMA DEPARTMENT OF ENVIRONMENTAL QUALITY

DEQ
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Prepared by:

PARSONS

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8000 Centre Park Drive, Suite 200
Austin, TX 78754

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ACRONYMS AND ABBREVIATIONS

CAFO	Concentrated Animal Feeding Operation
CDL	Cropland Data Layer
CFR	Code of Federal Regulations
CV	Coefficient of Variation
CWA	Clean Water Act
DMR	Discharge monitoring report
HUC	Hydrologic unit code
kg	Kilograms
LA	Load allocation
mg/L	Milligram per liter
MOS	Margin of safety
NASS	National Agricultural Statistics Service
NPDES	National Pollutant Discharge Elimination System
NSE	Nash-Sutcliffe Efficiency
NLW	Nutrient limited watershed
O.S.	Oklahoma statutes
OAC	Oklahoma Administrative Code
DEQ	Oklahoma Department of Environmental Quality
OSWD	Onsite wastewater disposal
OWRB	Oklahoma Water Resources Board
r^2	Correlation coefficient
SWAT	Soil and Water Assessment Tool
SWS	Sensitive public and private water supply
TMDL	Total maximum daily load
TSI	Trophic state index
USDA	United States Department of Agriculture
USEPA	United States Environmental Protection Agency
USGS	United States Geological Survey
µg/L	Microgram per liter
WLA	Wasteload allocation
WQM	Water quality monitoring
WQMP	Water quality management plan
WQS	Water quality standard
WWTP	Wastewater treatment plant

Executive Summary

This report documents the data and assessment methods used to establish total maximum daily loads (TMDL) for Guthrie Lake (OK620910040060_00), and Liberty Lake (OK620910040080_00). The Oklahoma Department of Environmental Quality (DEQ) placed these waterbodies in Category 5 of the Water Quality in Oklahoma (2008 Integrated Report) for nonsupport of the public and private water supply designated use because of elevated levels of chlorophyll-*a*.

Both of these lakes are in the Lower Cimarron-Skeleton basin in central Oklahoma. Guthrie Lake is a 274-acre lake in Logan County with a conservation pool storage of 3,875 acre-feet. It was impounded in 1919 and serves as a recreational lake; it is utilized for water supply for the City of Guthrie (Oklahoma Water Resources Board [OWRB] 2007). Guthrie Creek, which is 5.8 miles long, is the primary tributary flowing to Guthrie Lake. Liberty Lake is a 167-acre lake in Logan County with a conservation pool storage of 2,740 acre-feet. It was first impounded in 1948 and serves as a recreational lake and as a municipal water supply for the City of Guthrie (OWRB 2009). Liberty Lake Creek, which is 5.6 miles long, is the primary tributary flowing into Liberty Lake. The contributing watersheds of Guthrie Lake (OK620910040060_00) and Liberty Lake (OK620910040080_00) are herein after referred to as the Study Area.

The watersheds of both lakes are sparsely populated, with developed land accounting for less than three percent of the watershed area. The most common land use category throughout both watersheds is deciduous forest. Both watersheds also have a significant percentage of land classified as grassland/herbaceous.

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 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 nutrient load allocations necessary for reducing chlorophyll-*a* levels in the lakes, which is the first step toward restoring water quality and protecting public health. TMDLs determine the pollutant loading a waterbody can assimilate without exceeding applicable WQS. TMDLs also establish the pollutant load allocation necessary to meet the WQS established for a waterbody based on the relationship between pollutant sources and water quality conditions in the waterbody. A TMDL consists of a wasteload 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 stipulate specific control actions (regulatory controls) or management measures (voluntary best management practices) necessary to reduce nutrients within each 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 tribes, and local, state, and federal government agencies.

E.1 Problem Identification and Water Quality Target

Elevated levels of chlorophyll-*a* in lakes reflect excessive algae growth, which can have deleterious effects on the 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 excessive loading of the primary growth-limiting algal nutrients nitrogen and phosphorus to the waterbody, a process known as eutrophication.

The following excerpt from the Oklahoma WQS (Oklahoma Administrative Code [OAC] Chapter 45: 785:45-5-10) stipulates the numeric criterion set for sensitive public and private water supply (SWS) lakes, including Guthrie Lake and Liberty Lake (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.*

Neither Guthrie Lake nor Liberty Lake have been assigned the designation of "nutrient limited watershed" (NLW) in OAC 785:45-5-29. An NLW means a watershed of a waterbody with a designated beneficial use that is adversely affected by excess nutrients as determined by Carlson's Trophic State Index (TSI) (using chlorophyll-*a*) of 62 or greater, or is otherwise listed as "NLW" in Appendix A of Chapter 45 (OWRB 2011).

In Guthrie Lake, chlorophyll-*a* levels averaged 18.7 µg/L from 2003 to 2006 which is equivalent to a TSI of 60 (Carlson 1977). Chlorophyll-*a* data collected from Guthrie Lake WQM stations between 2003 and 2006 were used to support the decision to place the lake on the DEQ 2008 §303(d) list (DEQ 2008) for non-support of the Public and Private Water Supply Use in an SWS lake.

Pooling data collected between 2003 and 2006 from surface level sites in Liberty Lake, chlorophyll-*a* averaged 23.2 µg/L (TSI = 61). Chlorophyll-*a* data collected from Liberty Lake WQM stations between 2003 and 2006 were used to support the decision to place the lake on the DEQ 2008 §303(d) list (DEQ 2008) for non-support of the Public and Private Water Supply Use in an SWS lake.

During the years 1998 to 2006, total nitrogen levels in Guthrie Lake averaged approximately 0.97 mg/L, and total phosphorus levels averaged 0.053 mg/L. Total nitrogen is calculated as the sum of Kjeldahl nitrogen and two inorganic forms in different oxidation states: nitrate and nitrite nitrogen. Kjeldahl nitrogen is the sum of organic nitrogen and ammonia nitrogen. Total phosphorus is composed of organic phosphorus, inorganic orthophosphorus, and inorganic polyphosphates. Thermal stratification was not observed during the 2006-2007 assessment period, likely due to the shallow nature of the lake (OWRB

2007). Thus, nutrient fluxes from sediments were available year-round in the photic zone where light permits algal photosynthesis.

Total nitrogen levels in Liberty Lake averaged approximately 0.80 mg/L, and total phosphorus levels averaged 0.040 mg/L. As in Guthrie Lake, thermal stratification was not observed during 2005-2006 in Liberty Lake (OWRB 2007).

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 target established for each lake must demonstrate compliance with the numeric criterion prescribed for SWS lakes in the Oklahoma WQS (OWRB 2011). Therefore, the water quality target established for Guthrie Lake and Liberty Lake is to achieve a long-term average in-lake concentration of 10 µg/L for chlorophyll-*a*. Guthrie Lake is also included in the 303(d) list for Enterococcus, while Liberty Lake is listed for Enterococcus and dissolved oxygen criteria exceedances. These water quality issues will be addressed specifically at a future date.

E.2 Pollutant Source Assessment

This section includes an assessment of the known and suspected sources of nutrients contributing to the eutrophication of Guthrie Lake and Liberty Lake. Nutrient sources identified are categorized and quantified to the extent that reliable information is available. Generally, nutrient loadings causing eutrophication of lakes originate from point or nonpoint sources of pollution. Point sources are permitted through the NPDES program. Nonpoint sources are diffuse sources that typically cannot be identified as entering a waterbody through a discrete conveyance at a single location. Nonpoint sources may emanate from land activities that contribute nutrient loads to surface water as a result of rainfall runoff. For the TMDLs in this report, all sources of pollutant loading not regulated by NPDES are considered nonpoint sources.

Under 40 CFR, §122.2, a point source is described as a discernable, 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 nutrient loading include:

- NPDES municipal wastewater treatment plant (WWTP) discharges;
- NPDES industrial WWTP discharges;
- NPDES municipal no-discharge WWTPs;
- NPDES concentrated animal feeding operations (CAFO); and
- NPDES municipal separate storm sewer system (MS4) discharges.

None of these five types of facilities occurs within the Guthrie Lake watershed, while the Liberty Lake watershed has two no-discharge facilities. For the purposes of these TMDLs, no-discharge facilities are not considered a source of nutrient loading. It is possible that the wastewater collection system associated with no-discharge facilities could be a source of nutrient loading, or that discharges from the WWTP may occur during large rainfall events that exceed the systems' storage capacities. These types of unauthorized discharges are typically reported as sanitary sewer overflows. However, the two facilities in the watershed have not reported a sanitary sewer overflow since 2000. Furthermore, given the small size of the wastewater collection systems of these no-discharge facilities, the contributions of nutrient loads would be negligible.

As there are no point source discharges in the Study Area, the entire external nutrient loading to each lake originates from nonpoint sources. Nonpoint sources include those sources that cannot be identified as entering the waterbody at a specific location. The relatively homogeneous land use/land cover categories throughout the Study Area associated with forest and range management activities have a strong influence on the origin and pathways of nutrient sources to surface water. Nutrient sources in rural watersheds originate from soil erosion, agricultural fertilization, residues from mowing and harvesting, leaf litter, atmospheric deposition of nutrients, failing onsite wastewater disposal (OSWD) systems, and fecal matter deposited in the watershed by wildlife, livestock, and pets.

Given a lack of instream water quality data and pollutant source data available to quantify nutrient and sediment loading directly from the tributaries of Guthrie Lake and Liberty Lake, a watershed loading model – the Soil and Water Assessment Tool (SWAT) – was used to develop nonpoint source loading estimates. These estimates from SWAT were used to quantify the nutrient contributions to each lake. SWAT is a basin-scale watershed model that can be operated on a daily time step (Neitsch et al. 2005). SWAT is designed to predict the impact of management strategies on water, nutrient, sediment, and agricultural chemical yields. The model is physically (and empirically) based, computationally efficient, and capable of continuous simulation over long time periods. The major components of the model include weather, hydrology, soil temperature and properties, plant growth, nutrients, and land management.

There are no stream flow or water quality monitoring stations in the tributaries to Guthrie Lake or Liberty Lake. To calibrate the SWAT model, it was necessary to extend the modeled area to encompass watersheds with stream flow gages and nutrient concentration measurements. Thus, the SWAT model simulated the portion of U.S. Geological Survey (USGS) hydrologic unit 11050002 (Lower Cimarron River Basin) located downstream of USGS gage 07159100 – Cimarron River at U.S. Highway 81. The modeled domain is a 1,850 square mile area that includes the contributing watersheds of both Guthrie Lake and Liberty Lake.

A 16-year period (1994 - 2009) was simulated in the SWAT model. However, the first four years were considered a "spin-up" period for stabilizing model initial conditions, and the model output consisted of only the latter 12 years (1998 - 2009). The variables simulated in SWAT included flow, organic phosphorus, mineral ortho-phosphorus, organic nitrogen, ammonia nitrogen, nitrate nitrogen, nitrite nitrogen, and total suspended solids.

The SWAT hydrologic calibration was primarily performed based on flow data available at the USGS gages located on the Cimarron River at U.S. Highway 77 (0716000) and Skeleton Creek at State Highway 74 (07160500). A secondary calibration was performed at Cottonwood Creek near Seward (07159750). The primary calibration targets included annual flows, but modeled monthly flows and the resulting flow duration curves were also compared to measured values. Overall, the model reproduces the annual flows within the 15 percent target for most years, with overall errors below the target for the primary locations (-10% for the Cimarron River and -5% for Skeleton Creek) and an overall error of -19% for the secondary location. Resulting Nash-Sutcliffe Efficiency coefficients (NSE) and correlation coefficient (r^2) values were 0.934 and 0.950 for the Cimarron River, 0.878 and 0.954 for Skeleton Creek, and 0.809 and 0.631 for Cottonwood Creek. The high resulting coefficients indicate very good model performance.

After hydrologic calibration, the SWAT-predicted nutrient concentrations were calibrated to the average measured nutrient concentrations at five water quality stations: the Cimarron River at U.S. 77 (OK620910010010-001AT), Skeleton Creek at S.H. 74 (OK620910030010-001AT), Cottonwood Creek (OK620910-04-0010D), Chisholm Creek (OK620910-04-0100G), and Kingfisher Creek (OK620910-05-0010J). In most cases, the SWAT model reproduced the average nutrient concentrations within 20 percent of the measured averages. In some instances, the model did not replicate particular nutrient species well for a given period, but nevertheless the total phosphorus and nitrogen predicted averages were within the 20 percent target. However, it is noted that monitoring data available for calibration were from low to moderate flow conditions. As a result, there is more uncertainty on high flow loading values.

Based on the calibrated SWAT model, average loads of nutrients from each individual subwatershed were estimated for the period 1998 to 2009. The average daily flows and annual loads into Guthrie Lake and Liberty Lake are displayed in Table ES-1. Under current conditions, Guthrie Lake is estimated to receive a total annual load of 3,400 kg of phosphorus and 8,600 kg of nitrogen, on average, from nonpoint sources in its watershed. Liberty Lake is estimated to receive a total annual load of 2,700 kg of phosphorus and 7,400 kg of nitrogen, on average, from sources in its watershed.

Table ES-1 Average Daily Flows and Annual Nutrient Loads Discharging to Guthrie Lake and Liberty Lake

Parameter	Guthrie Lake	Liberty Lake
Watershed Size (square miles)	12.7	11.4
Flow (m^3/day)	2.69×10^4	2.01×10^4
Organic Phosphorus (kg/year)	1,900	1,500
Mineral Ortho-Phosphorus (kg/year)	1,500	1,200
Total Phosphorus (kg/year)	**3,400**	**2,700**
Organic Nitrogen (kg/year)	3,100	2,600
Ammonia Nitrogen (kg/year)	0	0
Nitrate Nitrogen (kg/year)	5,500	4,800
Nitrite Nitrogen (kg/year)	0	0
Total Nitrogen (kg/year)	**8,600**	**7,400**

E.3 Technical Approach and Methods

The objective of a TMDL is to estimate allowable pollutant loads and allocate those loads to the known pollutant sources in the watershed so appropriate control measures can be implemented and the WQS achieved. To ascertain the effect of management measures on in-lake water quality, it is necessary to establish a linkage between the external loading of nutrients and the waterbody response in terms of lake water quality conditions, as evaluated by chlorophyll-*a* concentrations. The following paragraphs describe the water quality analysis of the linkage between chlorophyll-*a* levels in Guthrie Lake and Liberty Lake and the nutrient loadings from their watersheds.

The water quality linkage analysis was performed using the BATHTUB model (Walker 1986). BATHTUB is a U.S. Army Corps of Engineers model designed to simulate eutrophication in reservoirs and lakes. BATHTUB has been cited as an effective tool for reservoir and lake water quality assessment and management, particularly where data are limited. The model incorporates several empirical equations of nutrient settling and algal growth to predict steady-state water column nutrient and chlorophyll-*a* concentrations based on water body characteristics, hydraulic characteristics, and external nutrient loadings.

The model was run under existing average, steady-state conditions. An averaging period of one year was used to depict the duration of mass-balance calculations for both lakes. A single, well-mixed lake was assumed for both reservoirs. Key water quality parameters for BATHTUB input include total phosphorus, inorganic ortho-phosphorus, total nitrogen, and inorganic nitrogen. Output from the SWAT model was the primary source of data input to the BATHTUB model. Although SWAT can provide daily output, BATHTUB is a steady-state model and not appropriate for interpreting short-term responses of lakes to nutrients. Therefore, the long-term average annual loads from the SWAT-modeled period were applied as inputs to BATHTUB.

The BATHTUB models for each lake were calibrated to measured in-lake water quality conditions (based on data from 1998 through 2006) using phosphorus and nitrogen calibration factors. The model-predicted concentrations of total nitrogen, total phosphorus, chlorophyll-*a*, and Secchi depth under existing average conditions are compared to average measured concentrations from each lake in Table ES-2.

Table ES-2 Model Predicted and Measured Water Quality Parameter Concentrations

Water Quality Parameter	Guthrie Lake		Liberty Lake	
	Modeled	Measured	Modeled	Measured
Total Phosphorus (mg/L)	0.054	0.053	0.043	0.040
Total Nitrogen (mg/L)	0.69	0.97	0.75	0.80
Chlorophyll-*a* (µg/L)	20.0	19.5	23.0	23.0
Secchi depth (meters)	0.5	0.52	0.5	0.48

Simulations were performed using the BATHTUB model to evaluate the effect of watershed and septic system loading reductions on chlorophyll-*a* levels. Atmospheric loads remained at their existing levels. Simulations indicated that the water quality target of 10 µg/L chlorophyll-*a* as a long-term average concentration could be achieved if the total phosphorus and nitrogen loads to Guthrie Lake were both reduced by 45 percent from the existing loads (Table ES-3). In Liberty Lake, the water quality target of 10 µg/L chlorophyll-*a* could be achieved if the total phosphorus and nitrogen loads were both reduced by 58 percent from the existing loads. These maximum daily loads include a 10 percent explicit MOS.

Table ES-3 Target Total Phosphorus and Nitrogen Loads and Reductions from Current Loads to Meet the 10 µg/L Chlorophyll-*a* Water Quality Standard

	Guthrie Lake	Liberty Lake
Maximum Allowable Load of Total Phosphorus (kg/year)	1,940	1,140
Maximum Allowable Load of Total Nitrogen (kg/year)	4,890	3,110
% Reduction	45%	58%

E.4 TMDLs and Load Allocations

TMDLs for the §303(d)-listed waterbodies covered in this report were derived using the outputs from the BATHTUB model. A TMDL is expressed as the sum of all WLAs (point source loads), LAs (nonpoint source loads), and an appropriate MOS, which attempts to account for the uncertainty concerning the relationship between loading limitations and water quality. This definition can be expressed by the following equation:

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

There are no point sources of wastewater discharging to Guthrie Lake or Liberty Lake or their tributaries. Furthermore, Oklahoma's implementation of WQS (OAC 785:46-13-4) prohibits new point source discharges to these SWS lakes, excepting storm water with approval from DEQ (OWRB 2011a). There are no municipal separate storm sewer systems within the Guthrie Lake watershed. Thus, the wasteload allocation for Guthrie Lake is zero (Table ES-4). The load allocation for all nonpoint sources to Guthrie Lake was conservatively estimated as 1,940 kg/yr of total phosphorus and 4,890 kg/yr of total nitrogen, representing a 45 percent reduction from existing loading.

A very small area (about 7 acres) of the NPDES-MS4 for Oklahoma County discharges to the upper part of the Liberty Lake watershed. Based on SWAT model results, the existing loads amount to 3.0 kg/yr of total phosphorus and 6.6 kg/yr of total nitrogen. Since this estimated loading is insignificant, this TMDL does not include a WLA for that area. The load allocation for all nonpoint sources to Liberty Lake was conservatively estimated as 1,140 kg/yr of total phosphorus and 3,110 kg/yr of total nitrogen, representing a 58 percent reduction from existing nonpoint source loading.

USEPA guidance allows for use of 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 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. In these TMDLs, the MOS has both an explicit component of 10 percent, and an implicit component incorporated by application of load reductions for both nitrogen and phosphorus. Seasonal variation was accounted for in these TMDLs by using more than five years of water quality data collected in each of the four seasons.

Load reduction scenario simulations were run using the BATHTUB model to calculate and express the TMDL as annual average phosphorus and nitrogen loads (in kg/yr) that, if achieved, should decrease chlorophyll-*a* concentrations to meet the water quality target. 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. It is important to recognize that the chlorophyll-*a* response to nutrient loading in both Guthrie Lake and Liberty Lake is affected by many factors such as: internal lake nutrient loading, water residence time, wind action and the interaction between light penetration, nutrients, sediment load, and algal response. As such, it is important to note that expressing this TMDL in daily time steps does not imply a daily response to a daily load is practical from an implementation perspective.

The USEPA's *Technical Support Document for Water Quality-Based Toxics Control* (USEPA 1991b) provides a statistical method for identifying a statistical maximum daily limit based on a long-term average and considering variation in a dataset. The method is represented by the following equation:

$$MDL = LTA \times e^{z\sigma - 0.5\sigma^2}$$

where *MDL* = maximum daily load
LTA = long-term average load
z = z statistic of the probability of occurrence (0.95 is assumed for this value)
$\sigma^2 = \ln(CV^2+1)$
CV = coefficient of variation

The coefficient of variation of daily nitrogen and phosphorus nonpoint source (NPS) loads were calculated from SWAT model output and ranged from 4.6 to 4.9 for phosphorus and from 3.4 to 3.7 for nitrogen. Assuming a probability of occurrence of 95 percent, the maximum daily load corresponding to the allowable average load of 1,940 kg of phosphorus and 4,890 kg of nitrogen per year to Guthrie Lake is translated to a daily maximum load of 5.8 kg/day of phosphorus and 16.6 kg/day of nitrogen. For Liberty Lake, the allowable average load of 1,140 kg of phosphorus and 3,110 kg of nitrogen per year is translated to a daily maximum load of 3.6 kg/day of phosphorus and 10.8 kg/day of nitrogen. Reduction of total phosphorus and total nitrogen loads to these levels is expected to result in achievement of WQS for chlorophyll-*a* in each lake.

Table ES-4 TMDLs for Chlorophyll-*a* Expressed in Kilograms of Total Phosphorus and Nitrogen Per Day

Waterbody Name	Waterbody ID	Nutrient	TMDL	WLA	LA	MOS
Guthrie Lake	OK620910040060_00	Total Phosphorus	5.8 kg/day	0	5.2 kg/day	0.6 kg/day
		Total Nitrogen	16.6 kg/day	0	14.9 kg/day	1.7 kg/day
Liberty Lake	OK620910040080_00	Total Phosphorus	3.6 kg/day	0	3.2 kg/day	0.4 kg/day
		Total Nitrogen	10.8 kg/day	0	9.7 kg/day	1.1 kg/day

E.5 Public Participation

After EPA preliminarily reviewed the TMDL report, a public notice was sent to all entities who request copies of all public notices as well as all entities in the Study Area watershed from DEQ's Stakeholder Database. The public had 45 days to review the TMDL report and make written comments. No public comments were received and no public meeting was requested.

SECTION 1
INTRODUCTION

1.1 TMDL Program Background

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 instream 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 chlorophyll-*a* for two lakes (reservoirs) in the Lower Cimarron-Skeleton (hydrologic unit code [HUC] 11050002) basin. Elevated levels of chlorophyll-*a* in lakes reflect excessive algae growth, which can have deleterious effects on the 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 excessive loading of the primary growth-limiting algal nutrients nitrogen and phosphorus to the waterbody, a process known as eutrophication. The purpose of this TMDL report is to establish nutrient load allocations necessary for reducing chlorophyll-*a* levels in the lakes, which is the first step toward restoring water quality and protecting public health. TMDLs determine the pollutant loading a waterbody can assimilate without exceeding applicable WQS. TMDLs also establish the pollutant load allocation necessary to meet the WQS established for a waterbody based on the relationship between pollutant sources and water quality conditions in the waterbody. A TMDL consists of a wasteload 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 process in aquatic systems, 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 each 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 tribes, and local, state, and federal government agencies.

This TMDL report focuses on waterbodies that DEQ placed in Category 5 [303(d) list] of the *Water Quality in Oklahoma, 2008 Integrated Report* (2008 Integrated Report) for non-support of the public and private water supply use. The waterbodies addressed in this report include:

- Guthrie Lake (OK620910040060_00), and
- Liberty Lake (OK620910040080_00).

Figure 1-1 is location map showing these Oklahoma waterbodies and their contributing watersheds. This map also displays locations of the water quality monitoring (WQM) stations used as the basis for placement of these waterbodies on the Oklahoma §303(d) list. These waterbodies and their surrounding watersheds are hereinafter referred to as the Study Area.

1.2 Watershed and Lake Description

Lake Characteristics. Guthrie Lake is a 274 acre lake in Logan County with a conservation pool storage of 3,875 acre-feet. It was impounded in 1919, and serves as a recreational lake and is utilized for water supply for the City of Guthrie (OWRB 2009). Guthrie Creek, which is 5.8 miles long, is the primary tributary flowing to Guthrie Lake.

Liberty Lake is a 167 acre lake in Logan County with a conservation pool storage of 2,740 acre-feet. It was first impounded in 1948 and serves as a recreational lake and as a municipal water supply for the City of Guthrie (OWRB 2009). Liberty Lake Creek, which is 5.6 miles long, is the primary tributary flowing to Liberty Lake.

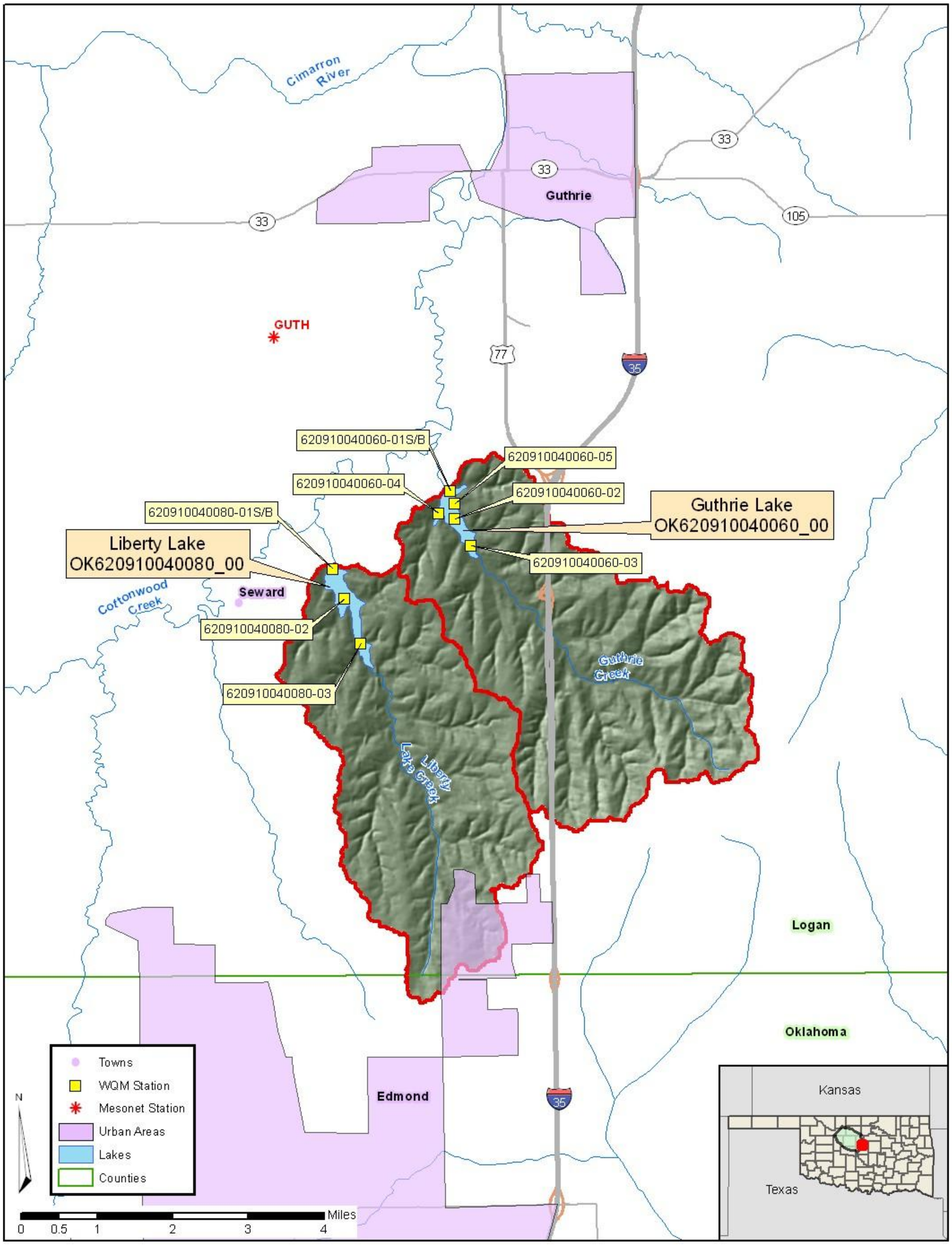
There is little developed land bordering the shoreline of either lake. Both lakes are popular fishing and boating recreation destinations. Table 1-1 provides general characteristics of each lake.

Table 1-1 General Lake Characteristics

Waterbody Name and WBID	Surface Area (Acres)	Conservation Pool Storage (Acre- Feet)	Normal Elevation (Feet MSL)	Average Depth (Feet)	Shoreline (Miles)	Management Agency
Guthrie Lake OK620910040060_00	274	3,875	982	12	5	City of Guthrie
Liberty Lake OK620910040080_00	167	2,471	1,411	13	5	City of Guthrie

MSL = Mean Sea Level

Figure 1-1 Guthrie Lake and Liberty Lake



General. Both lakes are within the watershed of the Cimarron River, a tributary of the Arkansas River located in the central portion of Oklahoma. Guthrie Lake's contributing watershed is located entirely in Logan County. The majority of the watershed of Liberty Lake is also located in Logan County, but a small portion lies in Oklahoma County. These counties are part of the Cross Timbers ecoregion (Woods et al. 2005), which is characterized by low, rolling hills covered with a mix of woodland, pastureland, and rangeland. This ecoregion divides the moister, more forested, eastern ecoregions from drier, prairie-dominated, western areas. Table 1-2, derived from the 2010 U.S. Census, demonstrates that the portion of Logan County in which the majority of these watersheds are located is sparsely populated (U.S. Census Bureau 2010). There are no towns located within either watershed; however, approximately 7 acres of the Liberty Lake watershed is within the Oklahoma City urbanized area.

Table 1-2 County Population and Density

County Name	Population (2010 Census)	Population Density (per square mile)
Logan	39,301	56
Oklahoma	716,704	1,001

Climate. Table 1-3 summarizes the average annual precipitation for Guthrie Lake (OK620910040060_00) and Liberty Lake (OK620910040080_00). Average annual precipitation values were derived from the Oklahoma Mesonet Dataset (http://www.mesonet.org) based on a period of record of 1994 to 2009 at the Guthrie station (Figure 1-1).

Table 1-3 Average Annual Precipitation by Watershed 1994-2009

Waterbody Name	Waterbody ID	Average Annual Precipitation (inches)
Guthrie Lake	OK620910040060_00	36.05
Liberty Lake	OK620910040080_00	36.05

Land Use. The contributing drainage areas of the Guthrie Lake and Liberty Lake watersheds are approximately 12.7 and 11.4 square miles, respectively. Table 1-4 summarizes the percentages and acreages of the land use categories for the contributing watersheds. The land use/land cover data were derived from the National Agricultural Statistics Service (NASS) 2008 Cropland Data Layer (CDL). The CDL is a crop-specific land cover classification data set. Land use in the watersheds of Guthrie Lake and Liberty Lake is displayed in Figure 1-2. The most common land use category throughout the Study Area is deciduous forest. Both watersheds in the Study Area also have a significant percentage of land classified as grassland herbaceous. The aggregated total of low, medium, and high intensity developed land accounts for less than three percent of the land use in each watershed.

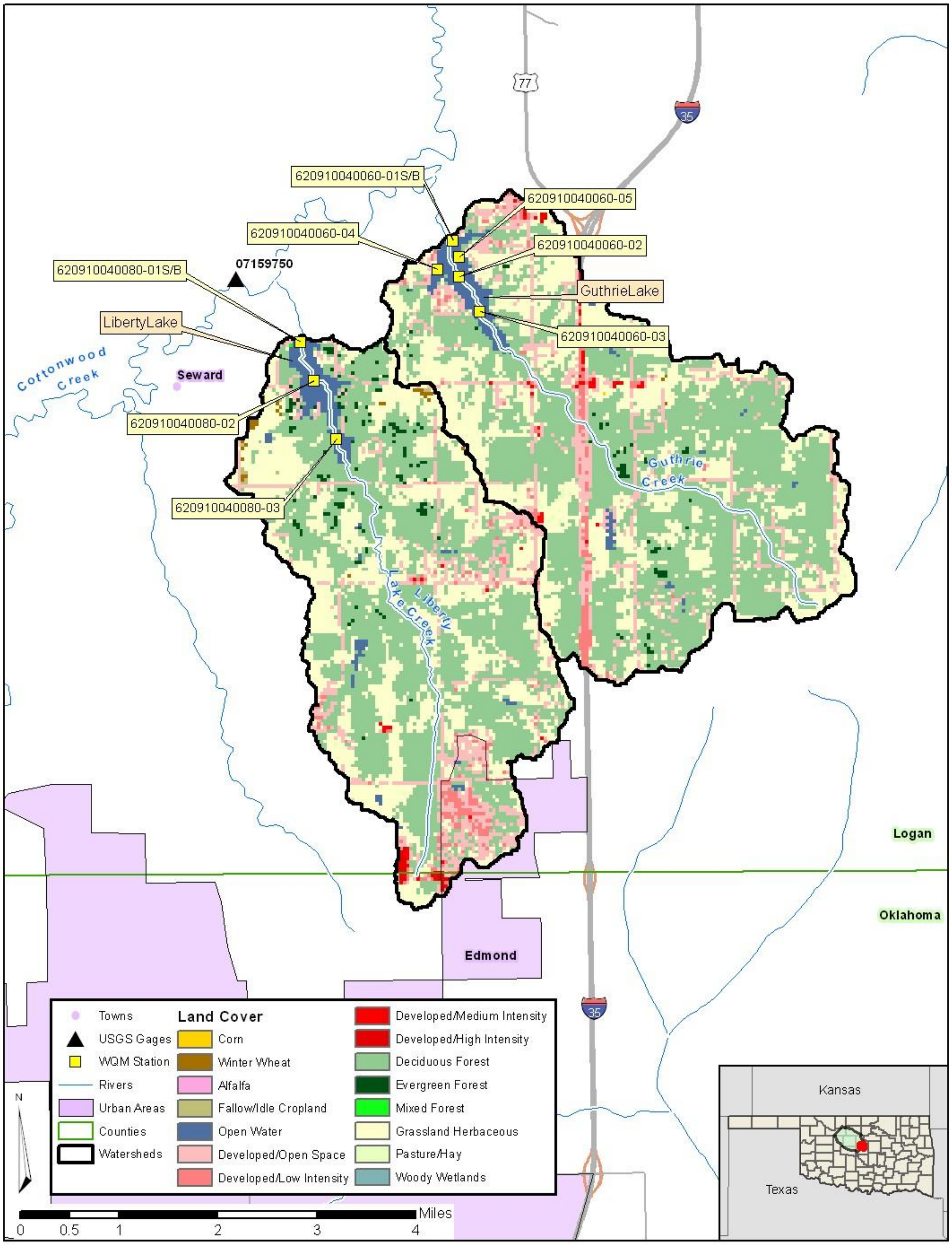
Table 1-4 Land Use Summary by Watershed

Description	Guthrie Lake		Liberty Lake	
	Acres	**Percent**	**Acres**	**Percent**
Corn	1	0.01	0	0
Winter Wheat	3	0.03	28	0.4
Fallow/Idle Cropland	1	0.01	10	0.1
Open Water	235	3	238	3
Developed/Open Space	870	11	836	11
Developed/Low Intensity	183	2	156	2
Developed/Medium Intensity	43	0.5	27	0.4
Developed/High Intensity	6	0.07	21	0.3
Deciduous Forest	4,096	50	3,364	46
Evergreen Forest	50	0.6	103	1.4
Mixed Forest	0	0	1	0.01
Grassland/Herbaceous	2,602	32	2,497	34
Pasture/Hay	36	0.4	13	0.2
Woody Wetlands	1	0.01	0	0.01
Total Drainage Area	**8,127**		**7,294**	

1.3 Flow Characteristics

Stream flow characteristics and data are key information when conducting water quality assessments such as TMDLs. However, there are no flow gages located on any of the tributaries to Guthrie Lake and Liberty Lake, at the lake outlets, or on Liberty Lake Creek or Guthrie Creek between the lake outlets and the point where they flow into Cottonwood Creek. Given the lack of historical stream flow data, flow estimates for these tributaries were developed using a watershed model calibrated to flow measurements at U.S. Geological Survey (USGS) gage stations in adjacent watersheds. This is discussed in further detail in Section 3.

Figure 1-2 Guthrie Lake and Liberty Lake Watershed Land Use



SECTION 2
PROBLEM IDENTIFICATION AND WATER QUALITY TARGET

2.1 Oklahoma Water Quality Standards

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 antidegradation 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 Antidegradation Policy is provided in Appendix A. The beneficial uses designated for Guthrie Lake and Liberty Lake are aesthetic, irrigation agricultural water supply, the warm water aquatic community subcategory of the fish and wildlife propagation, fish consumption, primary body contact recreation, and public and private water supply. Table 2-1, an excerpt from the 2008 Integrated Report (DEQ 2008), summarizes the designated use attainment status and the waterbody/pollutant combinations that require TMDLs for the two waterbodies. The TMDL priority shown in Table 2-1 is directly related to the TMDL target date. The TMDLs established in this report, which are a necessary step in the process of restoring water quality, only address the nonattainment of the public and private water supply use.

Table 2-1 Excerpt from the 2008 Integrated Report – Oklahoma §303(d) List of Impaired Waters (Category 5a)

Waterbody Name and WBID	Waterbody Size (Acres)	TMDL Date	TMDL Priority	Causes of Impairment	Designated Use Not Supported
Guthrie Lake OK620910040060_00	274	2010	4	▪ Chlorophyll-*a* ▪ Enterococcus	▪ Public and Private Water Supply ▪ Primary Body Contact Recreation
Liberty Lake OK620910040080_00	167	2010	4	▪ Chlorophyll-*a* ▪ Enterococcus ▪ Oxygen, Dissolved	▪ Public and Private Water Supply ▪ Primary Body Contact Recreation ▪ Warm Water Aquatic Community

Source: 2008 Integrated Report, DEQ 2008.

Both Guthrie and Liberty lakes are designated as SWS lakes. The definition of SWS is summarized by the following excerpt from OAC 785:45-5-25 of the Oklahoma WQS (OWRB 2011).

> ***Sensitive Public and Private Water Supplies (SWS).***
> *(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 A 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 Guthrie Lake and Liberty Lake (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.*

Neither Guthrie Lake nor Liberty Lake have been assigned the designation of “nutrient limited watershed” (NLW) in OAC 785:45-5-29. An NLW means a watershed of a waterbody with a designated beneficial use that is adversely affected by excess nutrients as determined by Carlson's 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 Problem Identification

In this subsection, water quality data indicating waterbody impairment caused by elevated levels of chlorophyll-*a* are summarized. Water quality data available for other nutrient parameters are also summarized. Table 2-2 provides the locations of WQM stations on each lake. These WQM stations are part of the Oklahoma Beneficial Use Monitoring Program network (OWRB 2007). Table 2-2 also provides a hyperlink to the OWRB Data Viewer from which lake water quality data were obtained. The locations of the WQM stations for Guthrie Lake and Liberty Lake are illustrated in Figure 1-1.

Table 2-2 Water Quality Monitoring Stations used for 2008 §303(d) Listing Decision

Water Body ID	Station ID*	Latitude	Longitude	Site Description
Guthrie Lake				
620910040060_00	620910040060-01B	35.81889	-97.43885	Bottom
620910040060_00	620910040060-01S	35.81889	-97.43885	Near Surface
620910040060_00	620910040060-02	35.81356	-97.43790	Near Surface
620910040060_00	620910040060-03	35.80842	-97.43420	Near Surface
620910040060_00	620910040060-04	35.81462	-97.44171	Near Surface
620910040060_00	620910040060-05	35.81643	-97.43782	Near Surface
Liberty Lake				
620910040080_00	620910040080-01B	35.80433	-97.46670	Bottom
620910040080_00	620910040080-01S	35.80433	-97.46670	Near Surface
620910040080_00	620910040080-02	35.79869	-97.46424	Near Surface
620910040080_00	620910040080-03	35.79005	-97.46053	Near Surface

* Hyper links are workable in the electronic version of this document.

2.2.1 Chlorophyll-*a* Data Summary

Table 2-3 summarizes chlorophyll-*a* data collected from Guthrie Lake WQM stations from 2003 through 2006. The data summary in Table 2-3 provides a general understanding of the amount of water quality data available and the severity of exceedances of the water quality criterion of 10 µg/L chlorophyll-*a*, as a long-term average at a depth of one-half meter. Chlorophyll-*a* from surface level samples averaged 18.7 µg/L, which is equivalent to a Carlson's TSI of 59 (Carlson 1977). According to the 2008-2009 Beneficial Use Monitoring Program (BUMP) Report, using water quality samples collected between October 2005 and July 2006, the TSI calculated for Guthrie Lake was 61 (OWRB 2009). As stipulated in the Implementation Procedures for Oklahoma's Water Quality Standards [785:46-15-3(c)] the most recent 10 years of water quality data are used as the basis for evaluating the beneficial use support for lakes (OWRB 2011a). Chlorophyll-*a* data collected from Guthrie Lake WQM stations between 2003 and 2006 were used to support the decision to place the lake on the DEQ 2008 §303(d) list (DEQ 2008) for non-support of the Public and Private Water Supply Use in an SWS lake. The water quality data are provided in Appendix B.

Table 2-3 Summary of Chlorophyll-*a* Measurements in Guthrie Lake 2003-2006 (all values in µg/L)

Station ID	Number of Samples	Minimum	Maximum	Average	Median
620910040060-01B†	4	7.8	30	15.3	11.7
620910040060-01S	8	7.6	32.8	18.7	18.3
620910040060-02	7	7.3	40.3	20.1	17.4
620910040060-03	7	7.2	30.0	17.3	15.0
620910040060-04	7	5.8	34.0	18.8	17.9
620910040060-05	7	6.6	35.5	18.5	17.4
Overall Surface Samples*	36	5.8	40.3	18.7	17.6

†note that data from this bottom station cannot be compared to the water quality criterion, which applies to samples collected at a depth of 0.5 meter. It is included for informational purposes only.

*Bottom data was excluded

Table 2-4 summarizes chlorophyll-*a* measurements collected from Liberty Lake from 2003 through 2006. Pooling data from surface level sites, chlorophyll-*a* levels averaged 23.2 µg/L (TSI = 61). According to the 2008-2009 Beneficial Use Monitoring Program (BUMP) Report, using water quality samples collected between October 2005 and July 2006, the TSI calculated for Liberty Lake was 67 (OWRB 2009). As stipulated in the Implementation Procedures for Oklahoma's Water Quality Standards [785:46-15-3(c)] the most recent 10 years of water quality data are used as the basis for evaluating the beneficial use support for lakes (OWRB 2011a). Chlorophyll-*a* data collected from Liberty Lake WQM stations between 2003 and 2006 were used to support the decision to place the lake on the DEQ 2008 §303(d) list (DEQ 2008) for non-support of the Public and Private Water Supply Use in an SWS lake. Water quality data are provided in Appendix B.

Table 2-4 Summary of Chlorophyll-a Measurements in Liberty Lake 2003-2006 (all values in µg/L)

Station ID	Number of Samples	Minimum	Maximum	Average	Median
620910040080-01B†	6	0.7	48	20.4	13.0
620910040080-01S	7	8.2	47	23.5	20.0
620910040080-02	7	9.3	45	23.3	20.0
620910040080-03	7	6.4	45	22.8	21.8
Overall Surface Samples*	21	6.4	46.5	23.2	20.0

†note that data from this bottom station cannot be compared to the water quality criterion, which applies to samples collected at a depth of 0.5 meter. It is included for informational purposes only.

*Bottom data were excluded

2.2.2 Nutrient Data Summary

During the years 1998 to 2006, total nitrogen levels in Guthrie Lake averaged approximately 0.97 mg/L, and total phosphorus levels averaged 0.053 mg/L (Table 2-5). Total nitrogen is calculated as the sum of Kjeldahl nitrogen and two inorganic forms in different oxidation states: nitrate and nitrite nitrogen. Kjeldahl nitrogen is the sum of organic nitrogen and ammonia nitrogen. Total phosphorus is measured directly and composed of organic phosphorus, inorganic orthophosphorus, and inorganic polyphosphates. Thermal stratification was not observed during the 2005-2006 assessment period, likely due to the shallow nature of the lake (OWRB 2007). Thus, nutrient fluxes from sediments were available year-round in the photic zone, where light permits algal photosynthesis.

Table 2-5 Summary of Average Nutrient Measurements in Guthrie Lake 1998-2006 (all values in mg/L)‡

Station ID	Nitrogen, Ammonia	Nitrogen, Kjeldahl	Nitrogen, Nitrate+Nitrite	Phosphorus, Ortho	Phosphorus, Total
620910040060-01B	0.070	0.975	0.064	0.019	0.071
620910040060-01S	0.050	0.901	0.042	0.013	0.054
620910040060-02	0.038	0.988	0.045	0.013	0.049
620910040060-03	0.032	0.960	0.048	0.013	0.053
620910040060-04	0.071	0.912	0.038	0.014	0.059
620910040060-05	0.082	0.91	0.038	0.013	0.052
Overall Surface Samples*	0.049	0.933	0.036	0.013	0.053

‡ Non-detects were averaged at half of the detection limit
* bottom data were excluded

Total nitrogen levels in Liberty Lake averaged approximately 0.80 mg/L, and total phosphorus levels averaged 0.040 mg/L (Table 2-6). As in Guthrie Lake, thermal stratification was not observed during 2005-2006 in Liberty Lake (OWRB 2007). Water quality data for nutrient parameters in both lakes are provided in Appendix B.

Table 2-6 Summary of Average Nutrient Measurements in Liberty Lake 1998-2006 (all values in mg/L)‡

Station ID	Nitrogen, Ammonia	Nitrogen, Kjeldahl	Nitrogen, Nitrate+Nitrite	Phosphorus, Ortho	Phosphorus, Total
620910040080-03	0.035	0.795	0.058	0.011	0.046
620910040080-02	0.033	0.811	0.105	0.010	0.042
620910040080-01S	0.036	0.667	0.065	0.009	0.037
620910040080-01B	0.118	0.782	0.069	0.011	0.053

Overall Surface Samples*	0.035	0.726	0.076	0.010	0.040

‡ Non-detects were averaged at half of the detection limit
* Bottom data were excluded

2.3 Water Quality Target

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 target established for each lake must demonstrate compliance with the numeric criterion prescribed for SWS lakes in the Oklahoma WQS (OWRB 2011). Therefore, the water quality target established for Guthrie Lake and Liberty Lake is to achieve a long-term average in-lake concentration of 10 µg/L for chlorophyll-*a*. Guthrie Lake is also included in the 303(d) list for Enterococcus, while Liberty Lake is listed for Enterococcus and dissolved oxygen criteria exceedances. These water quality issues will be addressed specifically on a future date.

SECTION 3
POLLUTANT SOURCE ASSESSMENT

This section includes an assessment of the known and suspected sources of nutrients contributing to the eutrophication of Guthrie Lake and Liberty Lake. Nutrient sources identified are categorized and quantified to the extent that reliable information is available. Generally, nutrient loadings causing eutrophication of lakes originate from point or nonpoint sources of pollution. Point sources are permitted through the NPDES program. Nonpoint sources are diffuse sources that typically cannot be identified as entering a waterbody through a discrete conveyance at a single location. Nonpoint sources may emanate from land activities that contribute nutrient loads to surface water as a result of rainfall runoff. For the TMDLs in this report, all sources of pollutant loading not regulated by NPDES are considered nonpoint sources. The following discussion provides a general summary of the point and nonpoint sources of nutrients emanating from the contributing watersheds of each lake.

3.1 Assessment of Point Sources

Under 40 CFR §122.2, a point source is described as a discernable, 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 nutrient loading include:

- NPDES municipal wastewater treatment plant (WWTP) discharges;
- NPDES industrial WWTP discharges;
- NPDES no-discharge WWTPs;
- NPDES concentrated animal feeding operations (CAFOs); and
- NPDES municipal separate storm sewer system (MS4) discharges,

None of these five types of facilities occurs within Guthrie Lake watershed, while the Liberty Lake watershed has two no-discharge facilities. The no-discharge facilities permitted within the Liberty Lake watershed are listed in Table 3-1 and their location is shown in Figure 3-1. For the purposes of these TMDLs, no-discharge facilities are not considered a source of nutrient loading. It is possible that the wastewater collection system associated with no-discharge facilities could be a source of nutrient loading, or that discharges from the wastewater plant may occur during large rainfall events that exceed the systems' storage capacities. These types of unauthorized discharges are typically reported as sanitary sewer overflows. However, the facilities in Table 3-1 have not reported a sanitary sewer overflow since 2000. Furthermore, given the small size of the wastewater collection systems of these no-discharge facilities, the contributions of nutrient loads would be negligible.

Table 3-1 NPDES No-Discharge Facilities in the Study Area

Facility	Facility ID	County	Facility Type	Type	Waterbody ID and Name
Logan County RWD#1	20974	Logan	Lagoon Total Retention	Municipal	Liberty Lake OK620910040080_00
Country Home Meat Company	WD83-006	Logan	Total Retention	Industrial	Liberty Lake OK620910040080_00

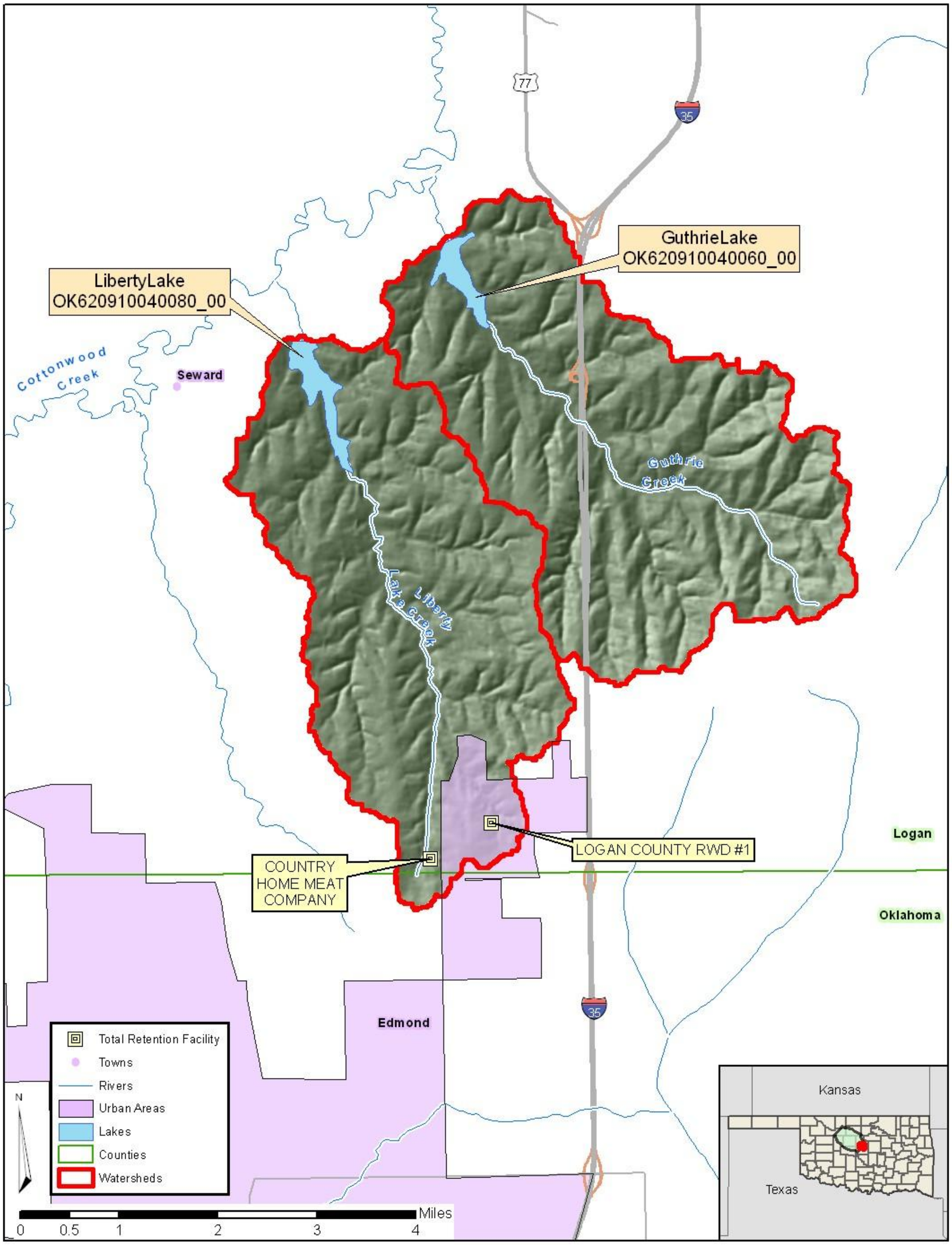
3.2 Estimation of Existing Pollutant Loads

As previously stated, there are no point source discharges in either Guthrie Lake or Liberty Lake watershed. Therefore, all nutrient loading to each lake originates from nonpoint sources. Nonpoint sources include those sources that cannot be identified as entering the waterbody at a specific location. The relatively homogeneous land use/land cover categories throughout the Study Area associated with forest, and range management activities have a strong influence on the origin and pathways of nutrient sources to surface water. Nutrient sources in rural watersheds originate from soil erosion, agricultural fertilization, residues from mowing and harvesting, leaf litter, and fecal waste deposited in the watershed by livestock. Causes of soil erosion can include natural causes such as flooding and winds, construction activities, vehicular traffic, and agricultural activities. Other sources of nutrient loading in a watershed include atmospheric deposition, failing onsite wastewater disposal (OSWD) systems, and fecal matter deposited in the watershed by wildlife and pets. The following sections provide general information on nonpoint sources contributing nutrient loading within the Study Area.

3.2.1 SWAT Model Development for Pollutant Source Loadings

Given the lack of instream water quality data and pollutant source data available to quantify nutrient and sediment loading directly from the tributaries of Guthrie Lake and Liberty Lake, a watershed loading model – the Soil and Water Assessment Tool (SWAT) – was used to develop nonpoint source loading estimates. These estimates from SWAT were used to quantify the nutrient contributions to each lake. SWAT is a basin-scale watershed model that can be operated on a daily time step (Neitsch et al. 2005). SWAT is designed to predict the impact of management strategies on water, nutrient, sediment, and agricultural chemical yields. The model is physically (and empirically) based, computationally efficient, and capable of continuous simulation over long time periods. The major components of the model include weather, hydrology, soil temperature and properties, plant growth, nutrients, and land management. A brief description of inputs and calibration of the SWAT model is presented in Appendix C. A summary of the SWAT modeling of pollutant sources is provided below.

Figure 3-1 NPDES No-Discharge Facilities in the Study Area

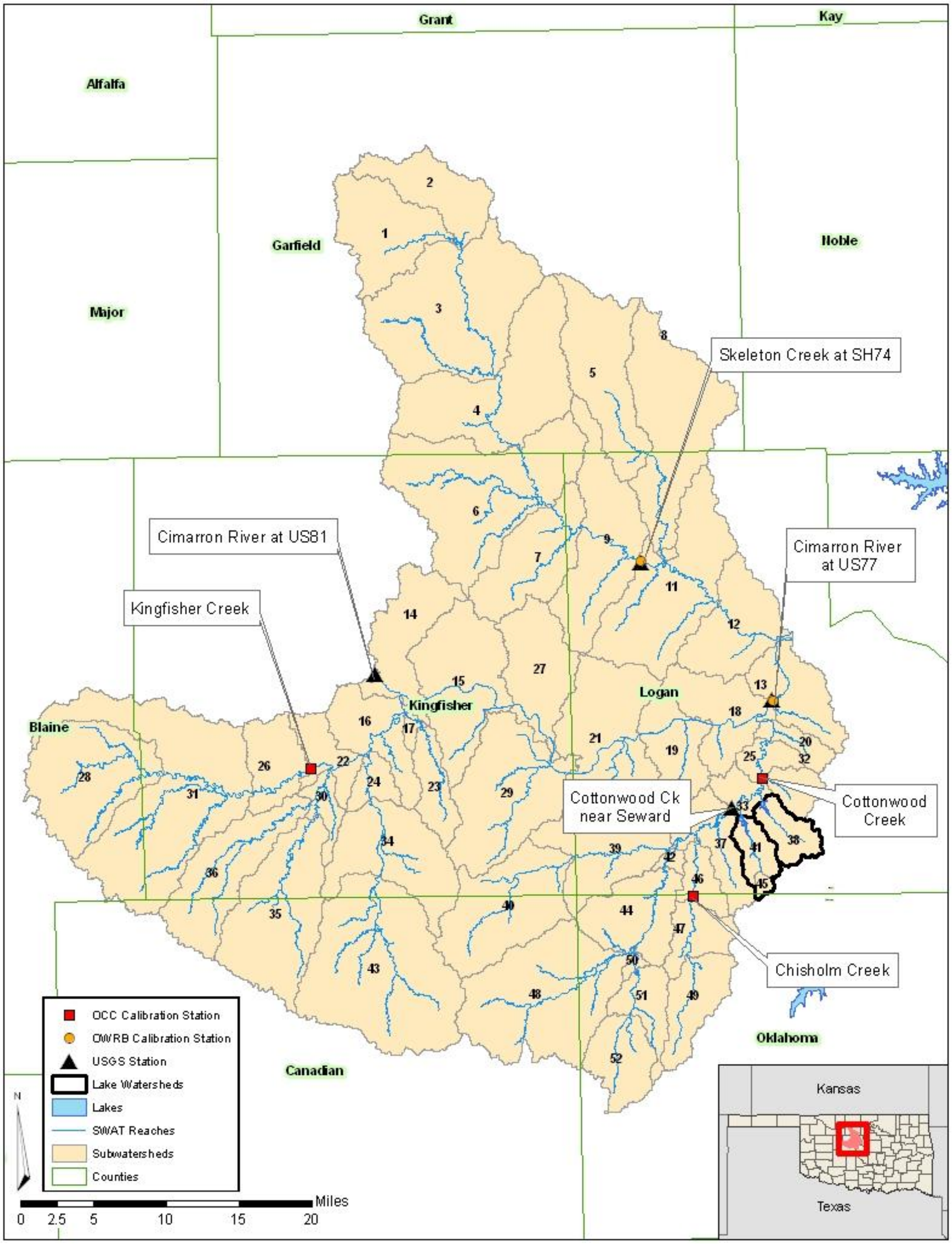


There are no stream flow or water quality monitoring stations in the tributaries to Guthrie Lake or Liberty Lake. To calibrate the SWAT model it was necessary to extend the modeled area to encompass watersheds with stream flow gages and nutrient concentration measurements. Thus, the SWAT model simulated the portion of USGS hydrologic unit 11050002 (Lower Cimarron River Basin) located downstream of USGS gage 07159100 – Cimarron River at U.S. 81. The modeled domain is a 1,850 square mile area that includes the contributing watersheds of both Guthrie Lake and Liberty Lake (Figure 3-2). In addition to the Cimarron River, the main streams located in the model domain are Skeleton Creek, Cottonwood Creek, Kingfisher Creek, Uncle John's Creek, Chisholm Creek, and Deer Creek. The watershed is predominantly rural with a few cities and towns, including all or parts of Enid, North Enid, Covington, Fairmont, Marshall, Kingfisher, Edmond, Crescent, Piedmont, Douglas, Dover, Waukomis, Cimarron City, Cedar Valley, Guthrie, Cashion, Okarche, and Oklahoma City. The modeled area was divided into 52 sub-watersheds (Figure 3-2) based on the National Elevation Dataset (http://ned.usgs.gov) and the National Hydrography Dataset (http://nhd.usgs.gov) of the USGS. The watersheds of Guthrie Lake and Liberty Lake are outlined in black in Figure 3-2. This figure also shows the locations of USGS gages and water quality monitoring stations at which the SWAT model was calibrated.

Soil data were derived from the STATSGO State Soil Geographic Database of the United States Department of Agriculture (USDA) Natural Resource Conservation Service (http://soils.usda.gov/survey/geography/statsgo/). Land use and land cover data were derived from the USDA National Agricultural Statistics Service (NASS) 2008 Cropland Data Layer (CDL) (http://www.nass.usda.gov/research/Cropland/SARS1a.htm) (USDA 2008). County-level summaries of annual cattle population estimates from the NASS were evenly distributed across pasture land (USDA 2007). Soil available phosphorus concentrations were the county averages for the period 1994 to 2001 from the Oklahoma State University Department of Plant and Soil Science (Storm et al. 2000).

Point source discharges of pollutants in the modeled watershed were included in the SWAT model, using discharge monitoring reports (DMR) to indicate flows and loads. Concentrated animal feeding operations (CAFOs) were not included in the SWAT model, given the insignificant contributions from the only no-discharge CAFO facility located in the modeled portion of the hydrologic unit. There are a significant number of OSWD systems (septic systems) in the vicinity of Guthrie Lake. Using a buffer zone of 300 ft around the lakes along with aerial imagery (Google Earth), it was estimated there are 76 septic systems around Guthrie Lake and two septic systems around Liberty Lake. Nutrient loadings from those systems were included directly in the lake models (see Section 4.2) and thus, were not simulated in the SWAT model.

Figure 3-2 Subwatersheds Simulated in the SWAT Watershed Model



A 16-year period (1994 - 2009) was simulated in the SWAT model. However, the first four years were considered a "spin-up" period for stabilizing model initial conditions, and the model output consisted of only the latter 12 years (1998 - 2009). The variables simulated in SWAT included flow, organic phosphorus, mineral ortho-phosphorus, organic nitrogen, ammonia nitrogen, nitrate nitrogen, nitrite nitrogen, and total suspended solids.

The SWAT hydrologic calibration was primarily performed based on flow data available at the USGS gages (Figure 3-2) located on Cimarron River at U.S. 77 (0716000) and Skeleton Creek at SH 74 (07160500). Daily flow measurements were available for the entire modeled period at the former gage, and from October 2001 through the end of 2009 for the latter gage. A secondary calibration was performed at Cottonwood Creek near Seward (07159750) because daily flow measurements were available only through June 2002. The primary calibration targets were annual flows, but modeled monthly flows (Figure 3-3) and the resulting flow duration curves were also compared to measured values. Overall, the model reproduces the annual flows within the 15 percent target for most years, with overall errors below the target for the primary locations (-10 percent for Cimarron River and -5 percent for Skeleton Creek) and an overall error of -19 percent for the secondary location. Resulting Nash-Sutcliffe Efficiency coefficients (NSE) and correlation coefficient (r^2) values were 0.934 and 0.950 for Cimarron River, 0.878 and 0.954 for Skeleton Creek, and 0.809 and 0.631 for Cottonwood Creek. The high resulting coefficients indicate very good model performance. Additional model calibration information is provided in Appendix C.

After hydrologic calibration, the SWAT-predicted nutrient concentrations were calibrated to the observed nutrient concentrations at five water quality stations (Figure 3-2): Cimarron River at U.S. 77 (OK620910010010-001AT), Skeleton Creek at SH 74 (OK620910030010-001AT), Cottonwood Creek (OK620910-04-0010D), Chisholm Creek (OK620910-04-0100G), and Kingfisher Creek (OK620910-05-0010J). In most cases, the SWAT model reproduced the average nutrient concentrations within 20 percent of the measured averages (Figure 3-4). In some instances, the model does not replicate particular nutrient species well for a given period, but nevertheless the total phosphorus and nitrogen predicted averages are within the 20 percent target. However, it is noted that monitoring data available for calibration are from low to moderate flow conditions. As a result, there is more uncertainty on high flow loading values.

3.2.2 Model-Estimated Nutrient Loading from Point and Nonpoint Sources

The SWAT model was used to estimate nutrient loads from processes such as soil erosion, agricultural fertilization, residues from mowing and harvesting, and fecal waste deposited in the field by livestock. Nutrient loading associated with atmospheric deposition and septic systems is incorporated into the lake model BATHTUB (see Section 4). Fecal waste deposited in the watershed by wildlife and pets is not considered to be a significant source of nutrient loading in either watershed so it was not quantified as a model input. Nutrient loading from developed lands was simulated using land use-specific regression equations of Driver and Tasker (1988), as implemented in SWAT.

Based on the calibrated SWAT model, average loads of nutrients from each of the individual subwatersheds were estimated for the period 1998 to 2009. For comparative purposes, the phosphorus and nitrogen loads are expressed on an areal basis in kilograms per hectare per year (kg/ha/yr) in Figures 3-5 and 3-6. The average daily flows and loads into Guthrie Lake and Liberty Lake are displayed in Table 3-2. Under current conditions, Guthrie

Lake is estimated to receive a total annual load of 3,400 kg of phosphorus and 8,600 kg of nitrogen, on average, from nonpoint sources in its watershed. Liberty Lake is estimated to receive a total annual load of 2,700 kg of phosphorus and 7,400 kg of nitrogen, on average, from sources in its watershed.

Table 3-2 Average Flows and Nutrient Loads Discharging to Guthrie and Liberty Lakes

Parameter	Guthrie Lake	Liberty Lake
Watershed Size (square miles)	12.7	11.4
Flow (m^3/day)	2.69×10^4	2.01×10^4
Organic Phosphorus (kg/year)	1,900	1,500
Mineral Ortho-Phosphorus (kg/year)	1,500	1,200
Total Phosphorus (kg/year)	**3,400**	**2,700**
Organic Nitrogen (kg/year)	3,100	2,600
Ammonia Nitrogen (kg/year)	0	0
Nitrate Nitrogen (kg/year)	5,500	4,800
Nitrite Nitrogen (kg/year)	0	0
Total Nitrogen (kg/year)	**8,600**	**7,400**

Figure 3-3 Observed and SWAT Modeled Average Monthly Flows

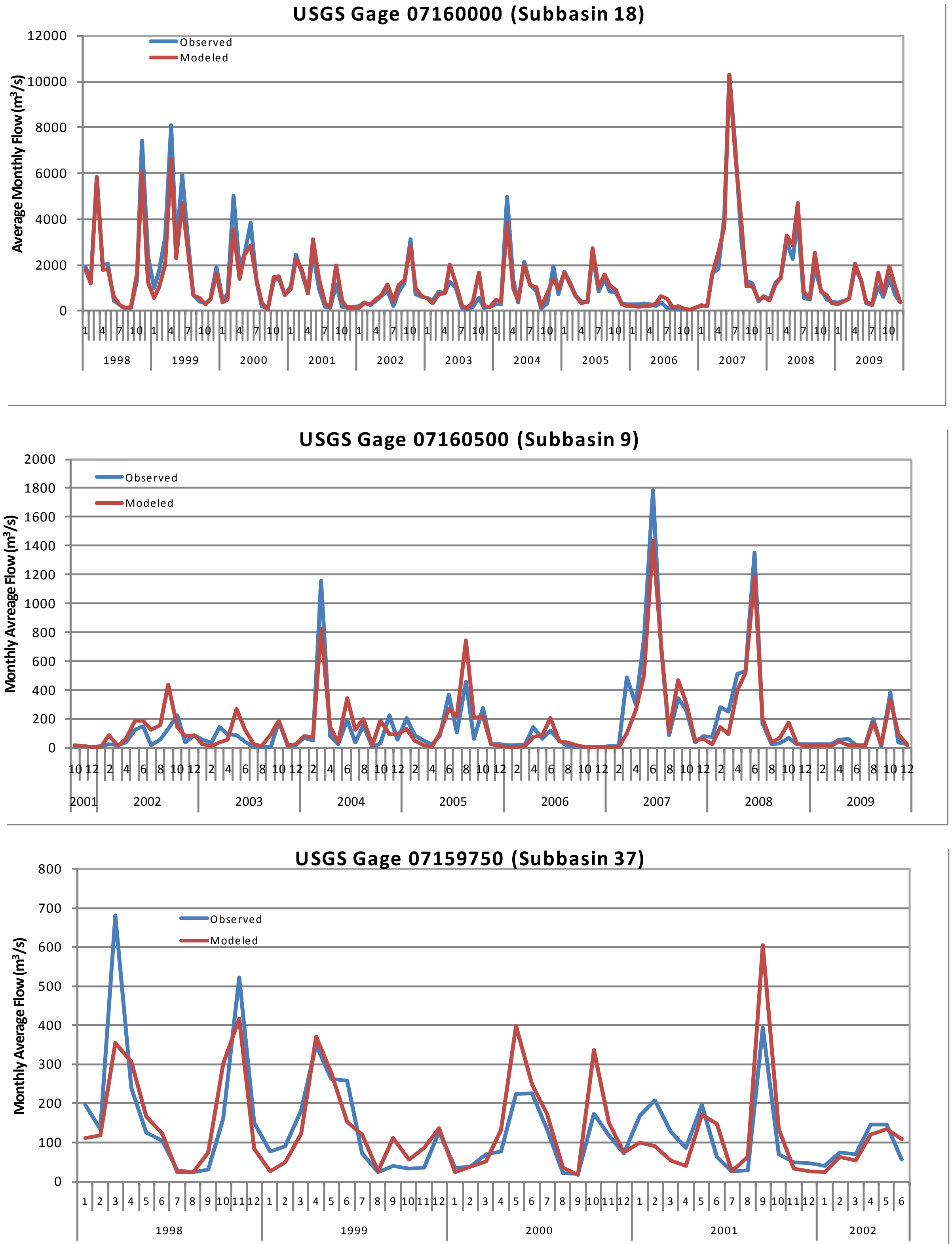
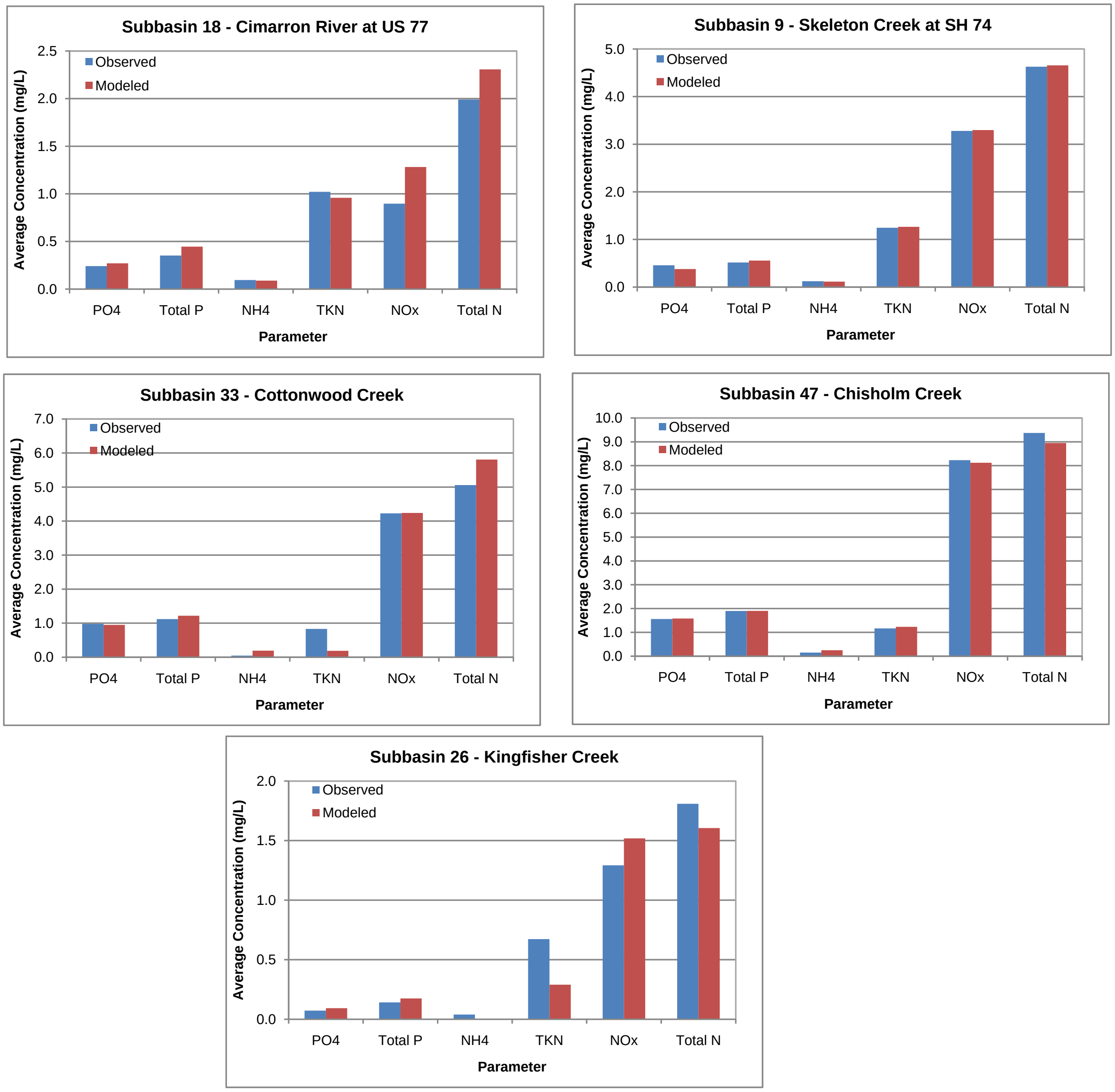


Figure 3-4 Observed and SWAT Modeled Nutrient Concentrations



PO4 = mineral phosphate phosphorus; TP = total phosphorus; NH4 = ammonia nitrogen; TKN = total Kjeldahl nitrogen; NOx = nitrate+nitrite nitrogen; Total N = total nitrogen

Figure 3-5 Average Total Phosphorus Loading from SWAT Subwatersheds

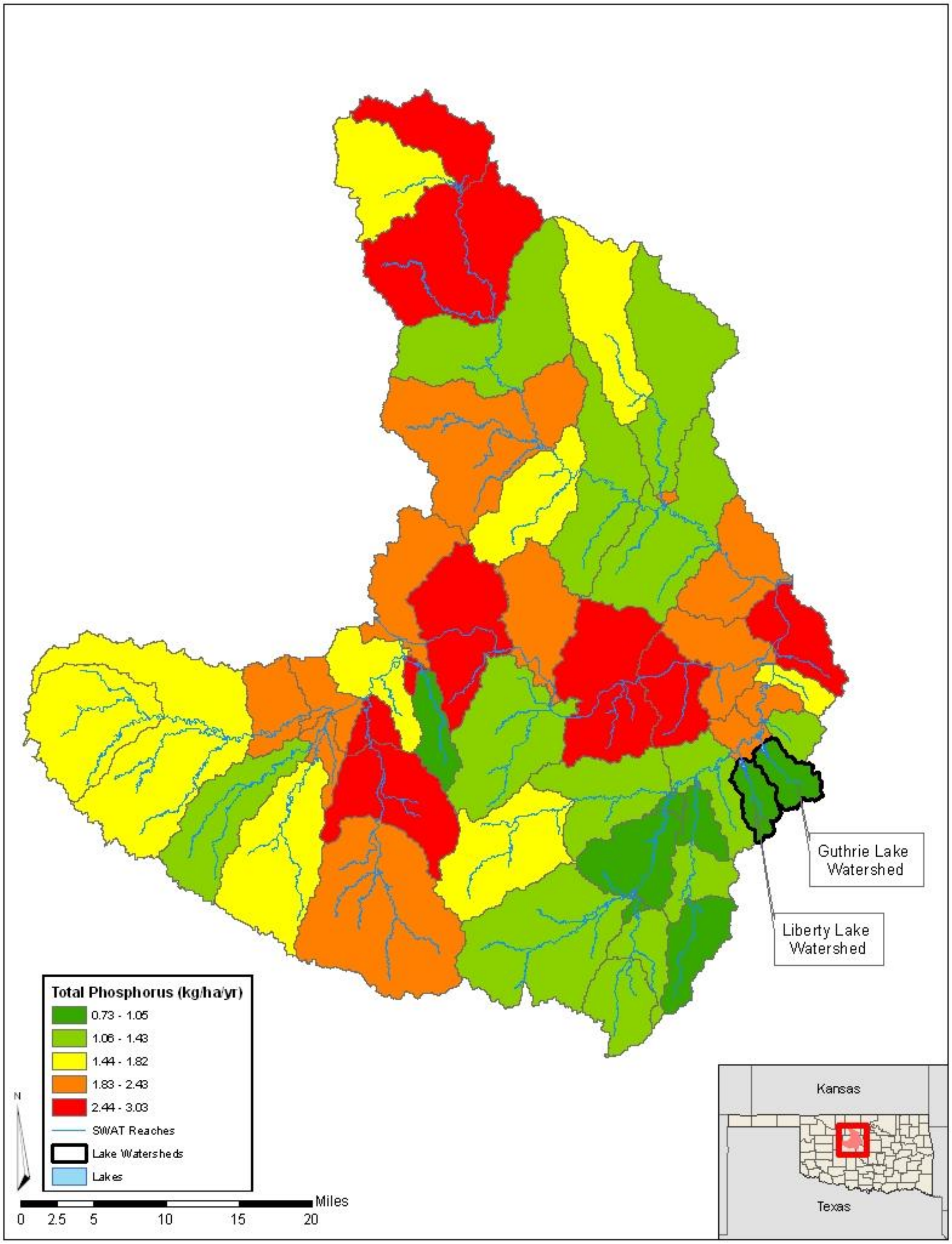
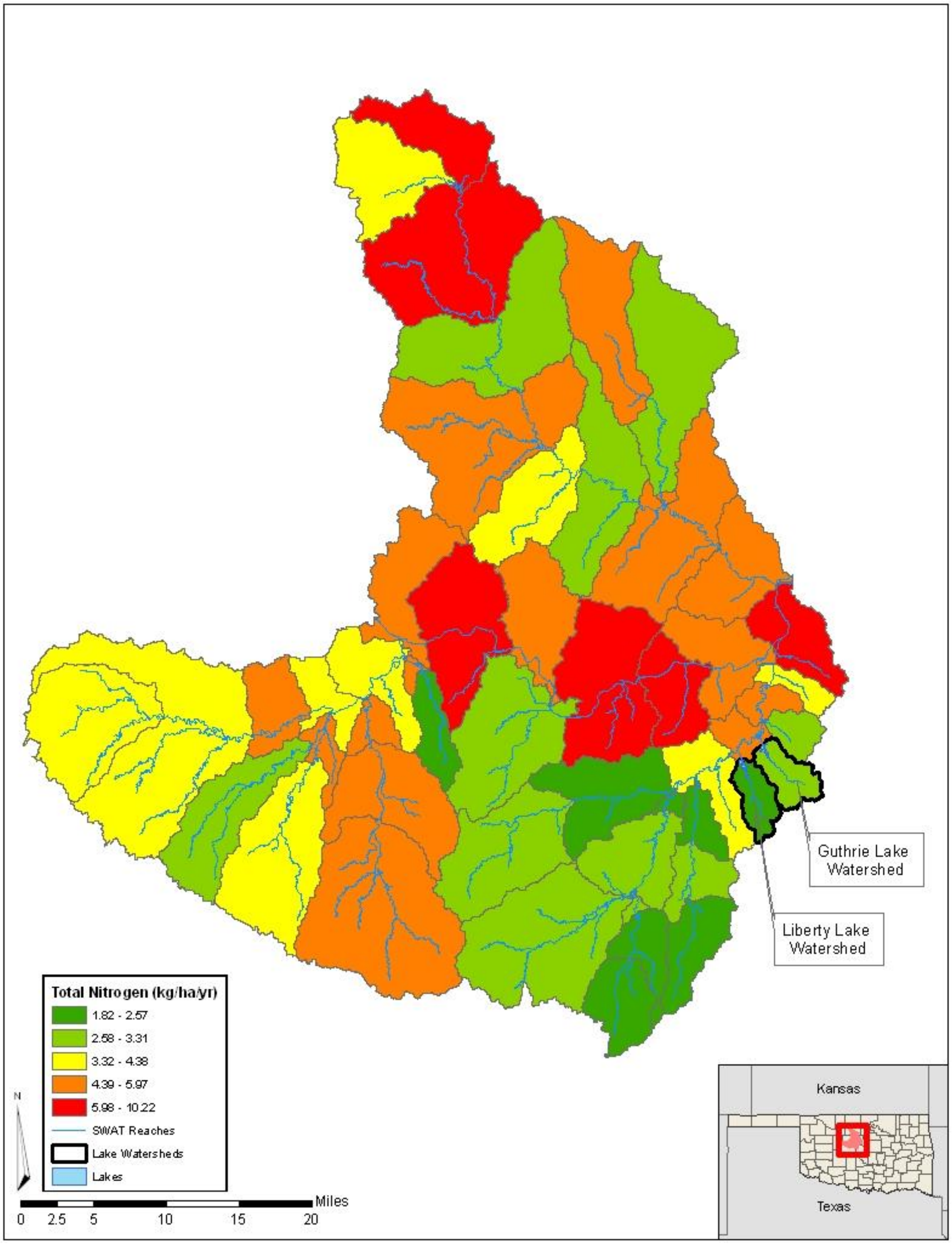


Figure 3-6 Average Total Nitrogen Loading from SWAT Subwatersheds



SECTION 4
TECHNICAL APPROACH AND METHODS

The objective of a TMDL is to estimate allowable pollutant loads and to allocate these loads to the known pollutant sources in the watershed so appropriate control measures can be implemented and the WQS achieved. To ascertain the effect of management measures on in-lake water quality, it is necessary to establish a linkage between the external loading of nutrients and the waterbody response in terms of lake water quality conditions, as evaluated by chlorophyll-*a* concentrations. This section describes the water quality analysis of the linkage between chlorophyll-*a* levels in Guthrie Lake and Liberty Lake and the nutrient loadings from their watersheds.

The report *Technical Methods Summary for Watershed and Water Quality Modeling of Sensitive Water Supply Lakes in Oklahoma* (Parsons 2010) provides a thorough description of the water quality modeling analysis. The sections below summarize the inputs and results of that modeling.

4.1 BATHTUB Model Description

The water quality linkage analysis was performed using the BATHTUB model (Walker 1986). BATHTUB is a U.S. Army Corps of Engineers model designed to simulate eutrophication in reservoirs and lakes. BATHTUB has been cited as an effective tool for reservoir and lake water quality assessment and management, particularly where data are limited. The model incorporates several empirical equations of nutrient settling and algal growth to predict steady-state water column nutrient and chlorophyll-*a* concentrations based on water body characteristics, hydraulic characteristics, and external nutrient loadings.

BATHTUB predicts steady-state concentrations of chlorophyll-*a*, total phosphorus, total nitrogen, water transparency, and a conservative substance (e.g., chloride or a dye tracer) in a water body under various hydrologic and loading conditions. To do this, the model requires inputs that describe the physical characteristics of each lake (e.g., depth, surface area), tributary flow rates and loadings (which can be estimated by BATHTUB or input from another model), and observed water quality concentrations to use as calibration targets.

4.2 BATHTUB Model Setup and Input Data

The model was run under average, steady-state conditions.

Lake Morphometry. BATHTUB allows the user to segment a lake into a hydraulic network. However, significant lake morphometry data are required to justify the complex assumptions inherent in partitioning a reservoir into multiple hydraulically linked segments. Bathymetric data for both Liberty and Guthrie Lakes was available through the Oklahoma Water Resources Board (http://www.owrb.ok.gov/studies/quality/lakes_watersheds.php#bathymetric). However, since both lakes are considered relatively well-mixed horizontally, a single segment was deemed applicable for both reservoirs. Based on availability of both flow and water quality data, for the purposes of TMDL development, a single segment was determined as sufficient for both lakes. In addition, without monthly or seasonal data to characterize residence time of each lake an averaging period of one year was used to depict the duration of mass-balance calculations (e.g., a single filling and emptying event in a year) for both lakes.

Meteorology. The BATHTUB model requires both precipitation and evaporation data. Precipitation data are available from the Oklahoma MESONET system and were provided in Section 1.2. Monthly water surface evaporation rates for several locations in Oklahoma were estimated by NOAA (http://www.nws.noaa.gov/oh/hrl/dmip/2/evap.html). MESONET also calculates a daily pan evaporation value for its stations with measured climatological data (http://agweather.mesonet.org/index.php/data/section/soil_water). Using a conversion factor of 0.77, water surface evaporation can be estimated from the MESONET pan evaporation data. Based on these two sets of data, a rate of 54 inches per year was applied for both Guthrie and Liberty Lakes.

Inflows and Loads. Key water quality parameters for BATHTUB input include total phosphorus, inorganic ortho-phosphorus, total nitrogen, and inorganic nitrogen. Output from the SWAT model, described in Section 3.2, was the primary source of data inputs to the BATHTUB model. Although SWAT can provide daily output, BATHTUB is a steady-state model and not appropriate for interpreting short-term responses of lakes to nutrients. Therefore, the long-term average annual loads from the SWAT modeled period were applied as inputs to BATHTUB.

Additionally, estimated nutrient loads from septic systems were input to BATHTUB as individual point sources. Septic system input to BATHTUB includes total flow and dissolved P and N concentrations. The following assumptions were made to estimate the total direct septic system load to Guthrie Lake and Liberty Lake:

- Septic systems located within a 300-foot buffer around Guthrie Lake and Liberty Lake (76 and two systems, respectively, as determined using ArcGIS and GoogleEarth imagery) were assumed to be discharging directly to the lakes and thus, were input to the BATHTUB model as nutrient sources.
- The systems were assumed to be close enough to surface waters so negligible adsorption of nutrients occurs. Thus, the P and N loads generated are directly discharged to the lakes.
- The systems located outside of 300-ft buffer area were assumed to be far enough from the lake that they do not represent a source of nutrients to the lakes.

Table 4-1 summarizes the estimated nutrient loadings from septic systems input to BATHTUB.

Table 4-1 Estimate of Loads from Septic Systems

Description	Guthrie Lake		Liberty Lake	
	Phosphorus	Nitrogen	Phosphorus	Nitrogen
Number of septic tanks in the vicinity of lake boundary (300 ft)	76		2	
Population served by septic systems[a]	152		4	
Total flow (hm^3/yr)[b]	0.00832		0.00022	
Nutrient concentration (mg/L)[c]	15	35	15	35
Total load from septics (kg/yr)	125	291	3	8

[a] Assuming 2 people/home
[b] Assumed system effluent flow 150 L/person/day (Woods 1991), 1 $hm^3 = 10^6 m^3$
[c] Average concentrations (Woods 1991)

BATHTUB also requires an estimate of atmospheric deposition of total and inorganic nitrogen and phosphorus. Atmospheric deposition can contribute a significant amount of phosphorus and nitrogen directly to a lake surface when the ratio of watershed area to lake surface area is low. Atmospheric deposition measurements from site OK17 (Kessler Farm Field Laboratory, in McClain County) of the National Atmospheric Deposition Program (http://nadp.sws.uiuc.edu/) were used. Table 4-2 summarizes the estimate of atmospheric nitrogen loads based on the data compiled from site OK17 for the period 1983-2010. These loads are 11% and 12%, respectively, of the watershed loads to Guthrie and Liberty Lakes.

Table 4-2 Estimate of Atmospheric Loads

Atmospheric Loads	Areal Mean (mg/m^2-yr)	Estimated Load to Guthrie Lake (kg/year)	Estimated Load to Liberty Lake (kg/year)	CV
Total Nitrogen	1127	924	913	0.2
Inorganic Nitrogen	200	164	156	0.5

Empirical Equations. BATHTUB consists of a series of empirical equations that have been calibrated and tested for lake application. These empirical relationships are used to calculate steady-state concentrations of total phosphorus, total nitrogen, chlorophyll-*a*, and water transparency based on the inputs and forcing functions. To predict each output (e.g., total phosphorus concentration), one of several built-in empirical equations must be selected. The BATHTUB model was run using the following options:

- phosphorus and nitrogen balance: second-order decay rate function
- chlorophyll-*a*: phosphorus, nitrogen, light, flushing
- Water transparency: Secchi depth vs. chlorophyll-*a* and turbidity

4.3 BATHTUB Model Calibrations and Output

The model was run under average existing conditions, and calibrated to measured in-lake water quality conditions (based on 2002-2008 data) using phosphorus and nitrogen calibration factors. Table 4-3 includes the calibration factors used for both lakes.

Table 4-3 Calibration Factors Used for Lakes

Calibration Factor	Guthrie Lake	Liberty Lake
Total Phosphorus	2.7	3.5
Total Nitrogen	0.1	0.2
Chlorophyll-a	1.6	2.1
Secchi Disk	1	1

The model-predicted concentrations of total nitrogen, total phosphorus, chlorophyll-*a*, and Secchi depth under existing average conditions are compared to average measured concentrations from each lake in Table 4-4.

Table 4-4 Model Predicted and Measured Water Quality Parameter Concentrations

Water Quality Parameter	Guthrie Lake		Liberty Lake	
	Modeled	Measured	Modeled	Measured
Total Phosphorus (mg/L)	0.054	0.053	0.043	0.040
Total Nitrogen (mg/L)	0. 69	0.97	0.75	0.80
Chlorophyll-*a* (µg/L)	20.0	19.5	23.0	23.0
Secchi depth (meters)	0.5	0.52	0.5	0.48

4.4 Modeled Load Reduction Scenarios

A summary of the existing loads to Guthrie and Liberty Lakes simulated in BATHTUB is presented in Table 4-5.

Table 4-5 Existing Loads

Water Quality Parameter	Guthrie Lake			Liberty Lake		
	Watershed	Septics	Atmospheric	Watershed	Septics	Atmospheric
Total Phosphorus (kg/yr)	3,400	125	0	2,700	3	0
Orthophosphorus (kg/yr)	1,500	125	0	1,200	3	0
Total Nitrogen (kg/yr)	8,600	291	924	7,400	8	913
Inorganic Nitrogen (kg/yr)	5,500	250	164	4,800	7	156

Simulations were performed using the BATHTUB model to evaluate the effect of watershed and septic system loading reductions on chlorophyll-*a* levels. Atmospheric loads remained at their existing levels. Simulations indicated that the water quality target of 10 µg/L chlorophyll-*a* as a long-term average concentration could be achieved if the total phosphorus and nitrogen loads to Guthrie Lake were reduced by 45 percent from the existing loads, to 1,940 kg/year of total phosphorus and 4,890 kg/year of total nitrogen. In Liberty Lake, the water quality target of 10 µg/L chlorophyll-*a* could be achieved if the total loads were reduced by 58 percent from existing loading, to 1,140 kg/year of total phosphorus and 3,110 kg/year of total nitrogen. Table 4-6 summarizes the percent reduction goals for nutrient loading established for each lake. In addition to these maximum allowable loads, an explicit margin of safety of 10 percent places further limits on loading of both nitrogen and phosphorus.

Table 4-6 Total Phosphorus and Nitrogen Load Reductions to Meet a 10 µg/L Chlorophyll-*a* In-lake Water Quality Target

	Guthrie Lake	Liberty Lake
Maximum Allowable Load of Total Phosphorus (kg/year)	1,940	1,140
Maximum Allowable Load of Total Nitrogen (kg/year)	4,890	3,110
% Reduction	**45%**	**58%**

Eutrophication is one of the leading causes of pollution in lakes and reservoirs throughout the world (Smith 2003). Therefore, determining which nutrients limit phytoplankton growth is an important step in the development of effective lake and watershed management strategies (Dodds and Priscu 1990; Elser *et al.* 1990; Smith *et al.* 2002). It is often assumed that algal productivity of most freshwater lakes and reservoirs is primarily limited by the availability of the nutrient phosphorus. Therefore, limits on phosphorus loading to lakes are sometimes considered a necessary, and typically sufficient, mechanism to reduce eutrophication. However, more recent studies in reservoirs indicate that both nitrogen and phosphorus play key roles, along with light, mixing conditions, predation by zooplankton, and residence time, in limiting algal growth (Kimmel et al. 1990). In a study of 19 Kansas reservoirs, Dzialowski et al. (2005) utilized bioassays to measure algal growth limitation, and found that phytoplankton growth substantially increased with phosphorus addition (implying that phosphorus alone limited growth) in only 8 percent of the bioassays. Nitrogen was the sole limiting nutrient in 16 percent of the bioassays. In 67 percent of the bioassays, significant algal growth did not occur upon addition of nitrogen or phosphorus singly, but did grow in response to addition of both nitrogen and phosphorus. In these systems, algal growth was considered to be co-limited by availability of phosphorus and nitrogen. Co-limitation by nitrogen and phosphorus was also reported to be the most common condition for two lakes in north Texas (Chrzanowski and Grover 2001). In some cases, growth limitation by phosphorus has been observed to be more common in the spring, followed by a shift to nitrogen limitation in the summer and fall.

Figures 4-1 and 4-2 display summary plots of multiple combinations of N and P concentrations and percent reductions that result in 10 µg/L chlorophyll-*a* estimated using BATHTUB. While the relative importance of nitrogen and phosphorus in limiting algal productivity in Guthrie and Liberty Lakes has not been established, this TMDL calculates load allocations for both nitrogen and phosphorus as a conservative approach to ensure that water quality targets are met. While the BATHTUB model is capable of simulating chlorophyll-*a* concentrations from both P and N concentrations, it is an empirically derived statistical algorithm that does not include the concept of a limiting nutrient. In other words, chlorophyll-*a* concentrations are a continuous function of both N and P contributions that can vary from season to season. Since there are infinite combinations of N and P concentrations that could result in the desired chlorophyll-*a* concentration and BATHTUB is not capable of discerning between them, reductions were assumed to be the same for both nutrient parameters. However, depending on the local environmental and socio-economical conditions, different percent reductions for the two nutrients based on the curves in Figures 4-1 and 4-2 may be used during the implementation of this TMDL to achieve the target chlorophyll-*a* level in the lakes.

Figure 4-1 Total N and Total P Combinations Resulting in 10 µg/L Chlorophyll-*a* - Guthrie Lake

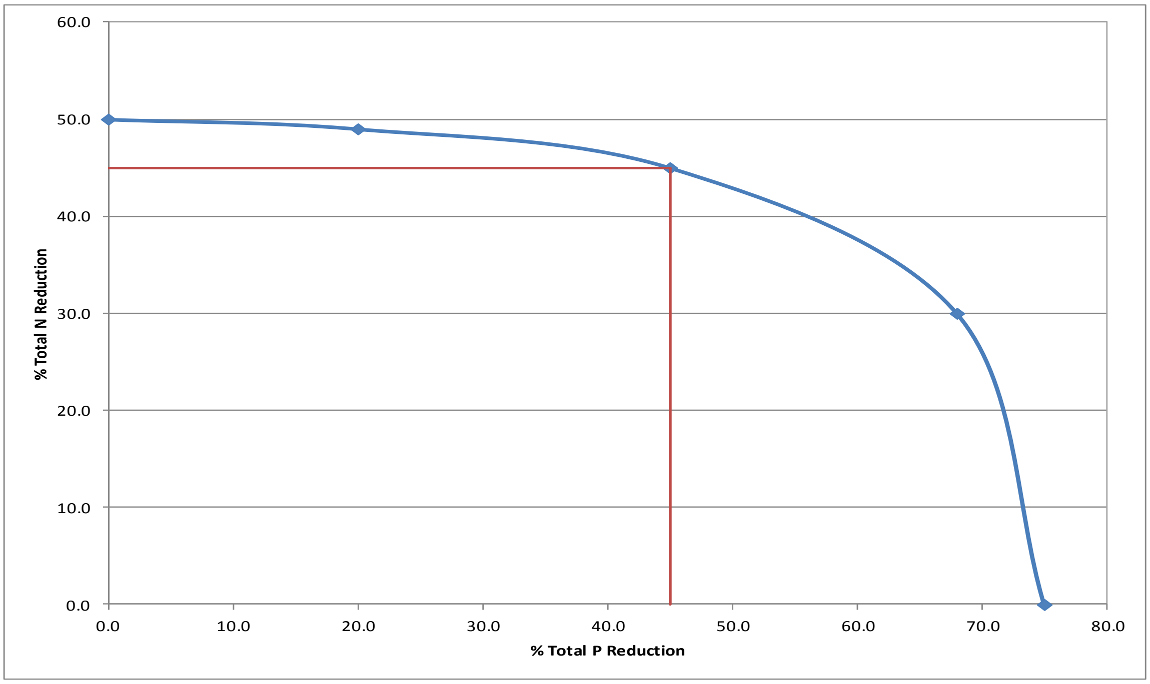
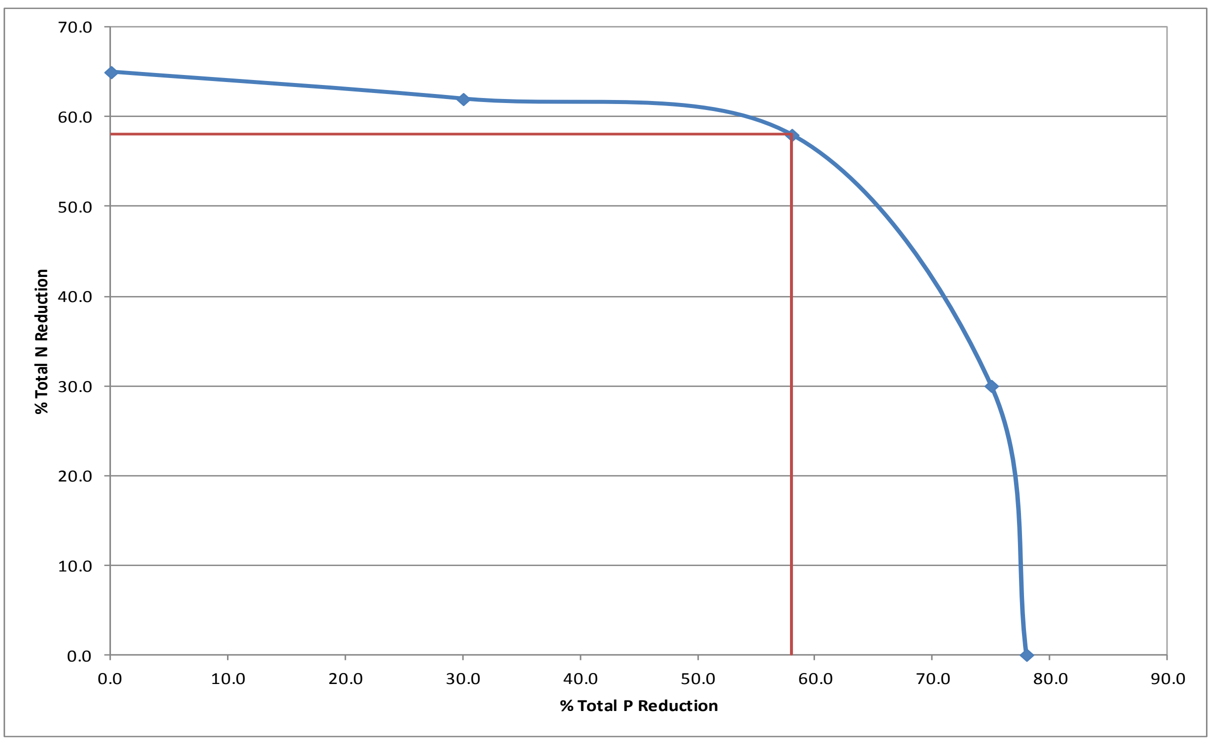


Figure 4-2 Total N and Total P Reduction Combinations Resulting in 10 µg/L Chlorophyll-*a* - Liberty Lake



SECTION 5
TMDLS AND LOAD ALLOCATIONS

Models were used to calculate TMDLs for each lake as annual average phosphorus and nitrogen loads (kg/yr) that, if achieved, should meet the water quality target established for chlorophyll-*a*. For reporting purpose, the final TMDLs, according to EPA guideline, are expressed for each lake as daily maximum loads (kg/day).

5.1 Wasteload Allocation

There are no point sources of wastewater discharging to Guthrie Lake or Liberty Lake or their tributaries. Furthermore, Oklahoma's implementation of WQS (OAC 785:46-13-4) prohibits new point source discharges to these lakes, excepting storm water with approval from DEQ (OWRB 2011a). "*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 OAC 785:45 with the limitation "SWS".*

A very small area (about 7 acres) of the NPDES-MS4 for Oklahoma County discharges to the upper part of the Liberty Lake watershed. Based on SWAT model results, the existing loads amount to 3.0 kg/yr of total phosphorus and 6.6 kg/yr of total nitrogen. Since this estimated loading is insignificant, this TMDL does not include a WLA for that area.

5.2 Load Allocation

The load allocation for all nonpoint sources to Guthrie Lake was conservatively estimated as 1,940 kg/yr of total phosphorus and 4,890 kg/yr of total nitrogen, representing a 45 percent reduction from existing loading.

The load allocation for all nonpoint sources to Liberty Lake was conservatively estimated as 1,140 kg/yr of total phosphorus and 3,110 kg/yr of total nitrogen, representing a 58 percent reduction from existing loading.

5.3 Seasonal Variability

Federal regulations (40 CFR §130.7(c)(1)) require that TMDLs account for seasonal variation in watershed conditions and pollutant loading. The WQS for chlorophyll-*a* specifically apply as a long-term average concentration (OAC 785:45-5-10(7)). Oklahoma procedures to implement WQS (OAC 785:46-7-2) specify that the mean annual average outflow represents the long term average flow in lakes (OWRB 2011a). Seasonal variation was accounted for in these TMDLs by using more than 5 years of water quality data collected in each of the four seasons.

5.4 Margin of Safety

Federal regulations (40 CFR §130.7(c)(1)) require that TMDLs include an MOS. The MOS is a conservative measure incorporated into the TMDL equation that accounts for the lack of knowledge associated with calculating the allowable pollutant loading to ensure WQSs are attained. USEPA guidance allows for use of 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 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.

These TMDLs include both an explicit and implicit MOS. The explicit MOS is 10 percent. The implicit MOS is incorporated by the application of load reductions for both nitrogen and phosphorus.

At the outset of developing these TMDLs a method was developed to use Monte Carlo analysis to investigate the uncertainty as an effective means to quantify an explicit MOS. This approach works well and, toward that end, a Monte Carlo version of BATHTUB was refined and applied (Parsons 2010). Although the BATHTUB model is available in the public domain, the source code is not. As part of this TMDL development effort to develop the Monte Carlo version of BATHTUB, a separate code that encompasses the state equations described in the BATHTUB documentation was created. During testing of the method, it was discovered that, under certain circumstances, the Monte Carlo code and BATHTUB version 6.1 produce different answers. The DEQ will conduct further investigation with the U.S. Army Corps of Engineers to try to determine the source of the differences. Once the computational differences are reconciled within the BATHTUB model, the DEQ will rely on an explicit MOS of 10 percent for both lakes in addition to the implicit MOS derived from establishing TMDLs for both nitrogen and phosphorus for each lake.

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, which attempts to account for the uncertainty concerning the relationship between loading limitations and water quality. This definition can be expressed by the following equation:

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

Load reduction scenario simulations were run using the BATHTUB model to calculate annual average phosphorus and nitrogen loads (in kg/yr) that, if achieved, should decrease chlorophyll-*a* concentrations to meet the water quality target. Given that transport, assimilation, and dynamics of nutrients vary both temporally and spatially, nutrient loading to both lakes from a practical perspective must be managed on a long-term basis 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. It is important to recognize that the chlorophyll-*a* response to nutrient loading in both Guthrie Lake and Liberty Lake is affected by many factors such as: internal lake nutrient loading, water residence time, wind action and the interaction between light penetration, nutrients, sediment load and algal response. As such it is important to note that expressing this TMDL in daily time steps does not imply a daily response to a daily load is practical from an implementation perspective.

The USEPA's *Technical Support Document for Water Quality-Based Toxics Control* (USEPA 1991b) provides a statistical method for identifying a statistical maximum daily limit based on a long-term average and considering variation in a dataset. The method is represented by the following equation:

$$MDL = LTA \times e^{z\sigma - 0.5\sigma^2}$$

where *MDL* = maximum daily load
LTA = long-term average load
z = z statistic of the probability of occurrence (0.95 is used for this value)
$\sigma^2 = \ln(CV^2+1)$
CV = coefficient of variation

The coefficient of variation of daily nitrogen and phosphorus NPS loads were calculated from SWAT model output and ranged from 4.6 to 4.9 for phosphorus and from 3.4 to 3.7 for nitrogen. As illustrated in Figures 4-1 and 4-2, there are infinite combinations of N and P reductions, as calculated by BATHTUB, that will achieve the 10 µg/L chlorophyll-*a* criterion. Here, we employ an equal reduction between N and P as a starting point for the TMDL. During implementation, it may become evident that some other combination of N and P reductions is more cost effective.

Using the equal reductions (45% for Guthrie and 58% for Liberty), the maximum load corresponding to the allowable average load of 1,940 kg of phosphorus and 4,890 kg of nitrogen per year to Guthrie Lake is translated to a daily maximum load of 5.8 kg/day of phosphorus and 16.6 kg/day of nitrogen. For Liberty Lake, the allowable average load of 1,140 kg of phosphorus and 3,110 kg of nitrogen per year is translated to a daily maximum load of 3.6 kg/day of phosphorus and 10.8 kg/day of nitrogen. Reduction of total phosphorus and total nitrogen loads to these levels is expected to result in achievement of WQS for chlorophyll-*a* in each lake.

Table 5-1 TMDLs for Chlorophyll-*a* Expressed in Kilograms of Total Phosphorus and Nitrogen Per Day

Waterbody Name	Waterbody ID	Nutrient	TMDL	WLA	LA	MOS
Guthrie Lake	OK620910040060_00	Total Phosphorus	5.8 kg/day	0	5.2 kg/day	0.6 kg/day
		Total Nitrogen	16.6 kg/day	0	14.9 kg/day	1.7 kg/day
Liberty Lake	OK620910040080_00	Total Phosphorus	3.6 kg/day	0	3.2 kg/day	0.4 kg/day
		Total Nitrogen	10.8 kg/day	0	9.7 kg/day	1.1 kg/day

SECTION 6
PUBLIC PARTICIPATION

This report was submitted to US EPA for technical review. After the technical approval was received, a public notice was circulated to the local newspapers and publications in the area affected by the TMDLs in this Study Area as well as to entities in DEQ's Stakeholder database who are either in the Study Area watershed or who have requested copies of all public notices. The public had 45 days to review the TMDL report and make written comments. No comments were received nor were there any requests for a public meeting.

After US 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.

SECTION 7
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